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ENHANCEMENT OF LOW VELOCITY IMPACT PROPERTIES OF BAMBOO/GLASS FIBRE HYBRID COMPOSITES USING CARBON NANOTUBES FOR AEROSPACE STRUCTURAL APPLICATIONS

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By

ARIFF FARHAN BIN MOHD NOR

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October 2018

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Recently, polymer nanocomposites have been fabricated using carbon nanotubes (CNTs) as reinforcement nanofillers. However, the effect of incorporating CNT into hybrid polymer composites with natural fibre is not clear. This study investigated the effect of using multi-walled carbon nanotube material (MWCNT) as the nanofiller in bamboo/glass hybrid composites on the mechanical properties (tensile and flexural) and impact properties. Composites containing various weight fractions of CNTs (0.1 wt.%, 0.3 wt.%, 0.5 wt.%, and 1.0 wt.%) were produced thus compared with the control hybrid composites in tensile and flexural properties. Meanwhile, only 0.5 wt.% CNT was compared with the control hybrid composites in low velocity impact (LVI) test at various energy levels from 7J to 35J and then subjected to the compression after impact (CAI) test for further analysis. The hybrid composites were prepared with epoxy resin by hand lay-up method. The experimental results revealed an increase in the tensile strength of the composites with the addition of up to 0.5 wt.% CNTs (+7.73% over the control hybrid). However, beyond this value, i.e., with 1.0 wt.% CNT additives, the composite strength showed a remarkable decrease (-36.8% compared with the control hybrid). The decrement supported with Field Emission Scanning Electron Microscopy (FESEM). Moreover, introducing CNTs into hybrid composites resulted reduced the flexural properties with increasing weight fractions as low as 8.45% compared with the controls. Besides that, LVI showed the enhancement of CNTs in hybrid composites

contributed towards the improvement in impact resistance (9.21% less in energy absorbed and maximum of +36.2% in term of peak force compared to the control hybrid) and CAI strength up to 23.7% corresponding to the controls. In sum, the tensile properties increased with the addition of up to 0.5 wt.% CNTs and increased the impact properties including CAI properties when introducing CNTs into the hybrid composites, but there was a decrease in the flexural properties. Hence, this thesis gives better understanding on the newly-hybridisation material's mechanical properties.

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

PENAMBAHBAIKAN IMPAK BERKELAJUAN RENDAH UNTUK HIBRID BULUH/GENTIAN GELAS MENGGUNAKAN TIUB KARBON NANO UNTUK APLIKASI-APLIKASI STRUKTUR AEROANGKASA

