FABRICATION AND CHARACTERIZATION OF WOVEN KENAF/BAMBOO MAT FIBER-REINFORCED EPOXY HYBRID COMPOSITES

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By

AHMAD SAFWAN BIN ISMAIL

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Chairman : Mohammad Jawaid, PhD
Institute : Tropical Forestry and Forest Products

Research on natural fiber as reinforcement in polymer composite has increased in the past few years. Natural fiber reinforced polymer composite poses high strength and is lightweight. Besides that, production of natural fiber as reinforcement requires less energy compared to synthetic fiber. In this study, kenaf and bamboo were used as reinforcements while epoxy was used as matrix. A preliminary study was conducted to choose suitable bamboo preparation between bamboo mat, bamboo fabric and bamboo powder for further study on fabrication and characterization of kenaf/bamboo hybrid composites. Bamboo, kenaf, and bamboo/kenaf hybrid composites were fabricated by hand lay-up method. In preliminary work, chemical composition of fibers, tensile, impact and morphological properties of bamboo mat, bamboo fabric, bamboo powder and woven kenaf reinforced epoxy composites were carried out. Following this, bamboo mat was chosen as reinforcement for further study on fabrication of kenaf/bamboo hybrid composites. Hybrid composites of woven kenaf/bamboo mat with different weight ratios of kenaf: bamboo in 70:30, 50:50 and 30:70 were made, Woven kenaf and bamboo mat reinforced epoxy composites were also made as control samples to compare properties with hybrid composites. The effect of hybridization of bamboo mat on mechanical, vibration, sound absorption and morphological properties of woven kenaf/epoxy composites were studied. Hybridization of woven kenaf with bamboo mat improved the mechanical properties of hybrid composites. Hybrid composite with ratio 50:50 showed the highest improvement on tensile strength (55.18 MPa) and modulus (5.15 GPa), elongation at break (2.42 mm), flexural strength (99.41 MPa) and modulus (6.12 GPa) and impact strength (45.06 J/m). Analysis of morphological properties of the samples were carried out using scanning electron microscopy (SEM) to observe fracture behavior and fiber pull out of the tensile fracture sample. Acoustic properties of woven kenaf, bamboo mat and kenaf/ bamboo hybrid composites analysis was conducted according to ISO 10534-2:2001. Sound absorption coefficients of composites were measured in two conditions: without air gap and with air gap (10, 20, 30 mm). Sound absorption coefficients for testing without air gap were less than 0.5. Introducing air gap improved the sound absorption coefficient. Density, void content, water absorption and thickness

swelling of the composite were determined. Hybridization of kenaf fiber with bamboo fiber has increased density while void content, water absorption and thickness swelling decreased. Hybrid composite of woven kenaf/bamboo mat with ratio 50:50 showed excellent overall properties in comparison to other hybrid composites. We concluded that woven kenaf/bamboo mat hybrid composites possess sufficient strength and modulus which is suitable for production of crash box and food tray tables.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

