PRODUCTION AND CHARACTERIZATION OF BAMBOO FIBRE REINFORCED PVC COMPOSITES

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ABSTRACT

Since many years, efforts have been made to find ways to make natural fibre compatible enough with its matrix. The interest of using natural fibre reinforced polymer composites is growing rapidly due to their low cost and high performance in term of mechanical properties and thermal stability. In this study, the potential of alkali treatment with NaOH and maleic anhydride grafted PP (MAPP) as coupling agent adding on bamboo fibre particles as reinforcements for polyvinyl chloride (PVC) was investigated with the samples prepared by extrusion and compression molding. Two types of bamboo fibre were used which are untreated and treated with 5wt% NaOH concentration with both composition varying from10 to 30 wt%. Tensile properties showed that Young's modulus increased with the increasing of fibre loading for all type of modifier, but have a little difference when 5% MAPP was added. Most of the results showed that the increasing bamboo fibre loading up to 20wt% increased the tensile strength but decreased back when 30wt% fibre loading were used. Using only 2.5% of MAPP with only 10wt% fibre loading have the highest tensile strength where the 30wt% fibre loading at the same amount of MAPP have the highest value of Young's modulus. The adding of both modifiers also increased the thermal stability of this composite. The results of this study demonstrate that this composite had properties comparable with other conventional composite. Hence, the alkali treatment and MAPP was a competitive agent of creating bamboo fibre reinforced PVC composites.

ABSTRAK

Sejak bertahun-tahun, usaha-usaha telah dibuat untuk mencari jalan untuk membuat serat semula jadi serasi dengan matriksnya. Kepentingan menggunakan serat semula jadi komposit diperkuat dengan polimer berkembang pesat kerana kos yang rendah dan prestasi mereka dalam sifat-sifat mekanikal dan kestabilan terma yang tinggi. Dalam kajian ini, potensi rawatan alkali dengan asid NaOH dan maleic dengan PP (MAPP) terhadap serat bulut bersama polivinil klorida (PVC) telah disiasat dengan sampel yang disediakan oleh penyemperitan dan pengacuan mampatan. Dua jenis serat buluh telah digunakan yang tidak dirawat dan dirawat dengan kepekatan 5% NaOH dengan komposisi kedua-duanya berbeza-beza, 10 hingga 30% dari segi berat. Sifat tensil menunjukkan bahawa modulus Young meningkat dengan peningkatan beban gentian untuk semua jenis pengubahsuai, tetapi mempunyai sedikit perbezaan apabila 5% MAPP telah ditambah. Kebanyakan keputusan menunjukkan bahawa 20% kandungan buluh meningkatkan kekuatan tensil tetapi menurun kembali apabila 30% kandungan buluh digunakan. 10% kandungan buluh dengan penambahan 2.5% MAPP mempunyai tensil yang tertinggi tetapi 30% kandunagn buluh dengan jumlah yang MAPP sama mempunyai nilai tertinggi modulus Young. Dengan menambah kedua-dua pengubahsuai juga telah meningkatkan kestabilan terma komposit ini. Keputusan kajian ini menunjukkan bahawa komposit ini mempunyai ciri-ciri yang setanding dengan komposit konvensional yang lain. Oleh itu, rawatan alkali dan tambahan MAPP adalah langkah yang kompetitif mewujudkan serat buluh komposit bersama PVC.

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LIST OF SYMBOLS

%	- Percentage
wt%	- Weight Percent
^oC	- Degree Celsius

LIST OF ABBREVIATIONS

ASTM -American Standard Testing Methods

HDPE - High Density Polyethylene

NaOH - Sodium Hydroxide

mm - Millimeter

mg - Miligram

MAPP - Maleic anhydride grafted polypropylene

MPa - Mega Pascal

Pa - Pascal

PBS - Polybutylenesuccinate

PE - Polyethylene

PE-g-MA - Maleated Polyethylene

PLA - Poly Lactic Acid

PMPPIC -Poly [methylene poly (phenyl isocyanate)]

