UNIVERSITI PUTRA MALAYSIA

LOW VELOCITY IMPACT SANDWICH STRUCTURE BAMBOO FOR AEROSPACE APPLICATIONS

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By

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Abundant sources of bamboo in Malaysia, if fully utilized, can increase its commercial value especially in developing greener composites. In this study, material characterizations on bamboo based composites, from Malaysian species of Bambusa vulgaris, were carried out by aiming on the low velocity impact properties. Bamboo powder, as the raw material in composites, was self-processed through a combination of manual and machining methods. Four different loadings of bamboo powder, which ranged from 500μm to 1mm in size, consisting of 0%, 10%, 20%, and 30% by weight were applied in the preparation of the composites. Woven glass fibre type E600, embedded at the outermost top and bottom layer of composites, was used as the main reinforcement with epoxy as the polymer matrix. Sandwich structured composites were fabricated through a combination of manual hand lay-up and compression moulding techniques. From the tensile testing and scanning electron microscopy images, poor bamboo-epoxy interfacial bonding lowered the strength of the composites as the fibre loading increased. However, the highest percentage of 30% loading suggested good stress transfer in composites through observation of the peak of the Tan δ curve through dynamic mechanical analysis. For both thermal degradation and water absorption properties, the addition of bamboo fibres lowers the thermal stability and enhances the water absorption respectively, which are the drawbacks of using natural fibres. Inconsistent damage propagations were observed on the non-hybrid bamboo composites after low velocity impact due to short size bamboo fibres aligned in random orientation within the epoxy matrix. However, the impact resistance increased as the bamboo fibre loading increased. The inclusion of woven glass fibres at the top and bottom layer of the composites significantly improved the impact resistance as these layers slowed down the penetration of the impactor, thus reducing the severity of the damages. Generally, the newly developed sandwich structured bamboo filled glass-epoxy hybrid composites have potential to be used in aerospace applications with low velocity impact properties.

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

IMPAK BERKELAJUAN RENDAH BULUH BERSTRUKTUR SANDWICH UNTUK APLIKASI AEROANGKASA

Oleh

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Pengerusi: Mohamed Thariq B. Hameed Sultan, PhD, PEng, CEng, PTech
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Sumber buluh yang banyak di Malaysia, sekiranya digunakan secara optimum,boleh meningkatkan nilai komersialnya terutama dalam membangunkan bahan mesra alam. Dalam kajian ini, perincian bahan terhadap komposit buluh daripada spesis yang berasal dari Malaysia, Bambusa Vulgaris, telah dijalankan dengan tujuan utama kepada sifat impak berkelajuan rendah. Serbuk buluh, sebagai bahan mentah dalam komposit, telah diproses secara manual dan menggunakan mesin. Dalam penyediaan komposit, serbuk buluh, dalam lingkungan saiz 500μm-1mm, telah dimasukkan dengan berat berlainan 0%, 10%, 20%, dan 30%. Anyaman gentian kaca jenis E600 telah disisipkan di lapisan paling luar atas dan bawah komposit, sebagai sokongan utama dengan epoksi. Komposit berstruktur sandwich telah dihasilkan melalui teknik hand lay-up dan mampatan acuan. Dari ujian tensile dan imbasan imej mikroskop elektron, didapati peningkatan jumlah gentian telah melemahkan ikatan gabung jalin buluh-epoksi pada komposit. Walaubagaimanapun, pemerhatian puncak Tan δ melalui analisis dinamik mekanikal mendapati peratus tertinggi iaitu 30% menunjukkan aliran tekanan yang baik dalam komposit. Dalam sifat degradasi haba dan daya serapan air, penambahan gentian buluh telah merendahkan kestabilan haba serta menambahkan daya serapan air, dan ini merupakan satu kelemahan dalam penggunaan gentian semulajadi. Penyebaran kerosakan yang tidak sekata telah dilihat pada komposit buluh tidak hibrid selepas impak berkelajuan rendah diakibatkan saiz gentian buluh yang pendek serta susunan rawak dalam matrik. Bagaimanapun, ketahanan impak meningkat apabila kandungan gentian buluh meningkat. Penambahan anyaman gentian kaca pada lapisan atas dan bawah komposit ternyata menambah baik ketahanan impak kerana lapisan ini memperlahankan penembusan impak seterusnya mengurangkan kerosakan. Komposit hibrid dengan struktur sandwich yang baru dibangunkan mempunyai potensi untuk digunakan dalam aplikasi aeroangkasa dengan sifat ketahanan terhadap impak berkelajuan renda

