ASSESSMENT OF KENAF AS MATERIAL FOR LAMINATED WOVEN KENAF/CARBON FIBRE EPOXY HYBRID COMPOSITES

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By

AISYAH HUMAIRA ALIAS

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Chair : Paridah Md. Tahir, FASc
Institute : Tropical Forestry and Forest Products

Natural fibers received much attention as a reinforcement material in polymer composite, due to the environmental concerns by substituting synthetic fibres. Natural fibre reinforced composite (NFRC) is a composite material made up of a polymer matrix mixed with natural fibres, including kenaf fibre. However, the performance of the NFRC is still not comparable with synthetic polymeric composite. Therefore, hybridisation of natural fibres with synthetic fibre is suggested to produce biodegradable composite. Some researchers have found that natural fibres in woven fabric form produced better composite properties due to fabric structure. In this study, a three-layer laminated hybrid composites was produced from woven kenaf (*Hibiscus cannabinus*) fabric and carbon fibre by using epoxy as a matrix. Each composite consists of a single ply woven kenaf at the center layer and carbon fibres fabric at the upper and lower layers. The ratio of fabrics and resin was 30:70 by mass. The study was divided into three main parts: (i) evaluation of yarn properties, (ii) characterisation of woven kenaf fabric, and (iii) development of lamination woven kenaf/carbon fibre epoxy hybrid composite. Analysis on the yarn properties, the morphological characteristics, and mechanical properties on four types of yarn at different linear densities were studied. It was found that yarn with high linear density contains more amount of fibres, wider in yarn diameter, and higher in moisture content. The tensile strength and elongation of kenaf yarn increased, but the Young's modulus reduced as the number of linear density increased. The production of woven fabric used two main parameters i.e., yarn linear density (500, 1000, 1500, and 2000 tex) and weave design (plain, satin, and twill). A total of 12 types of woven fabric were tested for basic properties and mechanical strength. The results show that the properties of woven kenaf fabric are more affected by yarn linear density compared to the weave design which appears to be contributed by the yarn size and properties. The crimp percentage and number of cross yarn were found to be the two major factors influencing the properties of the woven fabric. Fabric having 500 tex yarn with plain and satin design were found to have good fabric properties, thus were selected in the subsequent composite production. The physical properties

(density, volume fraction, and void content), mechanical properties (tensile, flexural, and impact), thermal (TGA and DSC) and morphological properties of different weave designs i.e., plain and satin composites was studied. The effects of different fabric count (5 × 5 and 6 × 6) and the presence of carbon fibre were also studied. The three-layer hybrid composites were prepared by using vacuum impregnated process in the presence of epoxy resin. The result found that the effect of weave design on the composites properties is more prominent than that of fabric count. Significantly higher of tensile and impact properties were given by composite with plain fabric. Composite made from kenaf satin fabric, however had good flexural properties. Apparently, composite made from plain design kenaf fabric had better adhesion between the fibres and matrix, consequently gives significantly higher strength. However, by using 5 × 5 fabric count improved the flexural modulus, while fabric count of 6 × 6 improved the tensile and impact strengths. Such improvements may be attributed by the high fibre content and good fabric structure. The thermal stability of the laminated hybrid composites was slightly inferior to 100% carbon fibre composite, with the thermal stability of plain fabric composite was better than the satin fabric composite. The addition of carbon fibre in the NFRC has improved the TGA properties of hybrid composite. The overall results indicated that the hybridisation of woven fabric and carbon fibre had successfully enhanced mechanical properties of the composite. The hybrid composite properties found significantly affected by the yarn and fabric parameters.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN TERHADAP GENTIAN KENAF SEBAGAI BAHAN UNTUK PENGHASILAN KOMPOSIT HIBRID EPOKSI BERLAPIS TENUNAN KENAF/SERAT KARBON