PP - Polypropylene

PVC - Polyvinyl Chloride

SEBS - Styrene-Ethylene-Butylene-Styrene

SEM - Scanning Electron Microscope

TGA -Thermo Gravimetric Analysis

CHAPTER 1

INTRODUCTION

1.1 Research Background

Public attention is now more on production of composite material by natural fibres as reinforcement with polymer because of low cost, low density, biodegradability, sound mechanical properties, water resistance, dimensional stability and processing ability (Bledzki, Reihmane & Gassan, 1998; Clemons, 2002). This natural fibre reinforced polymer composites can form a new class of materials or alternative which seem to have a good potential as a substitution for wood and glass based material. The dramatic growths on environmental composite are due to development of technology and we also considering on the economic factors.

Natural fibres which have a long history in human civilization have gained economic importance and are used globally. With a tropical climate good for planting natural fibres, Malaysia has set its path to grown technology in research and development reinforced composite materials. Natural fibres represent environmentally friendly alternative to traditional reinforcing fibres such as glass and carbon. This is because their low cost, high toughness, low density and good strength properties. (Ogihara, Okada & Kobayashi, 2008; Srebrenkoska, Gaceva & Dimeski, 2009) In Malaysia, there are huge amounts of natural fibre materials available (Feng, 2010). All of them have excellent potential of application and can contribute to the growth of industries. Table 1.1 lists some capacity of natural fibre available per year in Malaysia.

Table 1.1: Estimated capacity of raw material of natural fibre available per year in Malaysia (Feng, 2010)

Resources	Estimated capacity/year
Log production	~20.7 million m^3/year
Forest and wood residues	~10 million m^3/year
Rubberwood	2.1 million m^3/year
Oil palm biomass (trunk,EFB,frond)	30 million metric tons/year
Coconut stems	3200 metric tons/year
Rice husk/straw	500000 metric tons/year
Bagasse	180000 metric tons/year
Bamboo	10 million culms/year

As a cheap and fast-grown resources with good physical and mechanical strength which is comparable to wood species, this abundant resources can be turn out to be an alternative solution to the depleting of petroleum sources. But with substitution completely the petroleum based sources with natural fibre is not a good act. As well as to be environmentally friendly, we must consider the economic growth because a wide range of petrochemicals are produced in Malaysia such as olefins, acrylic acids, polyvinyl chloride, and polystyrene. A more practical solution would be to combine petroleum and natural fibre together to produce or develop a commercial product with various applications eventhough it is not fully environmentally friendly composite material. They maintain a balance between economics and environment allowing them to be considered for applications in the automotive, building, furniture and packaging industries.

In general, there is various kind of polymer that being use as the matrix for fibre reinforced composite. From Figure 1.1, it shows the world consumption of polymer. They are used in many applications because they are easy to process, high productivity low cost and versatility (Wirawan, Zainudin & Sapuan, 2009). From there it is liable that part of the polymer consumption have been used as the matrix for composite.

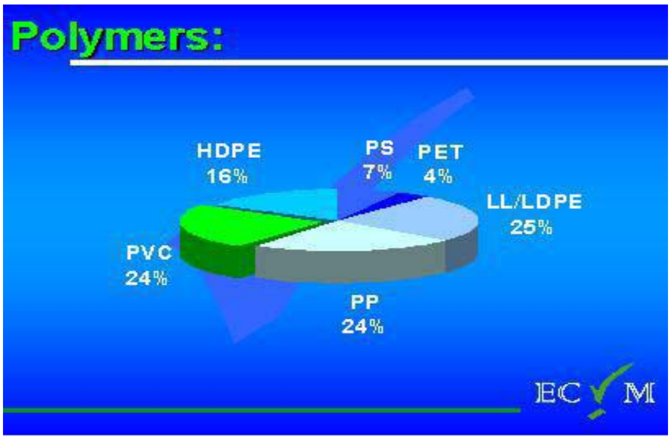

Figure 1.1: Polymer world consumption (PVC Facts and Issues, 2003)

It is such an effort to use the natural fibers as the reinforcement for polymer composites because of its hydrophilic characteristic made them poor incompatibility in adhesion with hydrophobic matrix and leading to nonuniform dispersion of fibres within the matrix. This is a major disadvantage of natural fibre reinforced composite (Wong, Yousif & Low, 2010).