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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 Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing Materials
BF	Bamboo fibre
BFRP	Bamboo fibre reinforced polymer
BV	Bambusa vulgaris
C	Compression
CMC	Ceramic matrix composites
DA	*Dendrocalamus asper*
DMA	Dynamic mechanical analysis
DP	*Dendracalamus pendulus*
DSC	Differential scanning calorimetry
E’	Storage modulus
E”	Loss modulus
EP	Neat epoxy
EP-BFC	Non-hybrid bamboo fibre filled epoxy composites
EP/G-BFC	Bamboo fibre filled glass/epoxy hybrid composites
F	Flexural
FESEM	Field emission scanning electron microscope
FRP	Fibre reinforced polymer
FTIR	Fourier transform infrared spectroscopy
GF	Glass fibre
GL	*Gigantochloa levis*
GS	*Gigantochloa scortechinii*
HDPE	High density polyethylene
HDT	Heat deflection temperature
I	Izod impact
ISO	International Organization for Standardization

MAPP	Maleic anhydride polypropylene
MDF	Medium density fibreboard
MMC	Metal matrix composites
NDE	Non-destructive evaluation
NFRP	Natural fibre reinforced polymer
PBS	Poly butylene succinate
PLA	Polylactic acid
PMC	Polymer matrix composites
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride
SEM	Scanning electron microscopy
T	Tensile
Tg	Glass transition temperature
TGA	Thermogravimetric analysis
TS	Thickness swelling
WA	Water absorption
XRD	X-ray powder diffraction

CHAPTER 1

INTRODUCTION

1.1 Introduction

The use of natural sources in the materials industry is very familiar nowadays due to their environmental-friendliness, low-cost and long term continuity supply (Kalaiyarasan, Ramesh, & Paramasivam, 2016; McAdam, O'Hare, & Moffett, 2008; Shirvanimoghaddam et al., 2016). Originating from three main sources, i.e. animals, plants and minerals, natural fibres from plant sources are seen to have a high potential contribution in the composites world especially in polymer matrix composites (PMC). A variety of cellulosic fibres from different parts of the plants, such as the leaf, seed, fruit, wood and stalk, can be extracted to fulfil the role of reinforcement in composites, including acting as additional fillers, as hybrid material to synthetic composites or as the main reinforcement in the natural green composites (Ljungberg, 2007; Ramesh, Palanikumar, & Reddy, 2017; Suib, 2017).

Most of the cellulosic fibres used in PMCs, such as kenaf, jute, flax and hemp, come from the bast group, which is one part of the plant. Only a few of the reinforcing fibres originate from the grass group, like bamboo and baggase (Huda, Reddy, & Yang, 2012). Bamboo comes from the grass family of Poaceae with more than 1000 species around the globe (Jawaid & Abdul Khalil, 2011; Thakur & Thakur, 2014). Bamboo ranges from tropical woody bamboo to herbaceous bamboo and from monopodial rhizomes to sympodial rhizomes. Malaysia grows sympodial bamboo, while monopodial bamboo can be found in Taiwan and China (Gratani, Crescente, Varone, Fabrini, & Digiulio, 2008; Soreng et al., 2015).

