PRODUCTION AND CHARACTERIZATION OF BAMBOO FIBRE REINFORCED PVC COMPOSITES

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for award of the Degree of Chemical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis entitled "Production and Characterization of Bamboo Fibre Reinforced PVC Composites" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature:
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...Dedicated to…

My Beloved Father and Mother

Abd Hamid Abd Kadir and Latifah Hj. Kassim

My Sister and Brothers

Thank You from the Bottom of My Heart for Being My Inspiration

and to My Lecturers and My Dear Friends

Thanks for Supporting Me

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All praises to Allah the Creator of this universe and peace be upon the holy prophet Muhammad S.A.W.

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Last but not least, my sincere thanks and gratitude to my family member for their love, support and faith in my ability to attain my goals.

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
^{o}C	- 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.

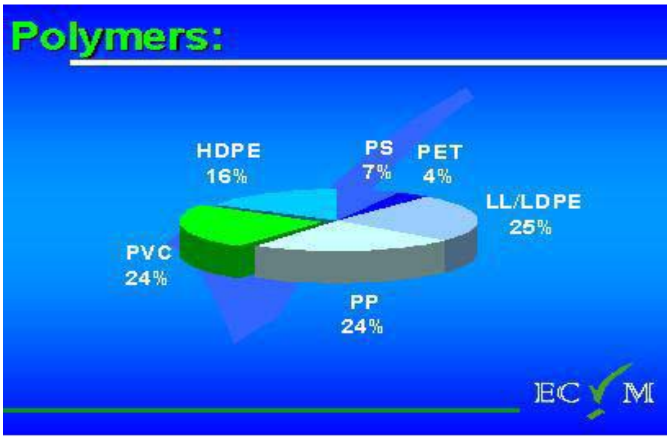


Figure 1.1: Polymer world consumption (PVC Facts and Issues, 2003)

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.

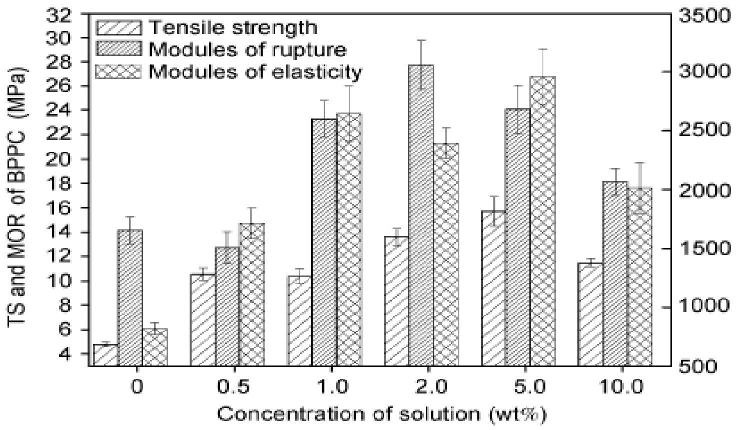


Figure 2.1: Mechanical properties of bamboo-particle reinforced PVC composites (Wang, Sheng, Chen, Mao & Qian, 2010).

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

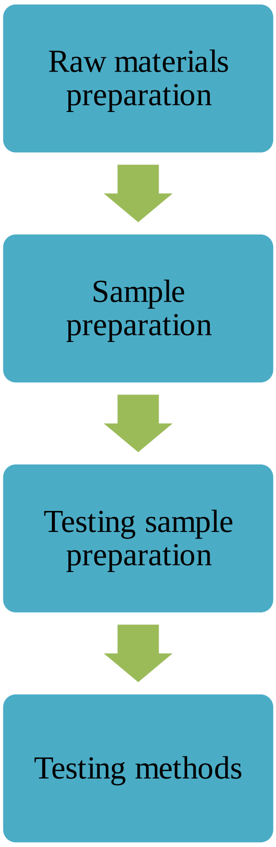


Figure 3.1: Procedures of experiment

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.

3.3 Sample Preparation

The preparation of sample was carried out in two stages which are namely as composite preparation and testing sample preparation.

3.3.1 Bamboo Fibre – PVC Composite Preparation

Different weight percent of treated bamboo fibre (10 wt % to 30 wt %) were used for the sample of 400g. There will be addition of MAPP during this process as it is a new work on PVC matrix and MAPP itself because no work has been done to mix MAPP with PVC before except with PE and PP. For treated bamboo fibre, it will mix only with PVC and for the untreated it will mix with PVC and MAPP with two different concentrations; 2.5% and 5%. The material then, was mixed at 165-185^{o}C. Higher temperature will result in reduction strength which may due to the degradation of fibre. The mixing speed was 150 rpm to produce slit extrudates. The obtained composites were then cut into granules or pallets that are suitable for compression molding by hot and cold machine press before being tested. The hot press operating temperature was 180°C with 10 minutes of compression at pressure of 16 MPa. After that the samples were cooled naturally in the air.

Figure 3.2: Extruder

Figure 3.3: Hot and cold machine press

3.4 Testing Sample Preparation

3.4.1 Tensile Test

The test samples were prepared by the hot press by using dumbbell shape mold before being tested. The dumbbell shape specimens with dimensions of 165 × 19 × 3 mm^3 were used according to ASTM D638 procedure for the tensile testing.