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Oktober 2018

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Dewasa ini, polimer komposit nano telah diperkukuhkan dengan penggunaan tiub karbon nano (CNTs) sebagai pemampat nano. Bagaimanapun, masih terdapat lompang kajian yang besar berkenaan penggunaan CNT ke dalam komposit polimer hibrid yang menggunakan serat semulajadi. Kajian ini memberi perincian lanjut dalam kesan penggunaan tiub karbon nano multi-lapisan (MWCNT) sebagai pemampat bersaiz nano. Selain itu, tujuan utama kajian ini dijalankan adalah untuk menguji kesan penggunaan karbon nano multi-lapisan sebagai pemampat bersaiz nano di dalam komposit hibrid buluh/gelas ke atas ciri mekanikal (tensile dan kelunturan) dan ciri impak. Komposit yang mengandungi peratusan berat CNT yang berbeza dihasilkan (0.1%, 0.3 %, 0.5%, dan 1.0%) dan dibandingkan dengan komposit hibrid terkawal dalam ciri tensile dan kelenturan. Sementara itu, hanya CNT dengan peratusan berat sebanyak 0.5% dibandingkan dengan komposit hibrid terkawal dalam ujian impak berkelajuan rendah (LVI) menggunakan kekuatan tenaga yang berbeza di antara 7J ke 35J. Kemudiannya, sampel CNT dengan peratusan berat 0.5% ini melalui ujian mampatan selepas impak (CAI) untuk analisis lanjutan. Komposit hibrid disediakan dengan resin epoksi menggunakan teknik hand lay-up. Keputusan eksperimen tersebut menunjukkan peningkatan dalam kekuatan tensile dengan penambahan sehingga 0.5% (+7.73% untuk hibrid terkawal). Walau bagaimanapun, jika nilai ini melebihi 1.0%, kekuatan komposit menunjukkan penurunan yang signifikan (-36.8% berbanding dengan hibrid terkawal). Penurunan ini terbukti dengan Imbasan Imej Mikroskop Elektron Lapangan (FESEM). Tambahan lagi, penambahan CNT ke dalam komposit hibrid telah mengurangkan ciri kelunturan dengan peningkatan pecahan berat serendah 8.45% berbanding dengan hibrid kawalan. LVI pula menunjukkan prestasi yang lebih baik kepada komposit hibrid dalam ciri ketahanan impak (9.21% kurang dalam penyerapan tenaga dan +36.2% maksimum untuk tenaga puncak untuk hibrid terkawal) dan kekuatan CAI meningkat sehingga 23.7% untuk hibrid terkawal. Kesimpulannya, ciri tensile meningkat dengan penambahan sehingga 0.5% CNT dan peningkatan ciri impak termasuklah CAI apabila CNT ditambah kepada komposit hibrid, namun ciri kelenturan akan berkurang atas faktor penambahan ini. Maka, tesis ini memberikan pemahaman yang lebih baik mengenai ciri-ciri mekanikal terhadap bahan hibrid yang baru.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing Materials
BF	Bamboo fibre
BFRC	Bamboo fibre reinforced composites
BV	Bambusa vulgaris
CAI	Compression after impact
CNTs	Carbon nanotubes
DA	Dendrocalamus asper
DP	Dendracalamus pendulus
DS	Dendrocalamus strictus
DWCNTs	Double-walled carbon nanotubes
EP	Neat epoxy
FE-SEM	Field emission scanning electron microscope
GF	Glass fibre
GL	Gigantochloa levis
GMT	Glass mat thermoplastic
GS	Gigantochloa scortechinii
mm	millimeter
MWCNTs	Multi-walled carbon nanotubes
PBS	Poly butylene succinate
PE	Polyester
PLA	Polylactic acid
PMC	Polymer matrix composites
PP	Polypropylene
TGA	Thermogravimetric analysis
SEM	Scanning electron microscopy
SWCNTs	Single-walled carbon nanotubes
UTM	Universal tensile machine
UWPI	Ultrasonic Wave Propagation Imaging
w/w%	Weight percentage

CHAPTER 1

INTRODUCTION

1.1 Introduction

Fibre basically refers to thin hair-like material, either short or long, similar to pieces of thread (Peijs 2000). Fibres are divided into two basic groups, i.e. natural fibre and synthetic fibre. Natural fibres originate from natural sources, such as plants, animals and minerals, and do not require formation. Meanwhile, synthetic fibres are made from raw materials such as petroleum based chemicals and various fabrication processes are required to synthesise the fibres. Synthetic fibres normally share common properties, such as resistance to most chemicals, low moisture absorption and high strength. Figure 1.1 shows the classification of fibres.

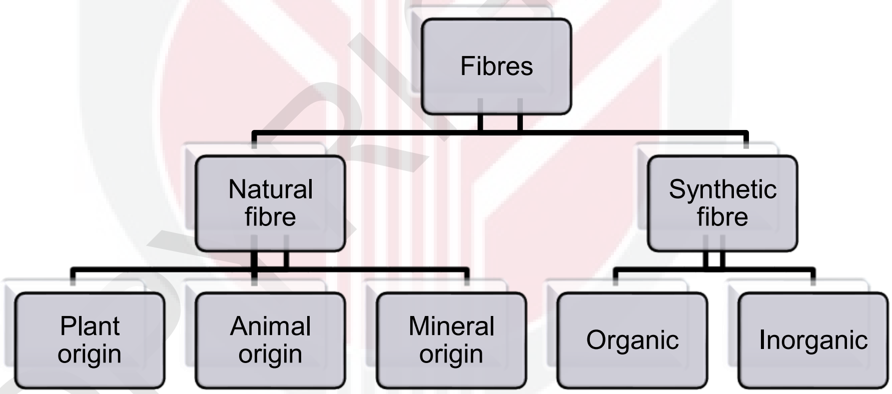

Figure 1.1: Classification of fibres (Jawaid and Abdul Khalil 2011)