Bamboo is one of the fastest-growing plants in the world, growing at a rate of 3 cm per hour, whilst some species can grow up to 122 cm per day (Farrelly, 1984; Guinness World Record, 2014). In most species, bamboo attains maturity in 4 to 6 years, where the growing cylindrical hollow culms are in their strongest stage and ready to be harvested. In Malaysia, bamboo is abundant throughout the country, with some species such as Bambusa vulgaris, Gigantochloa scortechinii, Gigantochloa levis, Gigantochloa ligulata, Dendrocalamus asper, Bambusa blumeana, Schizostachyum grande and Schizostachyum zollingeri being the most commonly harvested for commercial purposes, such as furniture, ornamental, crafts and utensils (Forest Research Institute Malaysia, 2013).

In terms of the strength and performance of the culms, bamboo is one of the natural fibres that exhibits comparable mechanical properties to conventional fibres (Mahdavi, Clouston, & Arwade, 2012). Bamboo is utilized traditionally in low-cost houses, bridges, and construction platforms (Bahari & Krause, 2015).

Although there is no scientific evidence on the strength of bamboo during the previous era, traditional people took the risk of using bamboo in key structural components such as bridges, which were used by many people every day. The Bidayuh ethnic in Sarawak build the bridges from bamboo culms for their daily use as shown in Figure 1.1a (Sarawak Borneo Tour, 2011).

The pillars of houses, which are the main structure in all buildings, made from bamboo proved the ability of bamboo culms to withstand high load from the whole building structure together with the household and furniture. Most houses of the rural people in Sabah and Sarawak were totally made up of bamboo, range from the culms, strips and woven strips as depicted in Figure 1.1b (Sarawak Borneo Tour, 2011).

Figure 1.1: Traditional use of bamboo culms in structural applications in Malaysia (Sarawak Borneo Tour, 2011)

These applications, as shown in Figure 1.1, drive the interest of many researchers to prove the high strength of bamboo scientifically, thus enabling its application in wider fields.

Today, bamboo in natural composites is used widely in various applications, such as the interiors of vehicles and aircrafts, bicycle helmets, bicycle frames and decks for leisure activities as shown in Figure 1.2 (Abdul Khalil et al., 2012; Ibrahim et al., 2015; Mahdavi et al., 2012; Nabi Saheb & Jog, 1999; Qiu, Van de Ven, & Molenaar, 2013; Tanaka, Okubo, Fujii, Ono, & Sakurai, 2007).

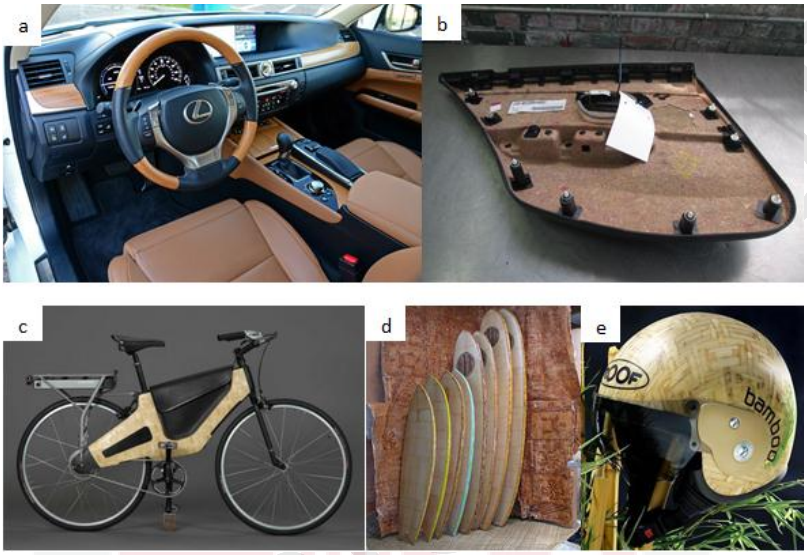

Figure 1.2: The potential use of bamboo in various applications nowadays (Lexus, 2012; Pacific Motors, 2016; Bicycle Design, 2015; Wooden Classics Hawaii, 2006; Treehugger, 2007)

