UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT AND CHARACTERIZATION OF SUGAR PALM [Arenga pinnata (Wurmb.) Merr]/GLASS FIBER REINFORCED POLY (LACTIC ACID) HYBRID COMPOSITES FOR MOTORCYCLE COMPONENTS

SHERWANI SHAH FAISAL KHAN

FK 2022 51

DEVELOPMENT AND CHARACTERIZATION OF SUGAR PALM [*Arenga pinnata* (Wurmb.) Merr]/GLASS FIBER REINFORCED POLY (LACTIC ACID) HYBRID COMPOSITES FOR MOTORCYCLE COMPONENTS

By

SHERWANI SHAH FAISAL KHAN

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

December 2021

© COPYRIGHT UPM

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia

© COPYRIGHT UPM

DEDICATION

To Al-Quran, the greatest source of knowledge

"Such as remember Allah, standing, sitting, and reclining, and consider the creation of the heavens and the earth, (and say): Our Lord! You created not this in vain. Glory be to You! Preserve us from the doom of Fire" (Surah Al-Imran 3: 191)

&

To my beloved father and mother

&

To my beloved wife

&

To my beloved daughter

© COPYRIGHT UPM

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT AND CHARACTERIZATION OF SUGAR PALM [*Arenga pinnata* (Wurmb.) Merr]/*GLASS* GLASS FIBER REINFORCED POLY(LACTIC ACID) HYBRID COMPOSITES FOR MOTORCYCLE COMPONENTS

By

SHERWANI SHAH FAISAL KHAN

December 2021

Chairman : Mohd Sapuan bin Salit, PhD, PEng
Faculty : Engineering

The automotive industry is always focusing on advanced composites to improve the strength-to-weight ratio. To meet this need, many unique composite materials have been developed or fabricated in the automotive industry. Both synthetic and natural polymers are being used in the production of composite materials for automotive applications. The use of synthetic polymers derived from petroleum sources is hazardous to the environment. The majority of the motorcycle's body frame parts are composed of an ABS *(Acrylonitrile Butadiene Styrene)* engineering thermoplastic. ABS is a petroleum-based plastic that is non-biodegradable, is not a renewable resource, and is not environmental friendly. Because of the environmentally hazardous properties of ABS plastic, researchers are leaning toward biodegradable plastic in order to save the environment. This might have been achieved with biodegradable materials such as poly(lactic acid) (PLA) and natural fiber composites. PLA is an excellent choice for replacing ABS since it is a bio-degradable type of plastic that is made from plant-based materials such as corn starch or sugarcane. PLA is a biobased, biodegradable, biocompatible, compostable, and non-toxic polymer with low material and manufacturing costs as well as desired mechanical properties. Sugar palm [*Arenga pinnata (*Wurmb.) Merr] fiber has been chosen to mixed with PLA and glass fiber, because of its availability, particularly in Southeast Asia, and its proven performance. Therefore, this research describes the development and characterization of hybrid and non-hybrid composites of sugar palm and glass fiber reinforced poly(lactic acid) for Modenas Kriss 110 motorcycle battery housing part. To evaluate the impact of different wt.% of fiber loading, treatment and hybridization, hybrid and non-hybrid sugar palm/glass fiber (SPF/GF) reinforced PLA composites were developed using a Brabender Plastograph, followed by a compression molding method. Initially the effect of various fiber loading i.e. 10 wt.%, 20 wt.%, 30 wt.% and 40 wt.% on poly(lactic acid) were determined. The best physical, tensile, and flexural properties for SPF/PLA composites were exhibited by 30 wt.% SPF loading, whereas the maximum impact strength value was shown by 40 wt.% SPF loading. The major difficulty associated with natural fiber is its hydrophilic nature and lack of adhesion with the hydrophobic matrix. The inherent difficulties can be solved by