Unfortunately, the performance of bamboo fibre as a reinforcement in polymer composites is inadequate because of its low cellulose content (26-43%) and high lignin content (21-31%). In such condition, it is important to apply surface modification to improve the reinforced composite properties. Behind polyethylene (PE) and polypropylene (PP), Polyvinyl Chloride (PVC) is the third most widely used thermoplastic. Because it is inexpensive, durable and easy to use, a large majority of the PVC is used for construction goods. As choosing polyvinyl chloride (PVC) for the matrix, the production of vinyl chloride needs chlorine where on weight basis, chlorine accounts for 56.8% of total weight. PVC is hence less affected by the cost of petroleum than other polymer so it still is less expensive compared to other polymer.

1.2 Problem Statements

As a fibre, the overall mechanical properties of bamboo are comparable to or even better than those of wood (Liu et al, 2008). Thus, these advantages make it highly competitive nature fibre reinforcement in polymer composites. However, there are such a big limitations in using bamboo fiber as reinforcement in the matrices which including poor adhesion between the polar-hydrophilic fiber and nonpolar-hydrophobic matrix (Sombatsompop & Chochanchaikul, 2004; John & Anandjiwala., 2008; Wong, Yousif & Low, 2010) that lead to debonding of fibre under certain loading thus leads to poor mechanical properties of the composite as final materials. This research will overcome those limitations by applying chemical modification to the fibre besides investigating the best interaction of fibre-matrix to produce a high quality of composite.

1.3 Research Objectives

The objectives of this study are:

i. To investigate the effect of alkali treatment and modifier or coupling agent on adhesion between bamboo fibre and PVC.
ii. To study the effects on tensile properties and thermal stability of the composite with different weight percent of bamboo fibres.
iii. To characterize bamboo fibre reinforced PVC composites.

1.4 Scopes of Research

The scopes in this research are:

i. Preparation of fibre surface treatment by 5% amount of sodium hydroxide (NaOH) and modification by maleic anhydride polypropylene (MAPP) (2.5 and 5%).
ii. Preparation of composite with different weight percent of bamboo fibre (10-30wt %).
iii) Characterization of composite by tensile test

1.5 Significance of Study

The usage of bamboo fibre is not much practiced in Malaysia compared to wood or glass fibre although the bamboo itself is one of the natural fibre that grows abundantly in this country. As many works has been done with other natural fibres with polymers such as polypropylene (PP) and poly lactic acid (PLA), this research that involve PVC as the polymer will tried to develop a composite that can also be used in the industry. Research must be done eventhough the processing temperature, that is should not exceed the degradation temperature of the fibre is one of the drawback in this study. Little effort has been made so far to prepare bamboo fibre reinforced PVC composites and to improve their performance due to their properties. So, it is important for this study to know whether the composite material can be one of the alternatives besides having same natural fibres reinforced polymer as composite for industrial application.

CHAPTER 2

LITERATURE REVIEW

2.1 Chemical Composition of Natural Fibres

There are large varieties of natural fibres such as flax, hemp, bagasse, jute, bamboo, coir and sisal (Bozlur, Sibata, Diba & Uono, 2010). All of these natural fibres are cellulosic in nature. Some of the main components of natural fibres are cellulose, hemicelluloses, lignin, pectin and waxes. The hemicellulose molecules are hydrogen bonded to cellulose where by the lignin acts as coupling agent and increase the stiffness of cellulose and hemicelluloses composite. Due to reinforcing for the natural fibre, cellulose, hemicelluloses and lignin is more considered composition.

Cellulose is a linear natural polymer that contains hydroxyl groups. These hydroxyl groups have ability to interact with hydrogen bond. It has high degree of polymerization that is around 10000 (John & Anandjiwala, 2008). Hemicelluloses is a noncrystalline nature that have much shorter chains than cellulose chains because it has lower degree of polymerization around 50-300. It is very hydrophilic, soluble in alkali and easily hydrolyzed in acids.