FABRIKASI DAN PENCIRIAN SERAT KENAF/BULUH MEMPERKUKUH KOMPOSIT HIBRID YANG EPOXY

Oleh

AHMAD SAFWAN BIN ISMAIL

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Pengerusi : Mohammad Jawaid, PhD
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Penyelidikan serat semulajadi sebagai ejen pengukuh dalam polimer komposit telah meningkat dalam beberapa tahun yang lalu. Polimer komposit yang diperkukuh dengan serat semulajadi mempunyai kekuatan fizikal yang tinggi dan bersifat ringan. Selain itu, proses pengeluaran serat semulajadi untuk digunakan sebagai pengukuh dalam polimer menggunakan kurang tenaga berbanding pemprosesan serat sintetik. Dalam kajian ini, kenaf dan buluh digunakan sebagai pengukuh manakala epoksi digunakan sebagai matriks. Kajian awal dijalankan untuk memilih penyediaan buluh yang sesuai antara tikar buluh, kain buluh dan serbuk buluh untuk kajian lanjut mengenai fabrikasi dan pencirian komposit hibrid kenaf / buluh. Komposit hibrid buluh, kenaf, dan buluh / kenaf hibrid telah direka dengan kaedah *hand lay-up*. Pada peringkat awal kajian ini, komposisi serat kimia, tegangan, kesan dan sifat morfologi tikar buluh, kain buluh, serbuk buluh dan tenunan epoksi bertetulang kenaf dikaji. Tikar buluh dipilih sebagai pengukuh untuk kajian lanjut komposit hibrid kenaf / buluh. Komposit hibrid tenunan kenaf / tikar buluh dengan nisbah berat kenaf:buluh yang berbeza digunakan seperti berikut 70:30, 50:50 dan 30:70. Epoksi komposit yang diperkukuh dengan tenunan kenaf dan epoksi komposit yang diperkukuh dengan buluh dibuat sebagai sampel kawalan untuk membandingkan sifat-sifat dengan komposit hibrid. Kesan hibrid tikar buluh pada sifat mekanikal, getaran, penyerapan bunyi dan sifat morfologi tenunan kenaf / epoksi tenunan telah dikaji. Penambahan kenaf tenunan dan tikar buluh meningkatkan sifat mekanik komposit hibrid. Komposit hibrid dengan nisbah 50:50 menunjukkan peningkatan tertinggi pada kekuatan tegangan (55.18 MPa) dan modulus (5.15 GPa), pemanjangan pada rehat (2.42 mm), kekuatan lenturan (99.41 MPa) dan modulus (6.12 GPa) dan kekuatan impak (45.06 J / m). Analisis ciri-ciri morfologi sampel dilakukan dengan menggunakan pengimbas mikroskop elektron (SEM) untuk mengkaji kelakuan patah dan tarik serat dari sampel patah tegangan. Kajian ciri-ciri akustik tenunan kenaf, tikar buluh dan kenaf / komposit hibrid buluh telah dijalankan mengikut ISO 10534-2: 2001. Koefisien penyerapan bunyi komposit dinilai dalam dua keadaan: tanpa ruang udara dan dengan ruang udara (10, 20, 30 mm). Pekali penyerapan bunyi untuk ujian tanpa ruang udara adalah kurang daripada 0.5. Penambahan ruang udara pada struktur komposit meningkatkan pekali penyerapan bunyi. Ketumpatan, kandungan

lompang, penyerapan air dan pembengkakan ketebalan komposit juga dikaji. Kewujudan serat kenaf dengan serat buluh dalam struktur komposit meningkatkan ketumpatan manakala kandungan lompang, penyerapan air dan ketebalan bengkak berkurangan. Gabungan tenunan kenaf / buluh dengan nisbah 50:50 menunjukkan sifat keseluruhan yang sangat baik dibandingkan dengan komposit hibrid yang lain. Kesimpulannya, komposit hibrid tenunan kenaf / buluh mempunyai kekuatan dan modulus yang sesuai untuk pengeluaran kotak nahas dan meja dulang makanan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of master science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
BFRC	Bamboo fiber reinforced composite
BFRP	Bamboo fiber reinforced polymer composite
BG	Between group
CO_2	Carbon dioxide
cps	Centipoise
Df	Degree of freedom
DGEBA	Diglycidyl ether of bisphenol-A
FRP	Fiber reinforced polymer
HDPE	High density polypropylene
ISO	International Organization for Standard
K	Woven kenaf
LSD	Least significant difference
MAPP	Maleic anhydride modified polypropylene
MDF	Medium density fiberboard
MS	Mean square
NDF	Neutral detergent fiber
NROM	New rule of mixture
O_2	Oxygen
PALF	Pineapple leaf fiber
PLA	Polylactic acid
ROM	Rule of mixture
RTM	Resin transfer moulding
SEM	Scanning electron microscopy
SS	Sum of square
WG	Within group

CHAPTER 1

INTRODUCTION

1.1. Background of Study

Composite material is made up by more than one constituent with different properties. It has different properties compared to the individual original constituents. Composite constituents can be classified as matrix and reinforcement (Ain Umaira *et al*., 2016). Fiber reinforced polymer (FRP) is one of the composite materials which consists of polymer matrix (epoxy, vinyl ester or polyester thermosetting plastic, and phenol formaldehyde) and fiber (glass, carbon, aramid, paper, wood and asbestos) as reinforcement (Masuelli, 2013). Recently, due to the environmental concerns, researchers are now replacing synthetic fibers with natural fibers as the main component in composites. Natural fiber has acceptable mechanical properties, material renewability, cost-effective, biodegradability and eco-friendly (Ain Umaira *et al*., 2016).