© COPYRIGHT UPM

chemical treatments and hybridization. In this work, the sugar palm fiber was treated with alkaline (NaOH) and benzoyl chloride (C_6H_5COCl) solutions. Various methods were used to evaluate the physical and mechanical properties of treated and untreated sugar palm fiber/PLA composites. The treated SPF improved in physical (density, thickness, swelling, and water absorption), mechanical (tensile, flexural, and impact) as well as morphological properties of SPF/PLA composite and became more hydrophobic, when compared to the untreated fiber SPF/PLA composite. Among the two treatments, alkaline treatment improved tensile, flexural, and impact strength, (17.08 MPa, 32.34 MPa, and 4.39 kJ/m^2) whereas a benzoyl chloride (BC) treatment improved tensile and flexural modulus (602 MPa and 1916 MPa) while also increasing hydrophobicity, and for untreated SPF/PLA composite the tensile, flexural, impact strength, tensile, and flexural modulus were 6.85 MPa, 6 MPa, 1.56 kJ/m^2, 500 MPa, and 850 MPa. Morphological, FTIR, and flammability investigations confirmed that the 6% alkaline SPF treatment improved the physical, tensile, flexural, and impact properties of SPF/PLA composites. In general, the alkaline treatment (6% NaOH conc.) performed better than the BC treatment. The analysis of a hybrid and a non-hybrid composite of SPF/GF reinforced PLA composite revealed a promising improvement in the composite's physical, mechanical, and morphological properties. The alkaline treatment improved the tensile strength, modulus, flexural, and impact strength by 19%, 3%, 17%, and 15% for SPF/GF/PLA hybrid composite, while the BC treatment improve the tensile modulus and impact strength by 19% and 3%. In the last section of this study, the mechanical properties of SPF/GF/PLA hybrid composites such as creep, compression, and hardness were determined in comparison to commercially available ABS plastic motorcycle battery housing parts. Furthermore, the results revealed that hybridization of treated SPF with GF improved the overall performance of the composite as compared to both untreated or SPF/PLA single system composite. In conclusion, when compared to ABS plastic, employing treated SPF/GF/PLA hybrid composite results in a high-strength biodegradable plastic suitable for Modenas Kriss 110 motorcycle battery housing parts.

© COPYRIGHT UPM

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

PEMBANGUNAN DAN PENCIRIAN KOMPOSIT HIBRID ASID POLILAKTIK DIPERKUAT GENTIAN ENAU [*Arenga pinnata* (Wurmb.) Merr]/GLASS KACA UNTUK KOMPONEN MOTOSIKAL

Oleh

SHERWANI SHAH FAISAL KHAN

Disember 2021

Pengerusi : Mohd Sapuan bin Salit, PhD, PEng
Fakulti : Kejuruteraan

Industri automotif sentiasa memberi tumpuan kepada komposit termaju untuk meningkatkan nisbah kekuatan-kepada-berat. Untuk memenuhi keperluan ini, banyak bahan komposit yang unik telah dicipta atau dikembangkan dalam industri automotif. Kedua-dua polimer sintetik dan semula jadi digunakan dalam pengeluaran bahan komposit bagi aplikasi automotif. Penggunaan polimer sintetik yang berasal dari sumber petroleum adalah berbahaya kepada alam sekitar. Sebahagian besar bahagian bingkai badan motosikal terdiri daripada ABS (Stirena Butadin Akrilonitril) termoplastik kejuruteraan. ABS adalah plastik berasaskan petroleum yang tidak terbiodegradasi, bukan sumber yang boleh diperbaharui, dan telah membahayakan alam sekitar. Oleh kerana sifat plastik ABS yang berbahaya bagi alam sekitar, para penyelidik cenderung ke arah plastik biodegradasi untuk menyelamatkan alam sekitar. Ini mungkin dicapai dengan bahan biodegradasi seperti asid polilaktik (PLA) dan komposit gentian semula jadi. PLA adalah pilihan yang sangat baik untuk menggantikan ABS disebabkan ia adalah plastik jenis biodegardasi yang dibuat daripada bahan berasaskan tumbuhan seperti kanji jagung atau tebu. PLA adalah polimer berasaskan bio, terbiodegradasi, bioserasi, terkompos, dan tidak beracun dengan bahan dan kos pembuatan yang rendah serta mempunyai sifat mekanikal yang diinginkan. Gentian enau [*Arenga Pinnata* (Wurmb.) Merr] juga dipilih untuk dicampur dengan PLA, kerana ketersediaannya, terutama di Asia Tenggara, dan prestasinya yang terbukti. Oleh itu, penyelidikan ini menerangkan tentang perkembangan dan ciri-ciri komposit hibrid serta bukan hibrid daripada gentian enau dan diperkukuh dengan gentian kaca asid polilaktik untuk pemegang bateri motosikal Modenas Kriss 110. Untuk menilai kesan pelbagai kadar kandungan gentian %, rawatan dan hibridisasi, hibrid dan bukan hibrid komposit gentian enau/kaca (SPF/GF) diperkukuh PLA komposit dikembangkan menggunakan Brabender Plastograph, diikuti dengan kaedah pengacuan mampatan. Pada mulanya perlu untuk menentukan kesan pelbagai kadar kandungan gentian iaitu 10%, 20%, 30% dan 40% pada asid polilaktik. Sifat fizikal, tegangan, dan lenturan terbaik untuk komposit SPF/PLA ditunjukkan oleh kadar kandungan gentian SPF 30%, sedangkan nilai kekuatan hentaman maksimum ditunjukkan oleh kandungan gentian SPF 40%. Kesukaran utama