Because of exhausting non-renewable resources, the uncertainties on petroleum supply and its rising price, researchers have been seeking ways of switching to sustainable renewable resources for various applications. Environmental and sustainability issues require urgent solutions in order to decrease pollution and make the Earth greener. Therefore, numerous research efforts have been made to develop advanced and more efficient biodegradable composite materials to replace existing non-biodegradable synthetic composites at a lower pollution rate and lower cost (Chauhan and Chauhan, 2013).

Recently, many remarkable achievements have been made to develop green technologies in the field of materials production, especially, with regard to composite materials. Composite materials are broadly used in the aerospace industry and structural engineering, allowing to overcome the common disadvantages of the components when used individually. Enhanced properties are acquired when the materials are used as composites, if they do not disintegrate and merge completely when used together. New advanced materials are broadly applied, especially in advanced structures (Carlsson *et al.* 2014). Composites are commonly divided into two types – natural and synthetic fibre reinforced composites.

With the increasing demands to limit the environmental burden of synthetic fibres and maintain a low price in composites production, researchers came up with the idea of hybridizing the fibres in composites to maintain the quality and the performance of the materials produced. In simple terms, hybrid composites can be defined as a mix of both natural and synthetic fibres incorporated into a single matrix (Nunna *et al.* 2012). By hybridization, a balanced performance can be achieved between natural fibre and synthetic fibre. More solutions are being introduced to the industry in an effort to minimize and eliminate environmental concerns related to non-biodegradable materials. Sustainable materials may offer less dependence on petroleum resources and will serve as a significant contribution to a greener world. The idea of hybridization generates many possibilities for the design and production of composites from a variety of combinations. Hybrid composite materials have the potential to be used for a wide range of applications, for instance, in aerospace parts, such as propeller, floorboard and many more, as well as in other industries, such as the automotive, construction industries *etc*.

In the field of natural composites, bamboo has raised a significant interest as a sustainable material due to its high mechanical properties, and fast plant growth, thus allowing its sustainable use in the composites industry (Khalil *et al.* 2012; Yusoff *et al.* 2016; Shin *et al.* 1989). With a growth rate of 3 cm per hour, bamboo is reported to grow faster than most plants (Lobovikov *et al.* 2007).As opposed to it, most plants can only achieve their full height in 2 to 4 months and reach maturity in a period of 3 to 8 years (Lee *et al.* 1994; Liese 1987). In most countries, including Malaysia, the use of bamboo fibre has been neglected, although it provides a constant supply throughout the years. In certain construction processes, bamboo is used for structural application, mainly as building materials and construction platforms (Bahari and Krause 2015). By a detailed quantitative lifecycle analysis, Van der Lugt et al. (2006) found that bamboo provides less negative after-effects on the environment when used as common structural building material.

In the past ten years, a great expansion in the research of polymer nanocomposites has been made due to the high potential of using advanced materials in technology applications (Kurahatti *et al.* 2010; De Volder *et al.* 2013). Polymer nanocomposites are made up of a polymer matrix combined with a range of filler materials, of which at least one has dimensions in the nanometre range (one, two, or three-dimensionally). On the other hand, carbonaceous nanofillers, such as carbon nanotubes (CNTs), provide better structural and functional properties owing to their high aspect ratio, surface area, and mechanical strength (Lee *et al.* 2008; Behabtu *et al.* 2013; Guo *et al.* 2014). The main problem with nanocomposites is the dispersion of the nanofillers. Inadequate dispersion of nanofillers restricts the stress transfer within the composites, hence lowering their overall performance. Meanwhile, better dispersion of the nanofillers contributes to an effective stress transfer, which consequently increases the overall performance (Mei *et al.* 2016). In recent years, progress has been made in surface modification of nanofillers with the purpose of increasing the interfacial shear strength to overcome dispersion problems.