Utilization of natural fibers as filler or reinforcement materials in polymer composites has increased due to their processing flexibility, high specific stiffness and low cost which attract interest of manufacturers. Plastic is one of the important raw materials and its demand in industry has increased drastically. The use of natural fiber in polymer composites is gaining acceptance in many applications such as structural and automotive industry. Market for bio-based polymer composites is growing rapidly with 38% global average annual growth rate from 2003 to 2007. While in the Europe, average growth rate is 48%. Forecast for bio-based polymer composite showed that worldwide capacity of bio-based plastic will increase from 0.36 million metric ton in 2007 to 2.33 million metric ton by 2013 and 3.45 million metric ton in 2020 (Shen *et al*., 2009).

Application of kenaf fiber as twine in the USA in 1940 has led this fiber being used to manufacture rope and bagging. Rope and bagging from this fiber then was used in carpet backing, packing materials, papers and fencing (Tiwari and Srivastava, 2012). Kenaf fiber has good properties which attract those who need concrete composites loaded with natural fibers and improved final product performance. In recent year, kenaf has been used in various applications including structural, automotive, plastic and food packaging industries (Tiwari and Srivastava, 2012). This fiber can be used as reinforcement material for thermoplastic and thermoset polymer. Verma and Shukla (2018) has studied the use of kenaf as filler and high density polypropylene (HDPE) as matrix. In this study the effect of fiber loading and fiber treatment on mechanical properties were investigated. Another study was conducted by Hao *et al*., (2013) using non-woven kenaf mat as reinforcement and polypropylene as reinforcement. The effect of manufacturing condition on mechanical, thermal and acoustic performance of composite were studied.

Bamboo is a common material used as structural element in pre-industrial architecture in Asia and South American countries (Sen and Reddy, 2011). 22 million hectares of the

world covered by bamboo forest contributing to more than 30 million tonnes bamboo fiber a year (Fan and Fu, 2016; Rawi *et al*., 2013b). Bamboo fiber has excellent mechanical properties which are comparable to glass fiber (Rawi *et al*., 2013b). Besides that, bamboo is also suitable to be used as building material since it has similar mechanical properties to structural wood product (Mahdavi *et al*., 2012). In addition, bamboo is renewable and non-polluting material. Moreover, bamboo can produce 35% more oxygen (O_2) compared to other trees with the same condition and at the same time it can help to reduce carbon dioxide (CO_2) in atmosphere due to its high growth rate (Costa *et al*., 2017). There are a lot of studies and reviews on the potential of bamboo fiber as reinforcement (Abdul Khalil *et al*., 2012; Chattopadhyay *et al*., 2011; Kushwaha and Kumar, 2010a; Rassiah and Ahmad, 2013; Suhaily *et al*., 2013).

Combination of two or more filler/reinforcement materials in a single matrix can produce a material known as hybrid composite which has better overall performance compared to normal single reinforced composite. Scientists have investigated hybrid composite using different combination of fibers, using both synthetic and natural fibers in order to find the best combination to be used in many applications such as automotive, structural and aerospace industries. In this study, the potential of kenaf and bamboo fibers as reinforcement are explored, with the aim to use in automotive industries. The preliminary of study is to select the best type of bamboo preparation between bamboo mat, bamboo fabric and bamboo powder for further study on hybrid composites. Physical, mechanical, vibration, acoustic and morphological properties of hybrid composites were investigated.