© COPYRIGHT UPM

berkaitan dengan gentian semula jadi adalah sifat hidrofilik dan kekurangan lekatan dengan matriks hidrofobik. Kesukaran yang wujud dapat diselesaikan dengan rawatan kimia dan hibridisasi. Dalam kajian ini, gentian ijuk dirawat dengan larutan alkali (NaOH) dan larutan benzoil klorida (C_6H_5COCl). Pelbagai kaedah digunakan untuk menilai sifat fizikal dan mekanikal komposit gentian enau/PLA yang dirawat dan tidak dirawat. Gentian enau yang dirawat bertambah baik dari segi fizikal (ketumpatan, ketebalan, pembengkakan, dan penyerapan air), mekanikal (tegangan, lenturan, dan hentaman) serta sifat morfologi komposit SPF/PLA dan menjadi lebih hidrofobik, jika dibandingkan dengan komposit gentian SPF/PLA yang tidak dirawat. Di antara kedua-dua rawatan, kandungan 6% rawatan alkali meningkatkan kekuatan tegangan, lenturan, dan hentaman (17.08 MPa, 32.34 MPa, dan 4.39 kJ/m^2) sedangkan rawatan benzoil klorida (BC) meningkatkan modulus tegangan dan lenturan (602 MPa dan 1916 MPa) serta meningkatkan hidrofobik, dan untuk SPF/PLA komposit yang tidak dirawat, modulus tegangan, lenturan, kekuatan hentakan, tegangan, dan lenturan adalah 6.85 MPa, 6 MPa, 1.56 kJ / m^2, 500MPa, dan 850MPa. Analisis morfologi, FTIR, dan kemampuan terbakar bahan mengesahkan bahawa rawatan SPF alkali sebanyak 6% meningkatkan sifat fizikal, tegangan, lenturan, dan kesan komposit SPF/PLA. Secara amnya, rawatan alkali (6% NaOH ringkas) lebih baik daripada rawatan BC. Analisis komposit hibrid dan bukan hibrid komposit PLA diperkukuh SPF/GF menunjukkan peningkatan dalam sifat fizikal, mekanikal, dan morfologi komposit. Rawatan alkali meningkatkan kekuatan tegangan, modulus, lenturan, dan kekuatan hentakan sebanyak 19%, 3%, 17%, dan 15% untuk komposit hibrid SPF/GF/PLA, sementara rawatan BC membantu meningkatkan modulus tegangan dan kekuatan hentaman sebanyak 19% dan 3%. Pada bahagian terakhir kajian ini, sifat mekanik komposit hibrid SPF / GF / PLA seperti rayapan, mampatan, dan kekerasan ditentukan berbanding dengan bahagian pemegang bateri motosikal plastik ABS yang tersedia secara komersial. Selanjutnya, hasil kajian menunjukkan bahawa hibridisasi SPF yang dirawat dengan GF meningkatkan prestasi keseluruhan komposit berbanding dengan komposit sistem tunggal SPF/PLA yang tidak dirawat. Kesimpulannya, jika dibandingkan dengan plastik ABS, menggunakan komposit hibrid SPF/GF/PLA yang dirawat akan menghasilkan plastik biodegradasi berkekuatan tinggi yang sesuai untuk pemegang bateri motosikal Modenas Kriss 110.