Besides those two, lignin is hydrophobic in nature and is totally insoluble in most solvents also cannot be broken down to monomeric units. It gives firmness to the plants with very high molecular weight. High lignin amount exhibits high tensile properties of fibre. Lignin is not hydrolyzed by acids but soluble in hot alkali, readily oxidized and easily condensable with phenol (Bismarck, Mishra & Lampke, 2005).

2.2 Bamboo Fibre

Bamboo is highly competitive nature reinforcement in polymeric composites besides is abundantly natural resources. The overall mechanical properties of bamboo are such comparable to or even better than wood. Furthermore, bamboo can be renewed much more rapidly compared with wood since the time required for bamboo to reach its mature size is six to eight months, less than 5% of the time required for most woods (Mi, Chen, Cuo, & Chan, 1997). Compared to the most commonly used biofibres (wood, jute, coir, sisal and banana) bamboo exhibits low density and high mechanical strength (Bonse, Mamede, Costa & Bettini, 2010; John & Anandjiwala, 2008).

2.3 Polyvinyl Chloride (PVC) as Polymeric Composites

PVC is one of the most commonly used plastics in our worldwide society. As a hard thermoplastic, PVC is used as building materials, pipe and many other applications. Part of the reason is because it is easy to fabricate and can last for long time. (Wirawan, Zainudin & Sapuan, 2009). Similarly, PVC Facts and Issues (2003) found that the properties of PVC itself make it suitable in tough long life applications. Recently, mixing PVC with natural fibres has become an interesting alternative due to environmental friendliness of the natural fibres eventhough not many research has been done for PVC as the matrix. Xu, Wu, Lei, Yao & Zhang (2008) in their study on the effect of modifier, they use PVC with bagasse, rice straw and rice husk and compare with. The result of the study demonstrates that natural fibre/PVC composites had properties comparable with those of PVC/wood composite. Another research by Sombatsompop & Chaochanchaikul (2005) found that PVC/sawdust composites with the addition of silane as coupling agent have enhanced the mechanical properties compared with untreated PVC/sawdust composites.

2.4 Fiber Treatment and Modification

Due to incompatibility between natural fibers and polymer, some modification would be done to improve the performance of composite products.

2.4.1 Alkali Treatment

Alkali treatment tends to increase the amount of amorphous cellulose at the expense of crystalline cellulose. This alkali treatment removed natural and artificial impurities which improves the fibre-matrix adhesion. The important modification occurring due to alkali treatment is the removal of hydrogen bonding in cellulose hydroxyl groups of the fibre, thereby making them more reactive to the functional group of coupling agent, which in turn bonds to the polymer matrix. Good fibre – matrix bonding can be established. From various types of alkali, sodium hydroxide (NaOH) influence more on this process. It is because Na^+ has got a favorable diameter able to widen the smallest pores and consequently NaOH treatment results in higher amount of swelling (John & Anandjiwala, 2008).

$$\text{Fibre} - \text{OH} + \text{NaOH} \longrightarrow \text{Fibre} - \text{O-Na} + H_2O$$

In alkali treatment, the fibres will immerse in NaOH solution for some period. Wong, Yousif & Low (2010) used untreated and treated bamboo fibres with different NaOH concentration (1, 3 & 5%) and reported as the increasing alkali concentration it reduces the strain at failure and ductility but increased the strength of the fibre. Lee, Cho & Han, (2008) reported that 1 and 6% of NaOH treatment with henequen fibre has improve the interfacial shear strength and flexural properties. There were also some results that showed that the 5% amount of NaOH for alkali treatment with luffa, oilpalm and pineapple fibre gives positives effect to the mechanical properties (Boynard, Monteiro & Almeida, 2003; Josephs & Thomas, 2006; Lopattananon, Panawarangkul, Sahakaro & Ellis, 2006 as cited in John & Anandjiwala, 2008).

