UNIVERSITI PUTRA MALAYSIA

MECHANICAL, THERMAL AND IMPACT DAMAGE CHARACTERIZATION OF HYBRIDISED LONG SUGAR PALM/GLASS FIBRE-REINFORCED POLYMER COMPOSITES

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By

SYAFIQAH NUR AZRIE BT SAFRI

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Chairman : Mohamed Thariq Bin Hameed Sultan, PhD, Ir
Faculty : Engineering

In this research, long sugar palm fibre was hybridised with long glass fibre produced by the hand lay-up method to improve the performance of the sugar palm composites. This study investigates the effect of glass fibre addition to the sugar palm-based composites and benzoylation effect to improve the mechanical properties of the composites. The study was divided into two stages, where the first stage results shows that the benzoylation treatment of the sugar palm fibre and the glass addition to the sugar palm composites has been demonstrated to significantly improve the physical, tensile, flexural and compressive properties of the sugar palm/glass fibre composites. The results obtained with regard to the physical and mechanical properties revealed that the EP/30TSPF/70GF composites exhibited the best physical and mechanical properties by increasing the tensile strength by 55.7%, flexural strength by 46.8% and compressive strength by 36.7% when comparing with EP/UTSPF composites. Similar results were acquired from the thermal testing using TGA, DSC and DMA. It was found that EP/TSPF/GF had better thermal properties compared to other composites. The second stage of the study investigated the impact properties and post-impact properties of the hybrid composites. The low velocity impact testing was applied to EP/30TSPF/70GF as it is the best formulation of the sugar palm/glass fibre composites, as concluded from the characterization results. After the impact test, ultrasonic scanning method (C-scan) was used to investigate the failure of the EP/30TSPF/70GF composite together with compression after impact testing (CAI). From the experimental studies, it could be concluded that the impact damage showed excellent correlation with the impact response. The damage area obtained from the ultrasonic C-scan images and CAI testing shows that the damage area increasing as the impact energy increasing and the compressive strength of the EP/30TSPF/70GF composite decreased as the impact energy increasing.

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

PENCIRIAN MEKANIKAL, HABA DAN IMPAK KEROSAKAN TERHADAP GENTIAN PANJANG GENTIAN ENAU /KACA BERTETULANG HIBRID KOMPOSIT POLIMER

Oleh

SYAFIQAH NUR AZRIE BT SAFRI

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Dalam kajian ini, gentian enau yang panjang telah dihibridisasikan dengan gentian kaca yang panjang menggunakan kaedah 'belangai tangan' bagi menambah baikkan sifat-sifat komposit gentian enau. Dalam kajian ini sifat-sifat mekanik komposit dilihat selepas penambahan gentian kaca dan selepas gentian enau dirawat menggunakan rawatan 'benzoylation'. Kajian ini dibahagikan kepada dua peringkat. Peringkat yang pertama menunjukkan bahawa rawatan 'benzoylation' terhadap gentian enau dan penambahan gentian kaca pada komposit gentian enau meningkatkan sifat fizikal, tegangan, lenturan dan mampatan komposit. Keputusan ujian terhadap sifat fizikal dan mekanikal menunjukkan bahawa komposit EP/30TSPF/70GF mempunyai sifat fizikal dan mekanikal yang terbaik dengan peningkatan kekuatan tegangan sebanyak 55.7%, kekuatan lenturan sebanyak 46.8% dan kekuatan mampatan sebanyak 36.7% berbanding dengan EP/UTSPF. Keputusan ujian yang sama diperoleh daripada ujian haba yang dilakukan menggunakan TGA, DSC dan DMA. Keputusan ujian menunjukkan bahawa EP/TSPF/GF mempunyai sifat haba yang lebih baik berbanding dengan formula komposit gentian enau /gentian kaca yang lain. Tahap kedua kajian menyiasat sifat impak dan kesan impak ke atas komposit gentian enau /gentian kaca. Berdasarkan keputusan ujian peringkat pertama, komposit EP/30TSPF/70GF dipilih untuk ujian kesan halaju rendah. Kaedah pengimbasan ultrasonik dan ujian 'compression after impact' (CAI) digunakan untuk menyiasat kegagalan komposit EP/30TSPF/70GF dan kekuatan mampatan EP/30TSPF/70GF komposit selepas ujian impak. Kawasan kerosakan yang diperoleh daripada imej C-scan ultrasonik dan ujian CAI menunjukkan bahawa apabila tenaga impak meningkat, kawasan kerosakan semakin membesar dan kekuatan mampatan komposit EP/30TSPF/70GF menurun.