Figure 3.4: Dumbbell shape specimen

3.5 Testing Method

The mechanical testing methods that will be carried out were based on American Standard Testing Methods (ASTM). The tensile test performed by Tensile Test (ASTM D638).

3.5.1 Tensile Testing

The testing will be done in standard laboratory atmosphere and dumbbell shape specimen like shown in figure 3.3 is needed for the testing. The specimen will position vertically in the grips of the Universal tensile testing machine that used at cross-head speed of 5mm/min. The grips were tightened firmly to prevent any slip during the test. The précised five testing were chosen for each sample.

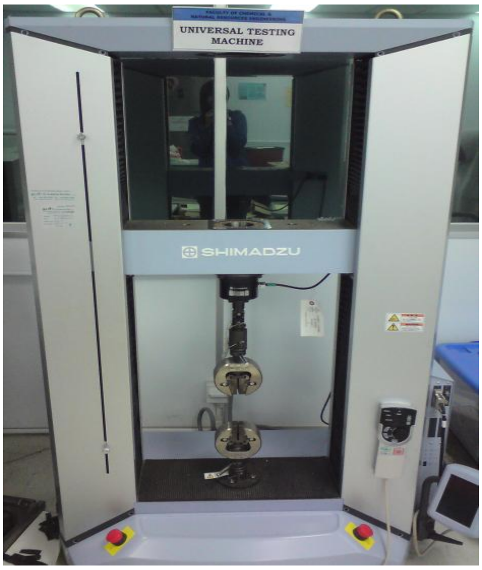


Figure 3.5: Universal testing machine

3.5.2 Thermal Stability

Thermogravimetric analysis (TGA) was employed to the thermal stability characteristic by comparing treated and untreated fibre with a Q500 thermogravimetric Analyzer under a nitrogen atmosphere. Dynamic TGA method was used for each sample at approximately 5.0 mg of composites sample then burned in the furnace and scanned from room temperature to 650°C at heating rate of 10°C/min. The dynamic TGA was employed to determine degradation temperature (T_d) of the composites based on the sample weight versus temperature. In dynamic TGA, weight change during temperature increase was recorded and values of T_d f or each sample were determined.

Figure 3.6: Thermogravimetric Analyzer Q500

CHAPTER 4

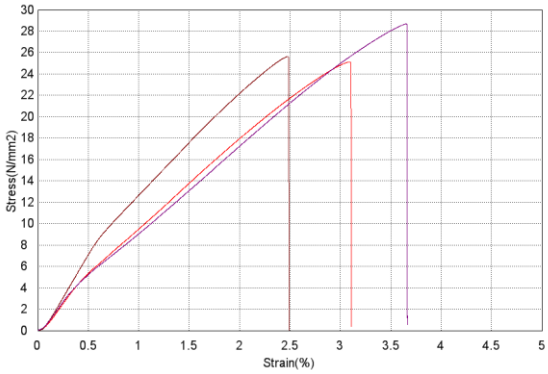
RESULTS AND DISCUSSION

4.1 Introduction

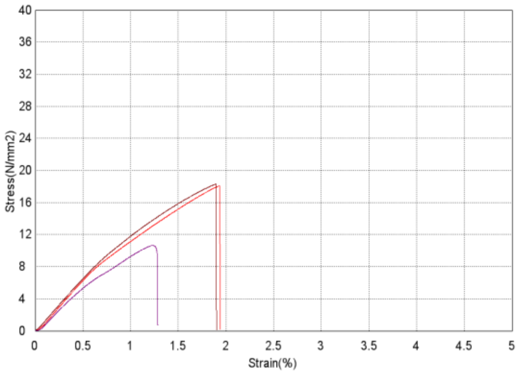
This chapter covers the properties of the treated bamboo fibre reinforced PVC composites with various bamboo fibre compositions.

4.2 Stress and Strain Behavior

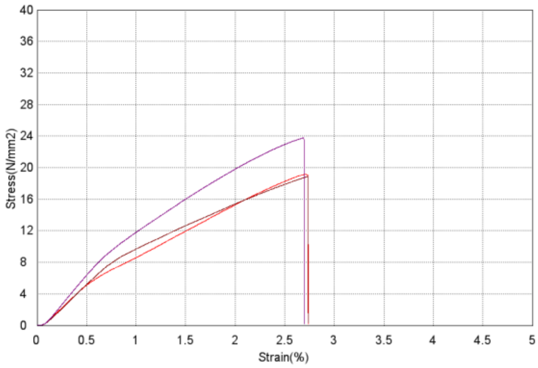
Figures 4.1 below indicate the stress-strain diagram of reinforced PVC with various type of modifier at 20wt% composition of bamboo fibres represent some of samples where the others data can be seen at Appendix A-J that were tested at crosshead speed of 5mm/min. It can be observed that all composites exhibit linear region behavior at initial stage for relatively small amount of elongation. After the linear region which shows the elastic behavior, the composite samples were finally failed with further increase in stress like brittle material. But comparing with the stress that can be absorbed, it can be seen clearly that when the concentration of each type of modifier increase, it increased the stress that can be absorbed by the composite itself.