2.4.2 Coupling Agent

By using some modification, it can improve composite properties. Coupling agents improve polymer composite properties by providing a chemical linkage between the polymer matrix and filler, improving polymer properties like moisture resistance and impact strength. Generally, tensile strength and Young's modulus of fibres increase with increasing cellulose content. Sombatsompop & Chochanchaikul, (2005) studied that the mechanical strength of PVC/fiber composites could be lower than the neat PVC if an appropriate coupling agent is not used due to poor interfacial bonding between natural fibers and PVC. PMPPIC has been reported as one of suitable coupling agents for natural fibre reinforced PVC composites (Wirawan, Zainudin & Sapuan, 2009). With PMPPIC treatment, the strength of composite is increasing with the increasing of fibre content. In a previous work (Liu et al. 2008), various coupling agents were used for bamboo/HDPE composite. Among them, maleated polyethylene (PE-g-MA) was proven to be the most effective. While the study by Keener, Stuart & Brown (2004) shows that the maleated coupling agent of PP and PE tend to increase in flexural and tensile strength

Traditionally, grafted maleic anhydride works with PE and PP matrices. But, there are some works that are still in developing to use PVC matrices that may help reduce water absorption and increase dimensional stability of wood-plastic composites (Improving wood-plastic composite performance, 2008) that also may be used in bamboo fibre. But Xu, (2009) said that using coupling agent is for reducing hydrophilic property of wood fibre but is not effective for enhancing the adhesion between PVC and wood fibre.

2.5 Tensile Properties of Bamboo Fibre Composite

Tensile properties are one of the most widely tested properties of natural fibres reinforces with polymer. Recently, the research has been made on bamboo fibre reinforced composite with different weight percent of bamboo fibre without having any modification, with modification by coupling agent and also with addition of compatibilizer. Ogihara, Okada & Kobayashi (2008) observed that when polybutylenesuccinate (PBS) as the matrix added to the fibre, it shows the increasing of the tensile strength when weight percent of fibre increased although there is small difference among 30-50% as shown in Table 2.1.

Table 2.1: Mechanical properties of bamboo fibre/PBS composite in the fiber direction (Ogihara, Okada & Kobayashi, 2008)

	Young's modulus (GPa)	**Tensile strength (MPa)**	**Longitudinal strain at fracture (%)**
10%	3.08	43.2	1.118
20%	6.15	55.6	0.885
30%	10.74	90.7	0.995
40%	12.64	78.4	0.772
50%	13.54	95.6	0.897

The weight fraction used is 10, 20, 30, 40 and 50%. The Young's modulus also increases with the increasing of bamboo weight percent. Similarly, Liu et al (2008) found that it increases with increasing weight percent of bamboo fibre with compatibilizer appearance. Besides of that, bamboo fibre with treatment of silane as coupling agent gives negative effect on tensile strength (Ge, Li & Meng, 2004). But Xu, Wu, Lei, Yao & Zhang (2008) echo them by resulting the different amount of styrene-ethylene-butylene-styrene (SEBS) modifier showed moderate effect to tensile strength of PVC/natural fibre composite.

Bonse, Mamede, Costa & Bettini (2010) in their investigation regarding the effect of compatibilizer which is maleic anhydride grafted PP (MAPP) with bamboo fiber content on mechanical properties of propylene/bamboo fibre composites, shows that increasing bamboo fibre content from 20-40% at the same level amount of compatibilizer increasing tensile strength. Moreover, increasing in compatibilizer content also increased the tensile strength. In other study by Wang, Sheng, Chen, Mao & Qian (2010) on mechanical properties of bamboo fibre reinforced PVC composites; they found that the bamboo surface treatment by 5% of sodium silicate gives the highest tensile strength and modulus which are 15.72 MPa and 2956.80MPa from the other solution concentration as shown in figure 2.1 below.