Oleh

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Gentian semulajadi telah mendapat perhatian sebagai bahan tetulang dalam komposit polimer, atas dasar keprihatinan terhadap alam sekitar dengan menggantikannya dengan gentian sintetik. Komposit bertetulang gentian semulajadi (NFRC) adalah bahan komposit yang terdiri daripada polimer sebagai matrik dan dicampurkan dengan gentian semulajadi, seperti gentian kenaf. Walau bagaimanapun, prestasi NFRC masih tidak dapat dibandingkan dengan komposit polimer sintetik. Sehubungan itu, hibridisasi gentian semulajadi dengan gentian sintetik dicadangkan untuk menghasilkan komposit bolehurai. Sesetengah penyelidik mendapati bahawa gentian semulajadi dalam bentuk fabrik boleh menghasilkan sifat komposit yang lebih baik kerana mempunyai struktur yang lebih kuat. Dalam kajian ini, komposit hibrid tiga lapis telah dihasilkan dengan menggunakan fabrik tenunan kenaf (*Hibiscus cannabinus*) beserta gentian karbon dan epoksi sebagai matrik. Setiap komposit terdiri daripada satu lapisan fabrik kenaf dibahagian tengah lapisan, dan dua lapisan fabrik gentian karbon dibahagian atas dah bawah lapisan. Nisbah bagi fabrik dan resin adalah 30:70. Kajian ini terbahagi kepada tiga bahagian utama: (i) penilaian sifat benang (ii) pencirian tenunan kenaf, dan (iii) penghasilan komposit hibrid epoksi berlapis tenunan kenaf/serat karbon. Analisa sifat benang, ciri morfologi serta sifat mekanikal ke atas empat jenis benang berlainan kepadatan liner telah dikaji. Didapati, benang dengan kepadatan liner yang besar mempunyai lebih banyak serat di dalam struktur benang, diameter benang yang lebih lebar, dan kandungan lembapan yang lebih tinggi. Benang dengan kepadatan liner yang besar mempunyai kekuatan tegangan dan pemajangan yang tinggi, tetapi modulus Young yang rendah. Tenunan fabrik kenaf dihasilkan dengan menggunakan dua parameter utama, iaitu kepadatan liner benang (500, 1000, 1500 dan 2000 tex) dan corak tenunan (biasa, satin, dan twill). Sifat asas dan kekuatan mekanikal 12 jenis fabrik tenunan telah diuji. Hasil ujian mendapati sifat fabrik tenunan lebih banyak dipengaruhi oleh ketumpatan liner benang berbanding corak tenunan kerana saiz dan sifat gentian. Peratusan kelim dan bilangan benang yang bersilang telah dikenal pasti sebagai faktor utama yang mempengaruhi sifat fabrik tenunan. Fabrik 500 tex dengan corak biasa dan satin didapati mempunyai sifat fabrik yang baik, dan dipilih untuk penghasilan komposit. Ciri-ciri fizikal (ketumpatan, pecahan isipadu, dan kandungan lowong), sifat mekanik (tegangan, lenturan, dan hentaman), termal (TGA dan DSC) dan sifat morfologi corak tenunan yang berbeza iaitu komposit biasa dan satin telah dikaji. Kajian kesan dengan menggunakan dua kepadatan fabrik (5 × 5 dan 6 × 6) dan menggunakan serat karbon turut dijalankan. Komposit hibrid tiga lapisan telah dihasilkan menggunakan tekanan vakum berudara bersama lapisan serat karbon. Hasil kajian didapati kesan corak tenunan lebih menonjol daripada kepadatan fabrik ke atas sifat komposit. Peningkatan yang ketara pada sifat tegangan dan hentaman daripada komposit dengan fabrik biasa. Walau bagaimanapun, sifat lenturan yang baik dikenalpasti daripada komposit dengan fabrik satin. Komposit dengan fabrik biasa mempunyai lekatan yang lebih baik antara gentian dan matrik, menghasilkan kekutan tegangan yang tinggi. Walau bagaimanapun, dengan menggunakan kepadatan fabrik 5 × 5, terdapat peningkatan dalam modulus lenturan, manakala kepadatan fabrik 6 × 6 telah meningkatkan kekuatan tegangan dan hentaman. Peningkatan ini disebabkan oleh kandungan serat yang tinggi serta struktur fabrik yang baik. Didapati kestabilan termal komposit hibrid berlapis sedikit rendah berbanding 100% komposit gentian karbon, dengan kestabilan termal komposit fabrik biasa lebih baik daripada komposit fabrik satin. Hibridisasi tenunan kenaf dengan serat karbon juga didapati telah meningkatkan sifat-sifat TGA komposit. Sebagai kesimpulan keseluruhan, hibridisasi antara fabrik kenaf dan serat karbon meningkatkan sifat mekanikal komposit. Sifat komposit didapati dipengaruhi oleh parameter benang dan fabrik.

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I certify that a Thesis Examination Committee has met on 16 April 2019 to conduct the final examination of Aisyah Humaira Alias on her thesis entitled "Assessment of Kenaf as Material for Laminated Woven Keaf/Carbon Fibre Epoxy Hybrid Composites" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
APP	Ammonium polyphosphate
ASTM	American society for testing and materials
CF	Cover factor
CMC	Ceramic matrix composite
CTE	Coefficient of thermal expansion
DMA	Dynamic mechanical analysis
DSC	Differential scanning calorimetry
DTG	Derivative thermogravimetric
EFB	Empty fruit bunch
FRPC	Fibre reinforced polymer composite
HDPE	High-density polyethylene
LSD	Least significant difference
MC	Moisture content
MDF	Medium density fibreboard
MMC	Metal matrix composite
MMT	Montmorillonite
NFPC	Natural fibre polymer composite
OMMT	Organically modified montmorillonite
OPEFB	Oil palm empty fruit bunches
PE	Polyethylene
PLA	Polylactic acid
PLLA	Poly-l-lactic acid
PMC	Polymer matric composite
PP	Polypropylene
PU	Polyurethane
PVA	Polyvinyl alcohol
PVC	Poly vinylychloride
SAS	Statistical analysis system
SEM	Scanning electron microscopy
Tg	Glass transition temperature
TG	Weight loss as a function of temperature
TGA	Thermogravimetric analysis
TPM	turns per metre
UTM	Universal Testing Machine
VIP	Vacuum infusion process