Modern machines and the latest technology available nowadays vary the processing methods of bamboo to be used in different forms from powder to the multifunctional bamboo veneer. Short bamboo powder was bound with adhesive and pressed in a mould to suit the design of a door panel for the well-known car brand BMW as shown in Figure 1.2b. The bamboo deck in Figure 1.2d was in high demand among the sport lovers in Hawaii for leisure activities. The use of bamboo veneer in safety equipment such as the helmet in Figure 1.2e shows that bamboo has gained trust in high risk safety applications.

The attractive physical features of bamboo have increased their use in building constructions, generally for tourism and centres of attraction. The high strength of bamboo with its attractive features can lower the cost of designing buildings and cottages for leisure places. Similar to wood based buildings, the use of bamboo in building construction results in more cosiness and coolness. The gap between the culms for the wall structure enables the wind to pass through easily, thus providing good air ventilation. In some ways, this advantage can further lower the cost of using a fan and air conditioning.

The light weight advantage of bamboo culms, with comparable strength to mild steel in some species, suits the current demand for producing environmentally friendly materials with acceptable properties to the originals (Bardelline, 2009; Huda et al., 2012). The distinctive fast-growing features of the bamboo plant make it a promising source of fibre supplies in the continuous production of composites.

1.2 Problem Statement

Environmental awareness drives the replacement of petroleum-based fibres with natural fibres as the reinforcement in composites (Ljungberg, 2007; Ramesh et al., 2017). As the properties of natural products cannot be standardized compared to standard man-made fibres, deeper and wider areas need to be discussed in order to commercialize their use in real life applications (Gururaja & Rao, 2012; Jawaid & Abdul Khalil, 2011; Thakur & Thakur, 2014). The mechanical, thermal, and physical properties are among the basic information that needs to be analysed for a newly-developed material.

Compared to the commonly studied plant fibres for composites, such as kenaf, jute, palm oil, rice husk and pineapple, they belong to either bast, leaf or seed groups (Faruk, Bledzki, Fink, & Sain, 2014). Bamboo belong to grass group, which very less plants belong to this group being exploited, thus less studies being conducted to highlight and explore the potential of plant from this grass group. Furthermore, it has to be known that bamboo ranges from herbaceous, which is non-woody, to woody culms. From these varieties, come thousands species around the world, thus offers wider scope, which each of the species definitely possess own benefits and potentials in different areas.

The abundant source of bamboo in Malaysia, if fully utilized, can generate an improvement in the economy of the nation. The fast-growth feature, combined with the suitable climate in Malaysia, trigger the expansion of bamboo distribution throughout the country. With undoubtedly high strength and lightweight advantage, the excess amount of bamboo is seen to have a bright future for use in various applications. However, limited information due to the scarce research and development activities related to Malaysian bamboo have caused a slowdown and restrained its commercial value in the market.

Based on most reported studies, the use of fillers or short fibres has been limited, being used only as additional material in polymer composites. It was generally understood that short fibres cannot sustain high load, thus hybrid composites need to be suggested (Dhawan, Singh, & Singh, 2013; Gacitua, Ballerini, & Zhang, 2005; Rothon, 1996). In order to maximize the potential of hybrid composites, several factors need to be addressed. The optimum ratio of the combined fibres, a suitable method of fabrication and the processing parameters during fabrication are among the fundamental aspects that need to be identified in introducing a new material.

In improving the strength and impact resistance of bamboo filled composites, the idea of embedding woven glass fibres to produce sandwich structured hybrid composites was introduced in this study. Through observations, it was found that short fibre filled composites will break apart into pieces under maximum impact energy, thus causing total failure to the composites. Therefore, the sandwich structured composites was predicted can hold the composite structure in one piece during severe damages.