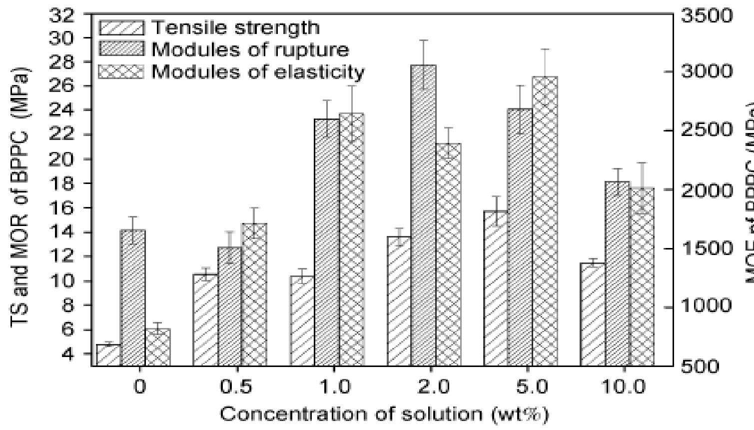

Figure 2.1: Mechanical properties of bamboo-particle reinforced PVC composites (Wang, Sheng, Chen, Mao & Qian, 2010).

2.6 Thermal Stability of Bamboo Fibre Composite

There are some researches that also study about the effect of the natural fibre/ PVC composite towards its thermal stability using thermogravimetric analysis. It is based on measurement of mass loss of material as a function of temperature. Table 2.2 shows the degradation temperature based on some natural fibre with PVC composite compared to the neat PVC with the adding of SEBS modifier. It shows that the modifier decreased the degradation temperature of the neat PVC itself showing the disadvantage on modifier adding towards the composite itself.

Table 2.2: Degradation temperature (T_d) of PVC/natural fibre composites (Xu, Wu, Lei, Yao & Zhang, 2008)

Composite type	**T_d (°C)**
Neat PVC	264.89
PVC/bagasse	209.11
PVC/rice straw	211.26
PVC/rice husk	217.52
PVC/pine	213.57

Showing an agreement of the study, Aznizam & Mohd Hazuwan (2008) also stated that the T_d of impact modified oil palm empty fruit bunch fibre PVC composites shifted to lower temperature compared to pure PVC because of the heat destabilization accelerated the dehydrochlorination of PVC resulting in the lowering of the degradation temperature itself.

CHAPTER 3

METHODOLOGY

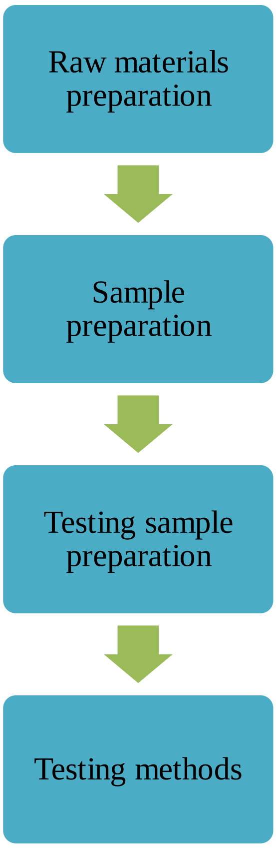

Figure 3.1: Procedures of experiment

3.1 Introduction

The study will consist of combination on four stages:

- Raw material preparation
- Sample preparation - Bamboo fibre / PVC composite preparation
- Testing sample preparation
- Testing methods

3.2 Raw Materials Preparation

3.2.1 Polyvinyl Chloride (PVC)

Polyvinyl chlorides that will use as matrix for bamboo fibre reinforced composite is a thermoplastic polymer and were supplied by IRM Composites Johor Bahru.

3.2.2 Preparation of Bamboo Fibre

There were two types of bamboo fibre used in this research, treated and untreated bamboo fibre. For the treated one, bamboo fibres obtained from the grinded bamboo clump were immersed in NaOH solution for alkali treatment for 24 hours at room temperature. This alkali treatment can removed impurities which can improve the fibre-matrix adhesion. According to reference, high concentration of NaOH worsened the mechanical properties of fibres. Therefore, in this research, 5 wt% of NaOH concentrations were used based on positive results from previous researchers. Then, they were washed with distilled water until the fibres were clean. After treatment, the fibre was dried for 24 hours at 80°C to ensure the moisture content is low.