CHAPTER 1

INTRODUCTION

1.1 Introduction

Composite materials reinforced with natural fibres are becoming more popular in many applications such as semi-structural building component, automotive, furniture and other applications. The most significant criteria of natural fibres are renewability and bio-degradability, which synthetic composite could not offer. Natural fibres can be used as a green substitute due to their advantages such as light weight, having good mechanical properties and low density with good strength. Natural fibres are bio-based materials that can be obtained abundantly from plants including wood, jute, bamboo, oil palm, kenaf, ramie, cotton and flax.

One of the potential natural fibres that is used in composite materials is kenaf bast fibre, a fibre that is obtained from the outer layer (from the epidermis to the phloem) of the kenaf stem. Kenaf bast has good potential as a reinforcement agent for natural fibre composite because it has long fibre with good mechanical properties and high strength that can be converted to a high performance composite (Paridah et al., 2011; Ohnishi et al., 2003; Kawai et al., 1999). Compared to ramie, flax, and jute, the yield of kenaf is relatively higher (up to 25 tonne/ha) thus gives more economic advantage (Wood, 2000; Rymsza, 2001; Kozlowski, 2000). Compared to softwood fibres, bast fibre is slightly shorter (2.48 to 3.60 mm) and thinner that can increase the ability of bonding and strength development (Khalil et al., 2010; Ashori, 2006). In addition, the slenderness ratio (fibre length/fibre diameter) of kenaf bast fibres is comparable to those of softwood fibres (Ververis et al., 2004) and bast fibre have low lignin content (14.7%) which attributed to the quality of bast fibres (Khalil et al., 2010).

Currently, there is a growing interest of using woven material in composite production for many applications such as structural applications (Baghaei et al., 2015; Khan et al., 2016; Jawaid et al., 2011), non-structural applications (Alavudeen et al., 2015; Pothan et al., 2003), household utilities (Abdellaoui et al., 2015; Sapuan et al., 2006; Sapuan and Malique, 2005), parts for automobile and aerospace components (Song et al., 2012; Le Duigou et al., 2011), flooring (Soma and Acharya, 2015), ballistic laminate composites applications (Yahaya et al., 2015; Azrin Hani et al., 2011) and bio-medical applications (Me et al., 2012). This type of composite is commonly known as a textile composite which made up from the technical textile rather than the conventional textile. In textile technology, there are three main techniques that are commonly practised, i.e., weaving, knitting, and braiding. However, the use of weaving technique that produces fabrics (also known as mats or preforms) has received much attention because they provide superior mechanical properties than both knitting and braiding techniques. Moreover, woven composite also has the ability to produce near net shape preforms or fabric with high flexibility and stability.

The structure and properties of the fabric are essential as they dictate the woven composite properties. Fabric is normally made up from bundles of yarn that consist of numerous fibres through several processes including spinning, carding, and twisting. The properties of yarn such as linear density, compaction, strength, and twist factor can influence most of the fabric properties. In fabric properties, strength influences the final performance of the woven composites significantly. Generally, the strength of the fabric is determined by the fibre yarn strengths as well as the conversion parameters, from fibre to yarn, and yarn to fabric. Thus, the composite performances are depending not only on the properties of the constituent yarn, but also the weaving design and structures.

Several studies have been carried out on utilising kenaf yarn for woven fabric composite production. Due to high fabricability of yarn, a number of production parameters are considered to produce acceptable woven fabric and composite quality. For instance, the selection of appropriate yarn type and weaving parameters significantly improve the composite properties, and weaving design is identified as one of the effective parameters. In addition, several researchers (Salman et al., 2015a; Saiman et al., 2014a; Hani et al., 2013a) produced a woven fabric polymer composite using solely kenaf, and they suggested that woven kenaf is suitable to be used as a reinforcement. However, the performance of the composites was still not comparable with the synthetic polymeric composite. Therefore, substituting a certain amount of synthetic fibre with kenaf fibres was suggested to produce a bio-polymeric composite. Hence, a wider understanding of the properties of yarn and woven fabric for composite is necessary, especially their effects on the final composite properties.