Moreover, among all the studies on bamboo composites reported previously, it was found that impact studies were the least being conducted, showing the gap in this area. Therefore this current study, which focussing on the impact analysis of bamboo based composites, can widen the potential applications of bamboo composites in different areas. In aerospace applications, these bamboo composites was seen to have potential to replace the current window shield in commercial aircraft and interiors of business aircraft.

1.3 Objectives of The Study

The current study aims to introduce a new polymer composite utilizing the Malaysian bamboo species Bambusa vulgaris in the form of short fibres with different loadings in composites. Woven glass fibres were embedded to improve the performances of the composites. To analyse the performances and provide information on the properties of the newly-developed sandwich structured hybrid composites, several experimental analyses were carried out based on the fundamental material's characterization techniques. To fulfil the previously mentioned aims of the current study, the following objectives were specified:

i. To identify the optimum percentage loading of short bamboo fibres in bamboo fibre filled glass/epoxy hybrid composites in terms of the mechanical and physical properties.

ii. To analyse the dynamic mechanical properties of different loadings of bamboo fibre filled glass/epoxy hybrid composites.

iii. To determine the thermal properties of bamboo based composites with the inclusion of glass fibres.

iv. To analyse the low velocity impact properties of different loadings bamboo fibre in non-hybrid and sandwich structured hybrid composites with varying impact energy level.

1.4 Research Scope

Since the study of natural fibre reinforced composites offers a very wide scope, the current research was conducted only within the following scopes:

i. The bamboo selected to be used throughout this study was from the Malaysian bamboo species Bambusa vulgaris.

ii. The fresh bamboo culms were collected from Raub, Pahang, Malaysia. The habitat of this species was found to be along the riverbank.

iii. Matured bamboo culms aged 4 years old were selected from one rhizome to minimize the difference in properties of the fibres.

iv. The bamboo culms were cut fresh from the ground in the morning, in good weather.

v. All the bamboo culms, cut from the rhizome, ranged from 6 to 10 m in length with approximately 3 cm thickness.

vi. The fresh culms were manually processed to produce several types of bamboo fibres, such as bamboo slabs, thin bamboo strips, woven bamboo mat, bamboo fibre bundles and long single fibres, without the use of any chemicals. However, due to facilities, energy and time constraints, these types of fibres were unable to be produced for the current study.

vii. As bamboo culms belong to a woody structure plant, the facilities available to process the wood were used to process the bamboo, thus produce the bamboo powder.

viii. The whole bamboo culms were used in the composites' fabrication, disregarding the sections along the culms. All the bamboo powder used in the composites was self-processed in the laboratory.

ix. This study does not cover the characterization of bamboo trees as well as bamboo fibres, but focuses on the bamboo composites.

x. The mechanical, dynamic mechanical, physical, thermal and impact properties of the developed composites were identified with respect to different loadings of the composites.

1.5 Thesis Organization

This thesis is organized into five different chapters that describe the whole study of the bamboo composites made from the Malaysian bamboo species Bambusa vulgaris.

i. Chapter 1 introduces the initiatives of previous researchers in suggesting various natural fibres as replacement for synthetic fibres in polymer matrix composites. This chapter also gives an overview of bamboo, a high potential plant to be used in various applications including structural applications.

ii. Chapter 2 gives a progress report of bamboo composites in their different aspects, which includes the fabrication and evaluation stages. The different types of bamboo fibres and polymers used in the fabrication of bamboo composites from previous studies are identified. Besides this, various standards testing, previously performed to evaluate the performances of bamboo composites, are compared among the reported studies.

iii. Chapter 3 describes the whole process involved in fabricating the bamboo composites. The different experimental analyses carried out to characterise the properties of the bamboo composites in various categories, such as thermal and impact, are also explained in this chapter.

iv. Chapter 4 depicts the results and the discussion of the findings from the experimental analysis. Figures and tables are presented to highlight the findings clearly.

v. Chapter 5 draws the conclusions from the results and summarises the findings from the whole study. In this chapter, improvements and future works are also suggested.

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