(a)



(b)



(c)

Figure 4.1 (a), (b), (c): Stress-strain graph of 20wt% bamboo fibre loading PVC composite of different type of modifier.

4.3 Tensile Properties

In tensile test, there are two properties that can be represented which are tensile strength and Young's modulus.

For tensile strength, it gives excessive different of result between each type of modifier. A figure 4.2 shows the results on tensile strength where the highest tensile strength is around 32 MPa which shows by 10wt% fibre loading with 2.5% MAPP adding. When the reinforcement fibre treated by 5% NaOH, the tensile strength increased with increasing fibre loading from10 to 20wt% but decreased at 30wt% same goes when it modified by 5% MAPP but for the modification by 2.5% MAPP, the fibre loading at10wt% hold the highest value of tensile strength between others. Moreover, increasing the MAPP content at the same level of fibre loading can be seen decreasing the tensile strength. These results can be explained by the incompatibility of higher amount of modifier with increasing of fibre loading in producing composite. This also might be affected by the test sample preparation by the hot press, the width and thickness of samples. To conclude, the absorbed stress before break, basically decrease because the interfacial adhesion and interaction between bamboo fibre and PVC was not good enough thus causing the reinforcement was not compatible which lead to decrement in tensile strength. A possible reason is the chemical composition of the bamboo fibre after treated and modification done towards it and also may be due to the different pressures which hold the fibre during the tensile test from the lower and upper gripper of the testing machine.

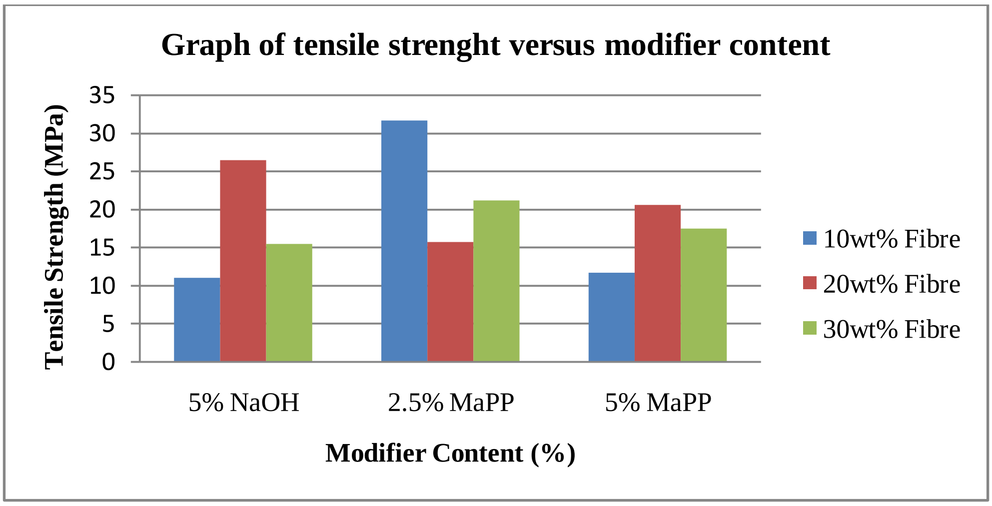


Figure 4.2: Effect of modifier content with various fibre loading on tensile strength

Comparing the effect of this two type of modifiers actually is a big different as been discussed before on chapter 3. The surface modification by NaOH can increase the interfacial adhesion of fibre-matrix interface leading to higher bonding under a certain loading of fibre by the swelling reaction of alkali treatment that widen the small pores whereby the use of coupling agent, modifier and compatibilizer agent such as MAPP is to reduce hydrophilic property of fibre by developing highly crosslinked interphase region thus not effective to enhance the adhesion like modification by NaOH.

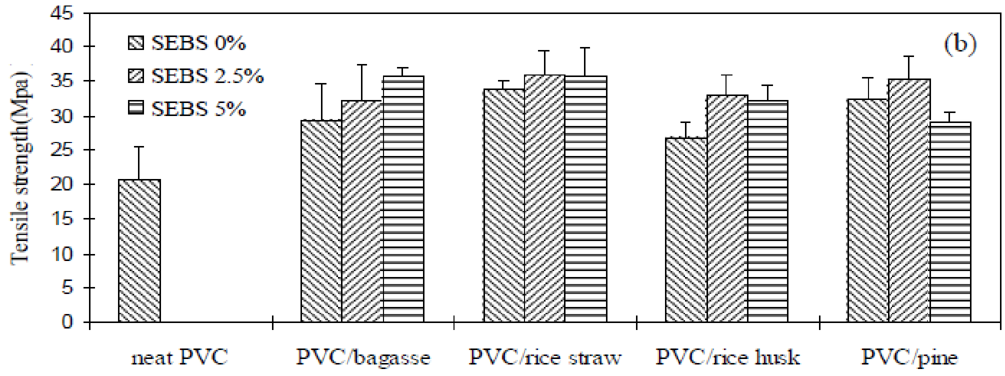


Figure 4.3: Tensile strength of four PVC/natural fibre composites with different levels of SEBS (Xu, Wu, Lei, Yao & Zhang, 2008)