1.2 Problem statements and justification

Kenaf fibres can be processed in many ways such as long continuous fibres, unidirectional fibres, chopped, particles, randomly oriented fibre, spun yarn, woven, and fabric. These types of composites have strength in all possible directions but not as strong as the woven fabric composite (Mallick, 1997). Navarro et al. (2008) mentioned that rather than the moisture content and types of fibre used, form of fibres (i.e., unidirectional, nonwoven, and chopped fibre) can affect the properties due to the non-homogeneity of fibre structure compared to the woven composite that was found to have advantages from its balanced mechanical properties.

Numerous researches have been done by utilising natural fibre in a form of woven fabric to produce woven fabric composite. Saiman et al. (2014a) fabricated a series of kenaf woven composite with different yarn linear density and weave structures using polyester matrix by vacuum infusion technique and found that both parameters have a significant influence on the tensile properties of composite. Research done by Hani et al. (2013a) demonstrated that woven kenaf and coir have high potential to be used as reinforcing materials, and they also concluded that fibre type and reinforcement structure parameters affect the mechanical properties of the composites. Unfortunately, the mechanical properties of natural fibres composite do not match up to those of the synthetic fibre composite. Natural fibres usually have lower mechanical properties when compared to synthetic fibres. The low mechanical properties of natural fibre are one of the main limitation in the development high performance products. Therefore, a solution by making a hybrid composite is done to replace only a fraction of the synthetic fibres. Hybridisation of synthetic fibre with natural fibre in FRPC has many benefits. Particularly they offer excellent thermal and mechanical properties.

On the other hand, Nurhanisah et al. (2017, 2018) and Me et al. (2012) studied on a woven kenaf bast fibre, glass fibre and polyvinyl alcohol (PVA) composite for a prosthetic leg socket fabrication. They made three types of kenaf laminated composites by incorporating kenaf fabric as one of the layers in the existing laminated composite structure in making the prosthetic leg socket. The results displayed an improved performance in the tensile and flexural strengths when incorporating with one layer of woven kenaf. However, good impact strength was only achieved when incorporating with two layers of woven kenaf in the composite. This has lead to suggestions of manipulating the woven fabric parameters such as weave design, fabric count, fabric thickness, and weight.

In this study, a three-layered laminated woven kenaf and carbon fibre hybrid composite was studied. The lamination consisted of carbon fibre for face layers and kenaf woven fabric on the core layer. Reinforcement by a layer of kenaf woven fabric in the interlaminate of carbon fibre composite is believed to leads hybrid composites with a great diversity of material properties (Assarar et al., 2015; Bagheri et al., 2014; Dhakal et al., 2013). Furthermore, by altering the fabric properties such as weave design and fabric density gives flexibility to tailor the final composite properties according to the requirements, which is one of the major advantages of the textile composites (Saiman et al., 2014b; Chattopadhyay, 2008; Gabrijelcic et al., 2008; Realff et al., 1997). Types of yarn and yarn arrangement in the woven fabric would affect the physical and mechanical properties of the woven composites because it can offer superior dimensional stability in the longitudinal and width wise directions. Moreover, the structure of woven fabric will determine the effectiveness of the matrix-woven fabric admixture, and finally the composite itself. In addition, hybrid with carbon fibre were suspected to produce good mechanical and thermal composite properties.

1.3 Objectives

This research aims to develop a three-layer laminated woven kenaf/carbon fibre hybrid composite impregnated with epoxy resin using vacuum infusion process (VIP). This was achieved with the following objectives:

i. To determine the effect of different yarn linear densities (500, 1000, 1500, and 2000 tex) on physical, mechanical, and morphological properties of kenaf yarn.
ii. To determine the effect of yarn linear densities (500, 1000, 1500, and 2000 tex) and weaving designs (plain, satin, and twill) on the physical, mechanical, and morphological properties of kenaf fabric.
iii. To determine the effects of hybridisation of woven kenaf/carbon fibre reinforced epoxy hybrid composite by VIP using different weave design and fabric count on its physical, mechanical, morphological, and thermal properties.

1.4 Thesis outline

This thesis is organised into five chapters. Chapter one introduces the overview of woven composite, justification, and objectives of the study. Chapter two reviews the relevant literature on natural fibre-reinforced polymer composite, specifically woven fibre reinforced polymer composite. Chapter three presents the overall research methodology for the overall structure of the research work. This chapter describes the materials used, experimental design, experimental test procedures and standards. The following chapter four presents the results and discussion of the research works. Chapter four is divided into several sections, covering the analysis on the properties of kenaf yarn with different linear densities, the effects of physical and mechanical properties of the woven fabrics, and the effects of weave design and fabric count on the physical, mechanical, thermal and morphological properties of laminated woven kenaf/carbon fibre epoxy hybrid composite. Finally, chapter five presents a summary of the research findings and recommendations for future works.

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