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I certify that a Thesis Examination Committee has met on 26 November 2018 to conduct the final examination of Syafiqah Nur Azrie Bt Safri on her thesis entitled "Mechanical, Thermal and Impact Damage Characterization of Hybridised Long Sugar Palm/Glass Fibre-Reinforced Polymer 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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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

ASTM	American Society for Testing Materials
DMA	Dynamic mechanical analysis
DSC	Differential scanning calorimetry
DTG	Differential Thermogravimetric
FRP	Fibre reinforced polymer
GF	Glass fibre
ISO	International Organization for Standardization
NDE	Non-destructive evaluation
NFRP	Natural fibre reinforced polymer
PMC	Polymer matrix composites
SEM	Scanning electron microscopy
TGA	Thermogravimetric analysis

CHAPTER 1

INTRODUCTION

1.1 Background of the study

There has been increasing interest in the substitution of natural fibres for synthetic ones in engineering applications. The main goal is to preserve the environment by using natural fibres and to reduce the use of synthetic ones. Natural fibres have an excellent tensile modulus and a lower density compared to metallic materials and synthetic fibres (Ahmad, Choi, & Park, 2015). Natural fibres have good mechanical properties with the additional benefit of being lightweight. Natural fibres have several advantages over their synthetic counterparts, such as low cost, acceptable specific strength properties, low density, and biodegradability (Hapuarachchi, Ren, Fan, Hogg, & Peijs, 2007). Natural fibres are currently used in seat backs, dashboards, door panels, package trays, headliners, and trunk liners (D. Puglia, Biagiotti, & Kenny, 2005). The benefits of natural fibres, such as their eco-friendliness and bio-renewability, offer advantages over synthetic ones (V. K. Thakur, Thakur, & Gupta, 2014). Natural fibres have excellent thermal and acoustic insulation performance and exhibit several advantageous properties over rock-wool or glass fibre owing to their cellular structure and low density (Cristaldi, 2010).

One of the types of natural fibre that are gaining recognition is sugar palm fibre. The sugar palm tree or *Arenga Pinnata* is a member of the Palmae family and can be easily found in South East Asia, especially in Malaysia. It has different names, depending on the region. In Malaysia, it is known as *enau* and it can be found in Negeri Sembilan, Perak, Pahang and Melaka. It grows at altitudes from the sea level up to 1400 m a.s.l (Miller, 1964). Several parts of the sugar palm tree can be exploited, such as the frond, the bunch, the trunk and the fibre, as shown in Figure 1. Sugar palm fibre, which is also locally called gentian enau, can be obtained from the tree, as it is wrapped around the sugar palm trunk. Gentian enau is known for its traditional applications, being used to manufacture paint brushes, door mats, ropes, cushions and fish nets (Salit, 2014). Gentian enau is also recognised for its good durability and high strength, and thus has attracted intense research attention, focusing on suitable applications. The availability of sugar palm tree in Malaysia has widen the possibility to reduce dependency on the synthetic fibre.