© COPYRIGHT UPM

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious, the Most Merciful

I am eternally grateful to Allah SWT for providing me with the strength, courage, and knowledge to complete my thesis. The completion of this thesis would not have been possible without His blessing and guidance. My heartfelt special gratitude to my excellent supervisor, Professor Ir. Dr. Mohd. Sapuan Bin Salit, for his continuing support and encouraging supervision during my research. Under his direction, I was immensely motivated to pursue a career in research and writing. Following that, I would like to offer my heartfelt gratitude to my co-supervisors, Associate Professor Dr. Edi Syams bin Zainudin (Department of Mechanical and Manufacturing Engineering, UPM), Associate Professor Dr. Zulkiflle bin Leman (Department of Mechanical and Manufacturing Engineering, UPM), and Prof. Ts. Dr. Khalina bt. Abdan (Department of Biological and Agricultural Engineering), for their guidance and instruction.

I would like to give special thanks to Universiti Putra Malaysia for the financial assistance provided through the Universiti Putra Malaysia Special Graduate Research Assistantship (SGRA) scholarship, Geran Putra Berimpak (GPB), UPM/800-3/3/1/GPB/2019/9679800, and Geran Putra Berimpak (GPB), UPM.RMC.800-3/3/1/GPB/2020/9694500.

My deepest gratitude goes to my mother and father (Ikhlas Sherwani) for their particular prayers and moral support, which pushed me to begin the programme despite huge constraints. My heartfelt gratitude also goes to my loving wife (Nida Qamar) for her support, patience, and prayers throughout my study period. Patience and ongoing prayer from my daughter (Fatima) are also acknowledged. Thanks to my siblings, Farhan, Farah, and Summaiya for their constant support. Thank you also to my entire family, especially my mother-in-law. I am also grateful to everyone who helped me complete this research successfully, including Dr. Ahmad Ilyas Rushdan, Tarique Jamal, Zatil Hazrari Kamaruddin, and Gohar Nadeem. Finally, I would want to express my sincere appreciation to all of my religious seniors, particularly Prof. Sanaullah, Prof. Faraheem, Prof. Abdul Mannan (Aligarh Muslim University, Aligarh), and Imran Ahmed, who have supported and encouraged me throughout this research.

Jazakumullahu Khairan!

© COPYRIGHT UPM

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:

Mohd Sapuan bin Salit@ Sinon, PhD, P.Eng
Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Edi Syams bin Zainudin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Zulkiflle bin Leman, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Khalina binti Abdan, PhD
Professor, Ts
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9 March 2022

© COPYRIGHT UPM

Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Professor Ir. Dr. Mohd Sapuan bin Salit

Signature: _____
Name of Member of Supervisory Committee: Associate Professor Dr. Edi Syams bin Zainudin

Signature: _____
Name of Member of Supervisory Committee: Associate Professor Dr. Zulkiflle bin Leman

Signature: _____
Name of Member of Supervisory Committee: Professor Ts. Dr. Khalina Abdan

© COPYRIGHT UPM

TABLE OF CONTENTS

© COPYRIGHT UPM

© COPYRIGHT UPM

© COPYRIGHT UPM

© COPYRIGHT UPM

LIST OF TABLES

© COPYRIGHT UPM

© COPYRIGHT UPM

LIST OF FIGURES

© COPYRIGHT UPM

© COPYRIGHT UPM

© COPYRIGHT UPM

© COPYRIGHT UPM

© COPYRIGHT UPM

LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
AM	Additive Manufacturing
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
ATR	Attenuated total reflectance
CFRP	Carbon fiber reinforced plastic
CHP	Cocos nucifera husk particle
DFCM	Dynamic fluid compression molding
DMA	Dynamic Mechanical Analyzer
EPS	Expanded Polystyrene
FGM	Functional graded materials
FTIR	Fourier Transform Infrared
GF	Glass Fiber
HDPE	High-density Polyethene
HIPS	High-impact polystyrene
KF	Kenaf Fiber
LDPE	Low-density Polyethene
NFC	Natural Fiber Composite
NFRPC	Natural Fiber Reinforced Polymer Composites
PALF	Pineapple Leaf Fiber
PLA	Poly(lactic acid)
PP	Polypropylene
PU	Polyurethane
RIM	Resin injection molding