When there was a good dispersion of bamboo fibre in PVC matrix the tensile strength was expected to increase with the addition of fibre. But from the result of tensile strength that were shown in figure 4.2 above, we can compare the bamboo fibre reinforced PVC composite with the previous study where some of the blending of the composites is comparable with other blending of other natural fibre/PVC composite such as bagasse, rice husk and pine and also the neat PVC itself. So, this shows that the it worth to use the bamboo fibre as reinforcement with some modification done on it where it had been stated by Xu, Wu, Lei, Yao & Zhang (2008) that their results of the study demonstrate that PVC composites filled with agricultural fibers (i.e., bagasse, rice straw, and rice husk) had properties comparable with those of PVC/wood composite indirectly proven that the bamboo fibre reinforced PVC composite also comparable with those of PVC/wood composite in terms of tensile strength. Same goes to the study by Wang, Sheng, Chen, Mao & Qian (2010) on mechanical properties of bamboo fibre reinforced PVC composites that show their highest tensile strength achieved 15.72 MPa as shown in figure 2.1. From this, we can improve the properties by changing the modifier use to produce the composite because the value in figure 4.2 clearly shows that the composite can achieve higher tensile strength.

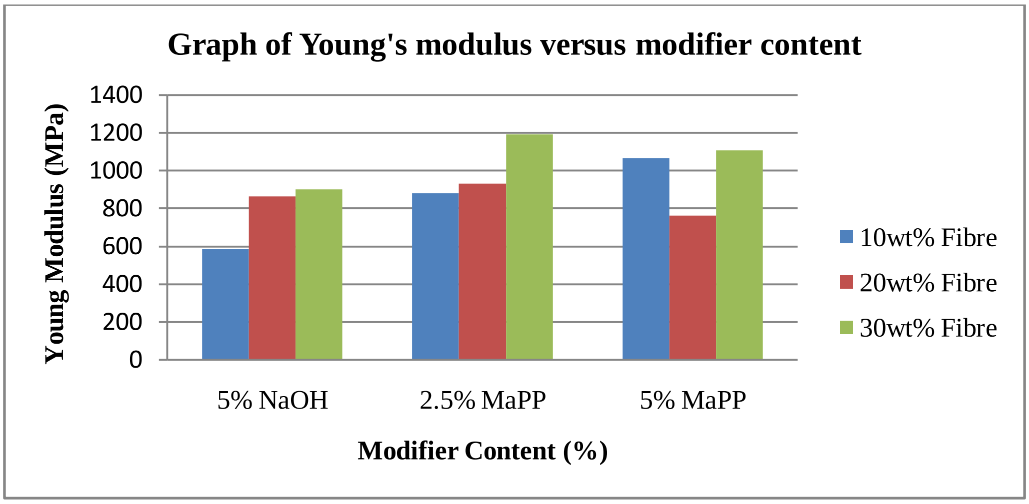


Figure 4.4: Effect of modifier content with various fibre loading on Young's modulus

Whereby figure 4.4 shows that Young's modulus increased with fibre loading for modification by 5% NaOH and 2.5% MAPP but experienced decreasing at 20wt% of fibre when modified by 5% MAPP that was from 1065 MPa to 760 MPa before increasing back at 30wt% fibre loading to 1106.35 MPa. The content of bamboo fibre had a strong positive effect on the young's modulus. The improvement of young's modulus of PVC show an agreement with previous study which stated that young's modulus were proportionally increased with fiber contents. (Abu Bakar, Hassan & Mohd Yusof, 2005). After 20wt% fibre loading for modification by 5% MAPP, the value dropped lower than the value of 20wt% fibre loading for NaOH modification. From observation, the optimum fibre loading was at 30wt% for all type of modifier and the most optimum condition which leads to highest Young's modulus was by modifying the 30wt% bamboo fibre by 2.5% MAPP.

The increased of the modulus elasticity actually mean that the PVC with reinforcement were becoming stiff and could withstand higher stress. The fibre can act as reinforcement because the major share of load is distributed among the fibre itself so it can overcome the applied stress. Some decreasing value of Young's modulus of the composite might be occur because of the PVC matrix was hard to flow between the bamboo fibre thus leaving voids and indirectly easily expose to degradation. Somehow if we relate the result in figure 4.2 and figure 4.4, it echo the result by Sanyal (2009) which stated that if the modulus of elasticity or Young's modulus of the fibre is high with respect to the modulus of elasticity of the composite, the fibre helps carry the load, therefore increasing tensile strength of the composite material. But still practically, this composition of 10 to 30wt% of fibre loading of composite can be produce.

Observing the condition at 20wt% of fibre loading in figure 4.5, it is kind of interesting matter to discuss. It can be seen that the highest tensile strength shows when the fibre being treated first by 5% of NaOH before composite production. Echo the study by Wong, Yousif & Low (2010), they stated that by treating the fibres, the surface toughness will increased, hence creating peaks and valleys on the surfaces thereby weakening the fibre causing break at lower strength but still the results shows opposite situation where indicates that 5% of NaOH solution is still mild enough to dissolve all lignin, which are the natural cementing substances of natural fibres (Mwaikambo & Ansell, 2006) and treatment by 5% NaOH increases the strain at break. Besides, treated fibre with alkali treatment increased the porosity that leads to better bonding with PVC thus can be use as reinforcement of PVC composites.