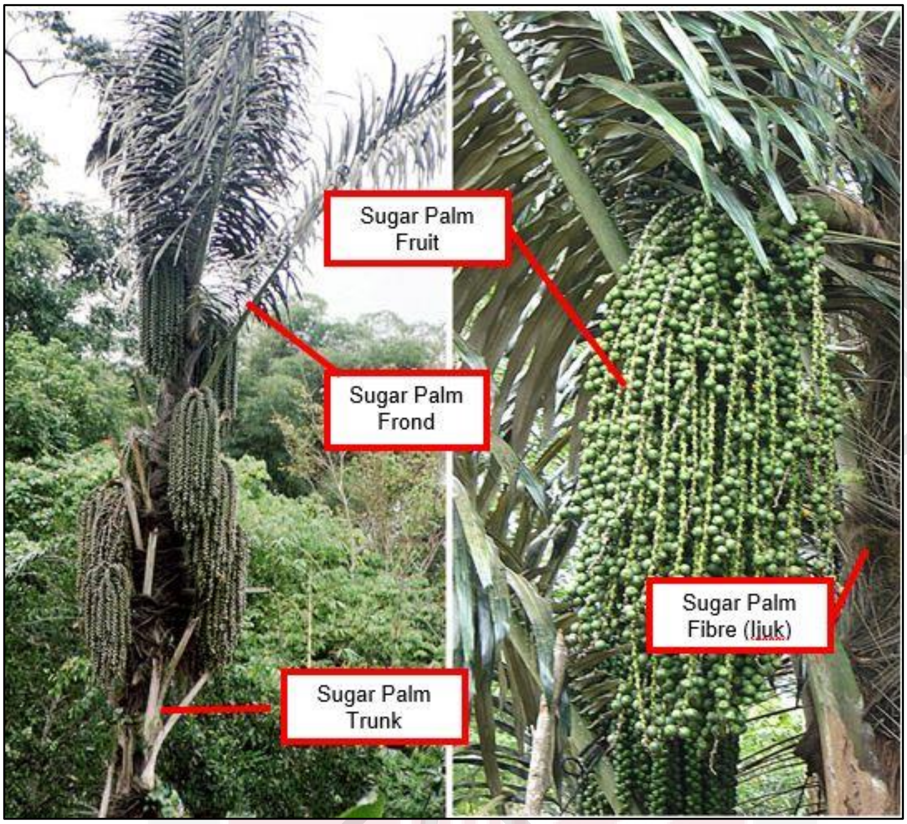

Figure 1: Sugar palm tree (Salit, 2014)

It is difficult to use natural fibres as reinforcement in plastics because of their hydrophilic nature, which is caused by the presence of hydroxyl groups. Surface modifications, also known as chemical modifications, must be performed considering that, usually, all natural fibres do not have good adhesion with polymer matrices because of their hydrophilic nature. One of the possible surface treatments applied to natural fibre involves the use of benzoyl chloride. Fibre modification helps to make the fibre surface more compatible with the matrix.

Natural fibre have potential to replace the conventional synthetic fibre in many applications. In this research, sugar palm fibre has been looked as the potential materials to be applied in the interior of the aircraft. The use of sugar palm fibre will bring positive impact on the environment and making sure on the sustainability of the manufacturing process.

1.2 Problem Statement

Sugar palm fibre has started being considered as an alternative to synthetic fibre. However, sugar palm fibre has its own disadvantages such as poor compatibility between fibres and matrix and lower strength compared to synthetic fibre (Rana, kumre, Rana, & Purohit, 2017; M. Sanyang, S. Sapuan, M. Jawaid, M. Ishak, & J. Sahari, 2016). Researchers have been looking for ways to improve the properties of sugar palm composites. Two major solutions have been found to enhance the properties of sugar palm fibre. One of the biggest flaws of sugar palm fibre is its hydrophilic nature. This hydrophilicity reduces the adhesion of the sugar palm fibre to other reinforcement fibres and to the matrix, thus reducing the performance of the obtained material. Chemical treatment of the sugar palm fibre can reduce its hydrophilic properties and improve the compatibility between the fibre and the matrix (Stana-Kleinschek, Ribitsch, Kreže, Sfiligoj-Smole, & Peršin, 2003). Researchers have implemented chemical modification of sugar palm fibre, especially by using silane treatment and alkaline treatment as explained in Chapter 2. However, one more treatment method has come into the research focus to enhance the properties of sugar palm fibre. In this thesis, benzoylation treatment was used to treat sugar palm fibre before fabricating composites. Benzoylation treatment was introduced to see how it can improve the composite properties. Thus, this research aims to explore the potential of sugar palm fibres after being treated by benzoylation.

Another solution to improve the performance of sugar palm composites is by hybridising. Natural fibre can be hybridised with either natural fibre or synthetic fibre (Syafiqah Nur Azrie Safri, Sultan, Jawaid, & Jayakrishna, 2018). However, to enhance the strength of the sugar palm fibre, synthetic fibre is the best choice. In this research, it was chosen to hybridise sugar palm fibre with glass fibre. This is because, glass fibre is well known for its strength, light weight and mouldability (Sanjay & Yogesha, 2017). Hybridised sugar palm/glass fibre composites were formulated in order to combine the good properties of both fibres so as to produce hybrid composites with great physical, mechanical, thermal, impact properties and post-impact properties. A lot of research has been carried out on hybridising sugar palm and glass fibre, however, to the best of our knowledge, no study on the benzoyl treatment of sugar palm fibre before preparing the hybrid composites has been reported so far.

Other than that, long sugar palm fibre is used in this research. Long natural fibre is the cellulosic fibre that is often suggested as an alternative to glass fibre. Commonly, composites made from long natural fibre have the highest tensile and flexural properties (Fan & Fu, 2017). Therefore, to enhance the performance of the sugar palm composites, the long type of fibre is used for both sugar palm and glass fibre.