1.2 Current Issues on Renewable and Sustainable Resources

Due to the growing environmental awareness, the demands for more renewable resources have been on the rise, especially considering the increasing level of pollution all around the world. Primarily, air and water pollution during the extraction process of fossil resources has often led to harming natural ecosystems, further supporting the need for new renewable resources. When looking into sustainable resources, researchers focus mostly on existing natural sources, especially plants, mainly because they are renewable and, at the same time, can maintain sustainability in terms of environmental, social and economic factors. The world needs a positive balance to start with. The environmental sustainability of materials based on natural sources will assure that there is no harm done to Mother Nature in the long run. Although there is a materialistic side to it as well, especially when concerning the elements to be used in the industries, materials derived from natural resources are less destructive to the natural ecosystem, as compared to the non-renewable ones. In terms of economic sustainability, the only concern is how can these renewable sources be marketed into a technology that can be accepted by the current demand? The thought that entails sustainability is very complex and researchers have only pointed out the tip of the iceberg to illustrate its diversities. The most logical solution is to use the full matrix of renewable sources and use them in the most sustainable ways. At their low cost, natural sources have the lowest environmental impacts, but come with high returns for big companies. In the long run, exploiting natural sources will contribute to local economic growth at large and, without a doubt, they will always be available everywhere.

1.3 Problem Statement

In recent years, the development of biodegradable and environmentally acceptable composites, which can be obtained by using natural fibres as reinforcement, has been in the focus of scientists, due to their environmental benefits and improved mechanical properties. Such materials are also known as natural fibre reinforced composites (i.e. biocomposites). Therefore, many scholars have been conducting research on full exploitation of natural fibres, such as bamboo, kenaf, flax, jute and many more, for various applications. Hence, the development of hybrid composites took the lead in composite material research in the past decade (Jawaid and Khalil 2011). Hybridisation of natural fibres, with their poor properties, with synthetic fibres is a technique to improve the strength and stiffness of a material, as well as its water resistance. Theoretically, in hybrid composites that contain two or more types of fibres in a single matrix, the advantages of one type of fibre could compensate for the disadvantages of the other. Therefore, a balance in terms of properties, costs and environmental friendliness is sought to be achieved. Current studies emphasize the enhanced potential of natural fibre hybridized with glass fibre as reinforcement with their positive findings (Venkateshwaran *et al.* 2011; Mishra *et al.* 2003). Meanwhile, in the field of nanocomposites, nanofillers usually act as reinforcement of the composites (Arash *et al.* 2014).

The leading business airplane manufacturers have received design practices and aides ecological protection endeavors by focusing on natural resources such as energy, water and materials use, as well as reducing waste production (Lohner *et al.* 2011). The interior components such as the flooring, sidewall, ceiling, furniture and seating are prevalently composite structures. They are made out of an auxiliary material secured with cements and metallic parts, and completed with various materials. The arrangement comprises of an installed metallic work in the CFRP as an expansion to the system of existing metallic structure. Another major challenge was the method of choice for floor board manufacturing as an assembly of longitudinal boards (Sarh *et al.* 2009).

Based on a literature survey, only a few studies have been reported on the hybridisation of bamboo and glass fibres to fabricate composites. Lack of research can be easily remarked in this field, especially with regard to impact properties. Moreover, no study on introducing CNTs as nanofiller into bamboo/glass hybrid composites has been reported yet. Thus, it is necessary to conduct research in this area to fill the knowledge gap. Considering the limited research in this area, in this work, the hybridization of bamboo and glass fibres was performed in order to benefit from the appealing properties of each type of reinforcement.

1.4 Objectives of the Study

The current study aims to prepare bamboo/glass hybrid composites and enhance their low velocity impact (LVI) properties by introducing CNTs as nanofiller. To evaluate the newly developed hybrid composites, several objectives have been specified as follows:

(i) To analyse the effects of different loadings of CNTs on the tensile and flexural properties of bamboo/glass hybrid composites.
(ii) To determine the low velocity impact properties of the hybrid composites with and without CNTs.
(iii) To identify the estimated damage area induced by low velocity impact through the non-destructive (NDE) technique of Ultrasonic Wave Propagation Imaging (UWPI).
(iv) To evaluate the residual strength of impacted hybrid composites by the analysis of their compression after impact (CAI) properties.