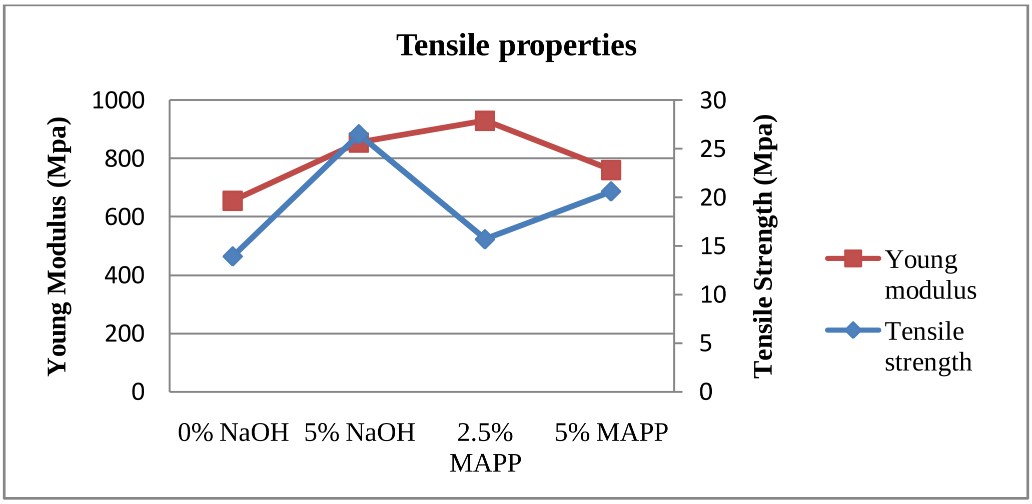


Figure 4.5: Tensile properties of 20wt% fibre loading with different modifier content

Comparing the figure 4.5 above, when the MAPP content increase, it can be seen that the tensile strength decrease but increased value can be seen for Young's modulus where have been agreed by previous researcher who studied in other natural fibre composite, Abu Bakar, Hassan, & Mohd Yusof, (2005). This indicate some error while the preparation was made or may have been caused by the self condensation reaction of the hydrolyzed MAPP on the surface of bamboo particles due to the presence of other linkage on the bamboo fibre surface that may have cause the reduction on either one of the tensile properties. (Sombatsompop & Chochanchaikul, 2005).

4.4 Thermal Stability

The dynamic TGA curves for bamboo fibre reinforced PVC composites for 20wt% fibre loading are plotted in figure 4.6. From the curves, it is obvious that the onset temperature of degradation increased when bamboo fibre were added to neat PVC.

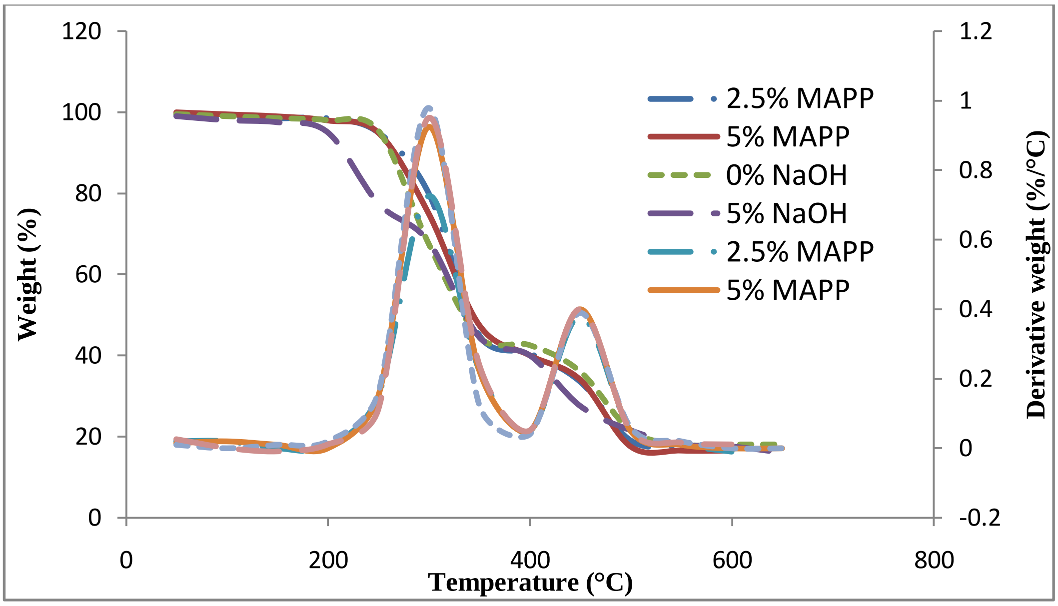


Figure 4.6: 20wt% bamboo fibre loading TGA curves

We can see that untreated bamboo fibre have the lowest degradation temperature because it has only OH group that can easily undergo the cleaving process from the fibre structure resulting in lower thermal stability. It might cause by the different degradation mechanisms of PVC and bamboo fibre itself where HCl released from degradation (dehydro- chlorination) of PVC can hasten this process by inducing further degradation and result in self accelerating degradation. (Xu, Wu, Lei, Yao & Zhang, 2008). However, the degradation of bamboo fibre follows a different two stages process with the low temperature stage from degradation of cellulose and hemicellulose and the high temperature stage from degradation of lignin.