Also, scarce research is known to deal with the impact properties of such composites, specifically in low velocity impact, including damage detection and the post-impact properties of these hybrid composites. Most researchers focus on the mechanical properties of sugar palm composites as been explained in more detail in Chapter 2. Therefore, this thesis aims to contribute to the body of knowledge on the impact properties, impact damage characteristics and post-impact properties of sugar palm/glass fibre hybrid composites. The findings of this research are expected to increase the knowledge with regard to the possibility of using benzoylation treatment in sugar palm fibre. Moreover, the results of the study should provide an insight into the properties of natural-synthetic hybrid composites made from long sugar palm and glass fibre. This combination of fibres is expected to alleviate environmental problems associated with the excessive use of synthetic fibre and provide a solution to the search for alternative materials for synthetic fibre. Other than that, these sugar palm/glass fibre composites was seen to have potential to replace the current materials used for the interiors of an aircraft.

1.3 Research Objectives

The principle aim of this research is to study the effect of benzoylation treatment on sugar palm fibre composites and to analyze the effect of glass fibre addition on the properties of the sugar palm/glass fibre composites based on the characterization testing. The specific objectives are:

i. To characterize the physical, mechanical and morphological properties of benzoyl treated and untreated sugar palm/glass fibre hybrid composites;
ii. To determine the thermal properties of benzoyl treated and untreated sugar palm/glass fibre hybrid composites using TGA, DSC and DMA techniques;
iii. To evaluate the impact properties of the benzoyl treated sugar palm/glass fibre hybrid composites using drop weight impact testing;
iv. To analyse the impact damage and post-impact characteristics of benzoyl treated sugar palm/glass fibre hybrid composites using ultrasonic C-scan and compression after impact testing.

1.4 Scope of the Study

The scope of this research is limited to the following:

i. This study does not consider details on the sugar palm tree characteristics such as the age of the tree.
ii. The composites were fabricated, using long sugar palm fibre and long glass fibre as reinforcement, and epoxy resin as the matrix.
iii. The hybrid composites were prepared by the conventional hand lay-up method based on the volume ratio of 90% of matrix and 10% of fibre. The ratio of the glass fibre in the composites was also varied as follows: 0%, 30%, 50% and 70% in terms of volume fraction.
iv. In this study, sugar palm fibre was treated by benzoylation before being hybridised with glass fibre.
v. This study specifically focused on the characterization of sugar palm/glass fibre hybrid composites, analysing the effects of benzoylation treatment and glass fibre addition to the composites on their properties.
vi. The aim of this research is to gain deeper understanding of the sugar palm/glass fibre hybrid composites by characterizing them in terms of physical, mechanical and and thermal properties.
vii. Also, this research is limited to the low velocity impact properties, impact damage and post-impact analysis using ultrasonic C-scan testing and compression after impact (CAI) testing.

1.5 Thesis Outline

This thesis consists of five chapters.

Chapter 1 presents background of the study, the problem statement, the objectives of the research, the scope and limitations of the study and the outline of the thesis.

Chapter 2 provides a literature review on sugar palm fibre. This chapter also explains benzoylation treatment and other chemical treatments applied to sugar palm fibre. This is followed by a detailed description of the physical, mechanical, thermal and impact properties of sugar palm based composites, as reported in the literature. This chapter also discusses the investigation of impact damage and post-impact properties using ultrasonic C-scan testing and compression after impact (CAI) testing.

Chapter 3 describes the methodology used in the current study. All the methodology used in this research is explained thoroughly. Thus, the first section provides details on the reinforcements, matrix and chemicals used in this research. The second section explains the benzoylation treatment applied to the sugar palm fibre, followed by the steps of composite preparation, from composite fabrication to specimen cutting. The following section delineates the testing techniques performed in this research, starting from physical and mechanical testing, to morphological characterisation, thermal, low velocity impact, ultrasonic and compression after impact (CAI) testing.

Chapter 4 presents and discusses the results obtained with regard to the physical, mechanical, thermal, impact, impact damage and post-impact properties of the tested specimens.

Chapter 5 summarises the conclusions drawn from the performed investigations and offers some recommendations for future research.