1.5 Scope and Limitations of the Study

This work is limited to the determination of LVI properties of hybridized short bamboo fibre and woven glass fibre reinforced epoxy composites containing CNTs as nanofiller. The scope and limitations of this study are as follows:

(i) Short bamboo fibre and woven glass fibre were utilised in this study.
(ii) The bamboo used in this study belonged to a Malaysian bamboo species *Bambusa vulgaris* and was harvested from Raub, Pahang.
(iii) 4 years old bamboo culms were selected from the same rhizome to reduce the variability of properties.
(iv) A ratio of 10 w/w% bamboo fibre was selected for the fabrication of all the composites and an additional 30 w/w% bamboo fibre was used for comparison with regard to tensile and flexural properties.
(v) The hybrids were fabricated so as to use the interwoven glass fibres as the outer layer, the short bamboo fibres as the core and CNTs as the nanofiller mixed with the epoxy resin.
(vi) Bamboo/glass hybrid composites were prepared by compression moulding (with a size of 300 mm x 300 mm), with various CNTs weight percentage: 0.0 w/w%, 0.1 w/w%, 0.3 w/w%, 0.5 w/w% and 1.0 w/w%.
(vii) The specimens corresponding to all the CNT weight percentage values were then tested for their mechanical (tensile and flexural) properties. At the next stage, only the composites containing 0.5 w/w% nanofiller were evaluated with regard to their LVI behaviour and compared with those containing 0.0 w/w% CNTs. The samples were then subjected to analyses by NDE alongside with DE approaches. More precisely, UWPI scanning (NDE) and CAI (DE) have been carried out on impacted specimens from LVI testing.

1.6 Outline of the Thesis

This thesis is organised in five chapters to present the whole study conducted on the bamboo/glass hybrid composites, enhanced with the addition of CNTs, as follows:

(i) Chapter 1 Introduction: the background of the study, problem statements, objectives, scope of the study and outline of the thesis are presented in this chapter.
(ii) Chapter 2 Literature Review: an overview of previous research on bamboo composites, CNT composites and natural-synthetic hybrid composites has been performed.
(iii) Chapter 3 Materials and Methodology: describes the preparation of the materials for the experiments, the fabrication procedures and the techniques used to assess the mechanical and impact properties of hybrid composites.
(iv) Chapter 4 Results and Discussion: provides the analysis of the results collected from the experimental studies. Tables and figures have been included to highlight the findings.
(v) Chapter 5 Conclusion and Recommendation: offers an overall summarization of the findings and the conclusions drawn from this research, as well as some recommendations for future studies.

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LIST OF PUBLICATIONS

Journal

Nor, A. F. M., Sultan, M. T. H., Jawaid, M., Azmi, A. M. R., & Shah, A. U. M. (2019). Analysing impact properties of CNT filled bamboo/glass hybrid nanocomposites through drop-weight impact testing, UWPI and compression-after-impact behaviour. *Composites Part B: Engineering*, *168*, 166-174.
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Azmi, A. M. R., Sultan, M. T. H., Jawaid, M., & **Nor, A. F. M.** (2018). A newly developed bulletproof vest using kenaf-X-ray film hybrid composites. In *Mechanical and Physical Testing of Biocomposites, Fibre-reinforced Composites and Hybrid Composites.* (pp. 157-169). Woodhead Publishing – Published

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Workshops and Seminars

Global Aerospace Industry Outlook and Insight into Malaysia's Aerospace Initiatives Talk, Aerospace Manufacturing Research Centre, UPM, 2 March 2017 – Participant

Composite Technology – Current and Future Trends Talk, Aerospace Manufacturing Research Centre, UPM, 16 March 2017 – Participant

International Workshop on Advanced Composites and its Manufacturing, Aerospace Manufacturing Research Centre, UPM, 10 April 2017 – Participant

Sharing Session on Student – Supervisor Relationship, Aerospace Manufacturing Research Centre, UPM, 2 May 2017 – Participant

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