To better illustrate the dynamic TGA curves, onset temperatures of the derivative weight were taken as Td and listed in the table 4.1. From the table, T_d of the composites was increasing with the addition of each modifier and higher than the T_d of neat PVC itself as shown by table 2.2 from Xu, Wu, Lei, Yao & Zhang (2008) where it clearly shows that the adding of modifier increases the thermal stability of the composite.

Table 4.1: Degradation temperature (T_d) of 20wt% bamboo fibre/PVC composite

Composite type	**First T_d (°C)**
Neat PVC	264.89
0% NaOH/PVC	274.96
5% NaOH/PVC	280.24
2.5% MAPP/PVC	275.79
5% MAPP/PVC	276.17

According to the chemical composition of the bamboo itself which content hemicelluloses, cellulose and lignin, it will have three stages of decomposition. As shown in the TGA curves the three stages decomposition were observed for all composites starting with dehydration and decomposition of volatile components at low temperature, followed by rapid weight loss for oxidative decomposition and finally slow decomposition corresponding to formation of char or residue as temperature increased. (Gao, Zhu & Sun, 2004). The rapid weight loss can be seen clearly in the table 4.2 where the second stage for each type of composite having the highest value of weight loss.

Table 4.2: Thermal properties of PVC and composites

Sample	Stage	Weight loss (%)	Temperature range (°C)
0% NaOH	First	38	210-305
	Second	52	305-450
	Third	10	450-610
5% NaOH	First	38	210-310
	Second	46	310-450
	Third	16	450-610
2.5% MAPP	First	39	215-310
	Second	49	310-465
	Third	12	465-625
5% MAPP	First	29	205-315
	Second	53	315-460
	Third	10	460-625

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Conclusion that is made here is based on the objectives of the study on production and characterization of bamboo fibre reinforced PVC composites and observations done throughout the whole study on the tensile properties of the composites. Both types of modification which is the alkali treatment and the adding of MAPP to the bamboo fibre reinforced PVC composites improve more in tensile strength and the Young's modulus. Increasing the fibre loading can increase the Young's modulus for all types of modifiers. Whereby, using NaOH as bamboo fibre treatment increasing the tensile strength up to 20wt% fibre loading same as the adding of 5% MAPP but it is likely to use only little amount of fibre when 2.5% MAPP is added because it resulting in the highest tensile strength value which is 31.67 MPa. The adding of each type of modifier also increases the degradation temperature of the composite which is better than the neat PVC itself. Variations on weight percent of bamboo fibre with other modification used can produce reinforcing PVC composite products that have high mechanical strength and thermal stability if it meets up with the optimum condition. The production of this reinforced composite is expected can replace the current composite used or the conventional reinforcement composite used in industry.

5.2 RECOMMENDATIONS

This study has its own limitation and therefore, there are some recommendations made for future studies to improve the current work for bamboo fibre reinforced PVC composites. The first one is by using different type of surface modification as the of 5% alkali treatment by using NaOH solution and MAPP have improve the composite properties so it is recommended to use different concentration in order to get optimum condition. It is also recommended to use different length of bamboo fibre as parameter so that we can see the effect of bamboo fibre length on the properties of the PVC blend composites itself.

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APPENDIX A

Tensile testing result of 20wt% untreated bamboo fibre/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	542.197	12.0488	1.54448	56.7420
PVC	479.639	10.6587	1.65784	17.4689
PVC	857.918	19.0649	3.17075	83.5530
Average	626.585	13.9241	2.12436	52.5880
Standard Devi	202.768	4.50596	0.90797	33.2373
Maximum	857.918	19.0649	3.17075	83.5530
Minimum	479.639	10.6587	1.54448	17.4689

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	1.26093	1.51315	1.55994	1.49815
PVC	0.38820	1.61223	1.66209	1.60810
PVC	1.85673	3.08156	3.17687	3.07563
Average	1.16862	2.06898	2.13297	2.06063
Standard Devi	0.73860	0.87832	0.90549	0.88074
Maximum	1.85673	3.08156	3.17687	3.07563
Minimum	0.38820	1.51315	1.55994	1.49815

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.06017	725.301
PVC	0.00000	1154.28
PVC	0.00000	1105.92
Average	0.02006	995.167
Standard Devi	0.03474	234.958
Maximum	0.06017	1154.28
Minimum	0.00000	725.301

APPENDIX B

Tensile testing result of 10wt% treated bamboo fibre with 5% NaOH/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	676.051	15.0234	2.40185	16.6742
PVC	545.956	12.1323	2.04360	4.46558
PVC	275.824	6.12942	1.23591	13.9443
Average	499.277	11.0950	1.89379	11.6947
Standard Devi	204.156	4.53681	0.59723	6.40766
Maximum	676.051	15.0234	2.40185	16.6742
Minimum	275.824	6.12942	1.23591	4.46558

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	0.37054	2.44306	2.51862	2.32979
PVC	0.09924	2.00402	2.06600	1.98229
PVC	0.30987	1.72650	1.77990	1.19883
Average	0.25988	2.05786	2.12151	1.83697
Standard Devi	0.14239	0.36130	0.37247	0.57932
Maximum	0.37054	2.44306	2.51862	2.32979
Minimum	0.09924	1.72650	1.77990	1.19883