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LIST OF PUBLICATIONS

Journals

Syafiqah Nur Azrie Safri, Mohamed Thariq Hameed Sultan, Mohammad Jawaid, Kandasamy Jayakrishna - Impact behaviour of hybrid composites for structural applications: A review, Composites Part B: Engineering, Vol. 133, pp. 112-121, 2018. (Impact Factor: 4.920, Q1) – **Published**

Safri, S. N. A., Sultan, M. T., Saba, N., & Jawaid, M. (2018). Effect of benzoyl treatment on flexural and compressive properties of sugar palm/glass fibres/epoxy hybrid composites. Polymer Testing, 71, 362-369. (Impact Factor: 2.247, Q2) – **Published**

S.N.A. Safri, M.T.H. Sultan, M.S.A. Majid, M. Jawaid - Dynamic mechanical analysis, low-velocity impact and compression after impact (CAI) behaviour of benzoyl treated sugar palm/glass/epoxy composites. Composite Structures (Impact Factor: 4.101, Q1) – **Submitted**

Book Chapters

Safri, S. N. A. B., Sultan, M. T. H., & Jawaid, M. (2019). Damage analysis of glass fiber reinforced composites. In Durability and Life Prediction in Biocomposites, Fibre-Reinforced Composites and Hybrid Composites (pp. 133-147). Woodhead Publishing – **Published**

Conferences

1st International Conference on Safe Biodegradable Packaging Technology (SafeBioPack 2018), 24th to 25th July 2018, Malaysian Industry-Government Group for High Technology (MIGHT), Cyberjaya, Malaysia – Presenter

Workshops and Seminars

1. Workshop on Predictive Engineering Analytical for Sustainability and Recent Trends, Aerospace Manufacturing Research Centre (AMRC) UPM, STRAND Aerospace Malaysia, Airbus Helicopters Malaysia (AHM), Siemens, IDS, DAG Technologies, 20th July 2017 – Participant
2. Technical visit Airbus Helicopters Malaysia (AHM), Aerospace Manufacturing Research Centre (AMRC) UPM, The Institute of Engineers Malaysia (IEM),3rd May 2017 – Participant
3. Introduction to Taguchi Method, Aerospace Manufacturing Research Centre (AMRC) UPM, Universiti Kebangsaan Malaysia (UKM), The Institute of Engineers Malaysia (IEM), 26th April 2017 – Participant
4. International Workshop on Advanced Composites and Its Manufacturing, Aerospace Manufacturing Research Centre (AMRC) UPM, Kalasalingam University, India, 10th -13th April 2017 - Committee, Participant
5. Global Aerospace Industry Outlook and Insight into Malaysia's Aerospace Initiatives, Aerospace Manufacturing Research Centre (AMRC) UPM, STRAND Aerospace Malaysia, 2nd March 2017 – Committee – Participant
6. TVET, A Case for Transformation, Aerospace Manufacturing Research Centre (AMRC) UPM, 5th November 2016 – Participant
7. Workshop on Thermal Mechanical Analyzer, Laboratory of Biocomposite Technology Institute Tropical Forestry and Forest Product (INTROP), 1st June 2016 – Participant
8. Introduction to Quantitative Research, School of Graduate Studies, Universiti Putra Malaysia, 25th May 2016 – Participant
9. Introduction to Qualitative Research, School of Graduate Studies, Universiti Putra Malaysia, 23rd May 2016 – Participant
10. Seminar on The Route to Become a Certified Engineer (CEng) and Professional Engineer (PEng), Aerospace Manufacturing Research Centre (AMRC) UPM, Institute of Mechanical Engineers Malaysia Branch (IMechE) The Institute of Engineers Malaysia (IEM), Board of Engineers Malaysia (BEM), Malaysia Society of Structural Health Monitoring (MSSHM), MySET, 1st April 2016, - Participant
11. Fundamentals Towards Graduate on Time (GOT) In Innovative Research, School of Graduate Studies, Universiti Putra Malaysia, 22nd March 2016 – Participant
12. Clean Sky Green Sky by Prof Ric Parker (Director of Research and Technology Rolls Royce), Aerospace Manufacturing Research Centre (AMRC) UPM, 3rd September 2015 – Participant
13. High Impact Journal Writing and Publishing Workshop – Institute Tropical Forestry and Forest Product (INTROP), 3rd to 4th June 2015 – Participant
14. Dynamic Mechanical Analysis of Polymeric Material, Laboratory of Biocomposite Technology Institute Tropical Forestry and Forest Product (INTROP), 11th March 2015 – Participant
15. Half Day Seminar on Fatigue and Durability Assessment, Universiti Putra Malaysia, 29th Jan 2015 – Participant

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