1.2. Problem of Statement

In the last few decades, research interest has shifted form monolithic materials to composites material. Composite materials usually consist of reinforcement and matrix. Synthetic fibers such as glass, kevlar, aramid and carbon are examples of conventional reinforced material. Polymer reinforced with these materials will have high mechanical performance. Composites reinforced with synthetic fiber are hard to dispose. This is because synthetic fibers are non-degradable materials and usually will be disposed at land field since they are not suitable to be incinerated using normal incinerator because they will reduce net heat, damage the furnace and these fibers will remain after incineration process (Okubo *et al*., 2004; Wallenberger and Weston, 2004). These materials require special incinerator to turn synthetic fiber such as glass fiber into ash but these equipments are expensive (Wallenberger and Weston, 2004). To overcome these problems, natural fibers are used to replace or reduce the use of synthetic fibers.

There are many advantages associated with the use of natural fibers in composite materials. Natural fiber composites provide a healthier working condition than the synthetic fiber composites. Compared to natural fibers, trimming, cutting and mounting of synthetic fibers components produce dust which causes skin irritation and respiratory diseases to human beings. In addition, natural fibers are less abrasive in nature compared to that of synthetic fibers. In term of performance, natural fibers cannot go beyond the capability of synthetic fibers but in some application, natural fibers can be used. In automotive industries there are some parts of car fabricated using totally natural fiber or hybrid natural fiber with synthetic as reinforcement depending on the requirement of the application. Therefore, the usage of petroleum base polymers and synthetic fibers can be

reduced. Natural fibers have different properties. In order to improve the properties of composites, hybrid composites can be produced by combining them with stronger natural fibers/synthetic fibers in the same matrix. Using a hybrid composite that contains two or more types of different fibers, the advantages of one type of fiber could complement what is lacking in the other (Jawaid and Abdul Khalil, 2011). As a result, a composite which have balance in performance and cost could be produced through proper material design.

Properties of hybrid composite will depend on the properties of fiber, fiber content, fiber size, fiber orientation and interfacial bonding between fiber and matrix. There are a lot of studies conducted on natural fiber polymer composite but only a few studies on the properties and characterization of natural fiber reinforced hybrid composites are available today. In most cases, durability issues were not addressed (Subhankar Biswas *et al*., 2015; Zainudin *et al*., 2014). Kenaf fiber is easily obtainable in the market in many from such as non-woven mat and woven mat. Besides that, the prices of kenaf fiber is cheap. Kenaf fiber has hollow structure which polymer is unable to penetrate and fill this hollow structure. The presence of hollow structure is one of the factors making kenaf fiber reinforced polymer composite to have lower mechanical properties, but this hollow structure helps to improve its acoustic properties. Good acoustic properties is needed in application which involves sound such as door panel and dash board in car. Bamboo fibres are known to be strong, stiff, containing an inferior microfibrillar angle, fibre axis, and a thicker cell wall, which has led to it being considered as ‘‘nature’s glass fibre’ (Li *et al*., 1995). In terms of sources, bamboo fiber is available abundantly in Asia and South America. Therefore, the aim of this study is to prepare woven kenaf/bamboo mat reinforced epoxy composite using hand lay-up method and study its physical, mechanical morphological and acoustic properties.

1.3. Objective of the Study

1. To evaluate the mechanical and morphological properties of woven kenaf bamboo powder (short fiber), non-woven bamboo mat and woven bamboo fabric reinforced epoxy composites.
2. To assess physical, mechanical and morphological properties of woven kenaf/bamboo mat reinforced epoxy hybrid composites.
3. To investigate acoustic properties of woven kenaf/bamboo mat reinforced epoxy hybrid composites.

1.4. Thesis outline

This thesis is structured into five chapters. The first chapter contains the background of this research, problem statement and objectives. Chapter two will provide the research and literature on natural fiber, polymer natural fiber reinforced polymer composite and hybrid composites. Third chapter will cover information on material, methodology and characterization of the research. Results and discussion will be covered in chapter four. In this chapter the result will be discussed based on scientific point of view and compared with published works. The last chapter will present the major outcome of the research finding and recommendation for future works.

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