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.00970	854.125
PVC	0.00004	898.470
PVC	0.00540	722.072
Average	0.00505	824.889
Standard Devi	0.00484	91.7612
Maximum	0.00970	898.470
Minimum	0.0	722.072

APPENDIX C

Tensile testing result of 20wt% treated bamboo fibre with 5% NaOH/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	1130.32	25.1182	3.09167	72.2663
PVC	1153.09	25.6243	2.47743	-2.3595
PVC	1290.43	28.6762	3.65165	81.6846
Average	1191.28	26.4729	3.07358	50.5305
Standard Devi	86.6180	1.92482	0.58732	46.0455
Maximum	1290.43	28.6762	3.65165	81.6846
Minimum	1130.32	25.1182	2.47743	-2.3595

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	1.60592	3.01413	3.10735	2.99892
PVC	-0.0524	2.41721	2.49197	2.40310
PVC	1.81521	3.55492	3.66486	3.54210
Average	1.12291	2.99542	3.08806	2.98137
Standard Devi	1.02321	0.56909	0.58668	0.56970
Maximum	1.81521	3.55492	3.66486	3.54210
Minimum	-0.0524	2.41721	2.49197	2.40310

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.01664	893.361
PVC	0.00991	1165.51
PVC	0.00558	790.648
Average	0.01071	949.840
Standard Devi	0.00557	193.708
Maximum	0.01664	1165.51
Minimum	0.00558	790.648

APPENDIX D

Tensile testing result of 30wt% treated bamboo fibre with 5% NaOH/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	959.757	21.3279	2.37094	-5.2277
PVC	467.667	10.3926	0.99708	20.6383
PVC	656.243	14.5832	1.78587	18.5569
Average	694.556	15.4346	1.71796	11.3225
Standard Devi	248.272	5.51714	0.68944	14.3706
Maximum	959.757	21.3279	2.37094	20.6383
Minimum	467.667	10.3926	0.99708	-5.2277

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	-0.1162	2.30315	2.37438	2.29981
PVC	0.45863	0.97133	1.00137	0.96717
PVC	0.41238	1.73733	1.79107	1.73229
Average	0.25160	1.67060	1.72227	1.66642
Standard Devi	0.31937	0.66841	0.68909	0.66876
Maximum	0.45863	2.30315	2.37438	2.29981
Minimum	-0.1162	0.97133	1.00137	0.96717

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.00000	1653.63
PVC	0.00396	1554.16
PVC	0.00406	942.113
Average	0.00267	1383.30
Standard Devi	0.00232	385.303
Maximum	0.00406	1653.63
Minimum	0.00000	942.113

APPENDIX E

Tensile testing result of 10wt% treated bamboo fibre with 2.5% MAPP/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	1491.01	33.1336	3.62696	155.355
PVC	1425.24	31.6721	3.33913	3.43084
PVC	1290.43	28.6762	3.65165	81.6846
Average	1402.23	31.1606	3.53925	80.1568
Standard Devi	102.251	2.27229	0.17375	75.9736
Maximum	1491.01	33.1336	3.65165	155.355
Minimum	1290.43	28.6762	3.33913	3.43084

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	3.45234	3.54479	3.65442	3.51815
PVC	0.07624	3.24394	3.34427	3.23896
PVC	1.81521	3.55492	3.66486	3.54210
Average	1.78126	3.44788	3.55452	3.43307
Standard Devi	1.68831	0.17669	0.18215	0.16853
Maximum	3.45234	3.55492	3.66486	3.54210
Minimum	0.07624	3.24394	3.34427	3.23896

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.00477	1068.71
PVC	0.00644	1165.48
PVC	0.00558	790.648
Average	0.00560	1008.28
Standard Devi	0.00084	194.586
Maximum	0.00644	1165.48
Minimum	0.00477	790.648

APPENDIX F

Tensile testing result of 20wt% treated bamboo fibre with 2.5% MAPP/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	813.288	18.0731	1.93187	7.18196
PVC	824.672	18.3261	1.89753	6.27756
PVC	479.127	10.6473	1.23007	66.7787
Average	705.696	15.6822	1.68649	26.7461
Standard Devi	196.297	4.36216	0.39564	34.6722
Maximum	824.672	18.3261	1.93187	66.7787
Minimum	479.127	10.6473	1.23007	6.27756

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	0.15960	1.88069	1.93885	1.87392
PVC	0.13950	1.84400	1.90103	1.84060
PVC	1.48397	1.24388	1.28235	1.19317
Average	0.59436	1.65619	1.70741	1.63590
Standard Devi	0.77049	0.35754	0.36860	0.38377
Maximum	1.48397	1.88069	1.93885	1.87392
Minimum	0.13950	1.24388	1.28235	1.19317

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.00979	1065.47
PVC	0.00413	1227.00
PVC	0.01905	1045.99
Average	0.01099	1112.82
Standard Devi	0.00753	99.3613
Maximum	0.01905	1227.00
Minimum	0.00413	1045.99