© COPYRIGHT UPM

RPP	Recycled Poly-propylene
SEM	Scanning Electron Microscopy
SLS	Selective laser sintering
SMC	Sheet molding compound
SPF	Sugar Palm Fiber
SPS	Sugar Palm Starch
TGA	Thermogravimetric analysis
TPU	Thermoplastic Polyurethane
UTM	Universal testing machine

© COPYRIGHT UPM

LIST OF SYMBOLS

^{0}	Degree
^{0}C	Degree Celsius
ρ	Density
gm	Gram
hr.	Hour
MPa	Mega Pascal
%	Percentage
M_f	Final Weight
M_i	Initial Weight
Wt.%	Weight percentage
GPa	Gega Pascal
µm	Micrometer
T_i	Initial thickness before water immersion
T_f	Final thickness after water immersion
Q_t	Mole % uptake
M	Molecular weight of the solvent
W_t	Weight of water uptake at time 't'
Q_∞	Mol % uptake at equilibrium
Ɵ	Slope sorption curves from the initial linear portion
D	Diffusion coefficient
S	Solubility
P	Permeability coefficient

© COPYRIGHT UPM

CHAPTER 1

INTRODUCTION

1.1 Background of the research

In developing countries, it has been observed that the usage of motorcycles is more than the cars. During the past decade, a number of studies were performed on the new design of engines, but very few on the material of the motorcycle frame. The majority of motorcycle parts are manufactured of Acrylonitrile Butadiene Styrene (ABS) plastic, which has several advantages, including a high melting point, low weight, high strength, strong mechanical characteristics, and a great surface finish (Saxena and Maiti 2021). However, ABS plastic is not biodegradable, is not a renewable resource, and is harmful to the environment (Kurniawan et al., 2021). Because of ABS plastic's environmentally harmful characteristics, researchers are moving toward biodegradable plastic to save the environment. Poly(lactic acid) (PLA) is a suitable replacement for ABS since it is a biodegradable plastic manufactured from plant-based ingredients such as corn starch or sugarcane, also known as "the green plastic." (Mukaffa et al. 2021). In this research, the PLA was reinforced with glass fiber and the most abundant Malaysian natural fiber, i.e., sugar palm fiber (SPF). Sugar palm fiber inclusion has a number of advantages, including lightweight, biodegradability, ease of machinability, non-toxicity, cheap cost, non-abrasive, availability, reduced pollution emissions, and low environmental impacts (Mukhtar et al., 2019). However, SPF has a major drawback of inadequate adhesion between the hydrophilic SPF and the hydrophobic PLA matrix (Atiqah et al., 2018a). This problem can be solved by chemically treating SPF, which results in good adhesion between treated SPF and other matrices. Weight and cost reductions are significant with glass/sugar palm fiber hybrid composites. As a result, this research was performed to determine the physical, mechanical, and morphological characteristics of various ratio SPF/GF/PLA hybrid composites. The research will concentrate on alkaline and benzoyl-treated sugar palm fiber to enhance the adhesion between SPF, GF, and PLA. In addition, when compared to commercially available motorcycle ABS components, the PLA/SPF/GF composite exhibits superior physical and mechanical characteristics. At the end of this research, based on the result obtained, the best hybrid composite was proposed, which is suitable for Modenas Kriss 110 motorcycle battery housing components.

1.2 Problem statements

Motorcycle manufacturers' extensive use of petroleum-based polymer or ABS plastic has resulted in severe environmental issues, particularly at the disposal stage. When these wastes are disposed of in the environment, i.e., land or water, they are not easily biodegradable, causing severe issues for civilization, animals, and the ecosystem. Furthermore, air pollution is a hazard as a result of the incineration of these wastes. To address this issue, several countries like Australia (Queensland), Greece, France, North America (Mexico), Malaysia, and many more have recently outlawed the use of plastic

© COPYRIGHT UPM

items (Schnurr et al., 2018). As a result, this research aims to solve the problem by creating a renewable and biodegradable polymer composite from natural sources.