APPENDIX G

Tensile testing result of 30wt% treated bamboo fibre with 2.5% MAPP/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	844.907	18.7757	1.73082	49.2255
PVC	1134.68	25.2151	1.90256	11.1087
PVC	873.860	19.4191	1.69223	40.7751
Average	951.149	21.1366	1.77520	33.7031
Standard Devi	159.600	3.54668	0.11197	20.0183
Maximum	1134.68	25.2151	1.90256	49.2255
Minimum	844.907	18.7757	1.69223	11.1087

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	1.09390	1.70810	1.76093	1.67890
PVC	0.24686	1.85575	1.91314	1.84548
PVC	0.90611	1.64738	1.69833	1.64146
Average	0.74896	1.73708	1.79080	1.72195
Standard Devi	0.44485	0.10716	0.11048	0.10861
Maximum	1.09390	1.85575	1.91314	1.84548
Minimum	0.24686	1.64738	1.69833	1.64146

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.01683	1153.21
PVC	0.01962	1366.04
PVC	0.00398	1199.66
Average	0.01348	1239.64
Standard Devi	0.00834	111.905
Maximum	0.01962	1366.04
Minimum	0.00398	1153.21

APPENDIX H

Tensile testing result of 10wt% treated bamboo fibre with 5% MAPP/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	401.675	8.92611	0.84674	32.9661
PVC	530.550	11.7900	1.06491	48.9163
PVC	640.874	14.2416	1.37178	22.6641
Average	524.366	11.6526	1.09448	34.8488
Standard Devi	119.719	2.66041	0.26377	13.2270
Maximum	640.874	14.2416	1.37178	48.9163
Minimum	401.675	8.92611	0.84674	22.6641

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	0.73258	0.82565	0.85118	0.82133
PVC	1.08703	1.03985	1.07202	1.03296
PVC	0.50365	1.33648	1.37781	1.33063
Average	0.77442	1.06733	1.10034	1.06164
Standard Devi	0.29393	0.25652	0.26445	0.25586
Maximum	1.08703	1.33648	1.37781	1.33063
Minimum	0.50365	0.82565	0.85118	0.82133

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.00519	1010.25
PVC	0.02121	970.084
PVC	0.00511	1033.95
Average	0.01050	1004.76
Standard Devi	0.00927	32.2848
Maximum	0.02121	1033.95
Minimum	0.00511	970.084

APPENDIX I

Tensile testing result of 20wt% treated bamboo fibre with 5% MAPP/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	862.023	19.1561	2.70842	7.57138
PVC	850.109	18.8913	2.73351	14.1637
PVC	1069.52	23.7672	2.68875	104.908
Average	927.217	20.6049	2.71023	42.2144
Standard Devi	123.382	2.74186	0.02243	54.3943
Maximum	1069.52	23.7672	2.73351	104.908
Minimum	850.109	18.8913	2.68875	7.57138

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	0.16825	2.65569	2.73782	2.62717
PVC	0.31475	2.65471	2.73681	2.65150
PVC	2.33129	2.61492	2.69579	2.60808
Average	0.93810	2.64177	2.72347	2.62892
Standard Devi	1.20876	0.02326	0.02398	0.02176
Maximum	2.33129	2.65569	2.73782	2.65150
Minimum	0.16825	2.61492	2.69579	2.60808

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.01197	1148.24
PVC	0.01304	848.759
PVC	0.03015	1016.81
Average	0.01839	1004.60
Standard Devi	0.01020	150.113
Maximum	0.03015	1148.24
Minimum	0.01197	848.759

APPENDIX J

Tensile testing result of 30wt% treated bamboo fibre with 5% MAPP/PVC

Name Parameters Unit	Max_Force Calc. at Entire A N	Max_Stress Calc. at Entire A N/mm2	Max_Strain Calc. at Entire A %	Break_Force Level(%/Max) 15 N
PVC	740.735	16.4608	1.51789	14.4482
PVC	570.296	12.6733	1.16293	27.7917
PVC	1044.51	23.2114	2.05058	4.12385
Average	785.180	17.4485	1.57713	15.4546
Standard Devi	240.211	5.33803	0.44678	11.8660
Maximum	1044.51	23.2114	2.05058	27.7917
Minimum	570.296	12.6733	1.16293	4.12385

Name Parameters Unit	Break_Stress Level(%/Max) 15 N/mm2	Break_Disp. Level(%/Max) 15 mm	Break_Strain Level(%/Max) 15 %	Max_Disp. Calc. at Entire A mm
PVC	0.32107	1.47571	1.52135	1.47235
PVC	0.61759	1.13381	1.16888	1.12804
PVC	0.09164	1.99225	2.05387	1.98906
Average	0.34343	1.53392	1.58137	1.52982
Standard Devi	0.26369	0.43217	0.44554	0.43338
Maximum	0.61759	1.99225	2.05387	1.98906
Minimum	0.09164	1.13381	1.16888	1.12804

Name Parameters Unit	EASL1_Stroke Force 1 N mm	Elastic Force 10 - 20 N N/mm2
PVC	0.00520	1199.58
PVC	0.00000	1151.92
PVC	0.01197	1155.56
Average	0.00572	1169.02
Standard Devi	0.00600	26.5282
Maximum	0.01197	1199.58
Minimum	0.00000	1151.92