PLA is the most promising biodegradable material among biodegradable polymers since it is easily attacked by bacteria (Siakeng et al., 2019). The degradation happens by hydrolysis caused by lactic acid, converted by microbial species to water and carbon monoxide. By composting PLA with other biomass waste, the biodegradation process was completed in two weeks, and the materials were totally degraded and disappeared in three to four weeks (Ibrahim et al., 2010). PLA is frequently used to replace synthetic polymers that can harm our environment owing to solid waste pollution. However, because poly(lactic) polymers are stiff and brittle, it is important to incorporate a portion of natural fiber into them to increase their mechanical properties and yield strength (Azlin et al. 2020; Serizawa, Inoue, and Iji 2006). Other researchers have conducted several investigations on the mechanical properties of natural fibers reinforced with PLA, including kenaf (Ochi 2008; Tawakkal et al., 2012; Yusoff, Takagi, and Nakagaito 2016), cotton gin waste, flax (Bajracharya, Bajwa, and Bajwa 2017), jute (Manral et al., 2019; Reddy et al., 2021), and hemp (Durante et al., 2017; Xu et al., 2019), as reinforcement in order to replace synthetic fiber in polymer composites.

SPF has the following advantages: low cost, biodegradable, non-toxic, low density, and excellent mechanical strength. However, SPF has several drawbacks, including non-adhesion with polymer matrices, excessive wetness, and poor modulus. Chemically modifying the surfaces of fibers will help solve some of these problems (Atiqah et al., 2019; Ilyas et al., 2020; Rozilah et al., 2020). One of the most common treatments is alkaline treatment, which has several advantages, including cheap cost, efficient surface modification, improved mechanical characteristics, and the production of a rough fiber surface (Radzi et al., 2019a). The rough surfaces acquired after alkaline treatment improve fiber interlocking for matrix penetration, establishing a large region of contact between the matrix and the fiber (Nurazzi et al., 2019). The mechanical properties were improved by 6% using alkaline treatment of SPF for roselle fiber RF/SPF hybrid composite due to the excellent adhesion between fiber and matrix (Radzi et al., 2019a). The treatment improved the wettability of the *Impomea pescaprae* fibers/epoxy composites, resulting in better bonding and hence, enhancing the overall strength of the composites (Vinod et al., 2019). Due to their biodegradability, it becomes advantageous to transform poly(lactic acid) (PLA) and sugar palm fibers into eco-friendly composites.

There is no investigation on the hybrid composite of sugar palm and glass fiber reinforced poly(lactic acid) with prior treatment of SPF with NaOH and benzoyl chloride, as evidenced by the literature. The chemical treatment of sugar palm fiber is intended to enhance fiber dispersion, fiber-matrix adhesion, and reduce moisture absorption. The treated and untreated fibers were characterized in order to investigate the influence of fiber treatments on physical, mechanical, and morphological properties for the effective use of fiber in motorcycle framing work. Hot compression molding was used to create the sugar palm fiber and glass fiber hybrid reinforced poly(lactic acid) composite. The basic features linked to its use, especially mechanical properties, were evaluated. After the characterizations, the best performing composite system was utilized to produce the composite plate and compare its different properties with the existing battery housing component of Modenas Kriss 110 motorcycle made from ABS plastic.

© COPYRIGHT UPM

1.3 Research objectives

The general objective of this research is to develop and characterise sugar palm and glass fiber reinforced poly(lactic acid) hybrid composites. The specific objectives are:

1. Development and determination of physical, mechanical and morphological properties of sugar palm fiber (SPF) reinforced poly(lactic acid) (PLA) composites.

2. Development and determination of physical, mechanical, morphological properties and flammability of treated sugar palm fiber (SPF) reinforced poly(lactic acid) (PLA) composites

3. Development and determination of physical, mechanical and morphological properties of sugar palm/ glass fiber (SPF/GF) reinforced poly(lactic acid) (PLA) hybrid composites.

4. Validation of physical, mechanical properties and flammability of sugar palm /glass fiber (SPF/GF)-reinforced poly(lactic acid) PLA hybrid composites with *Acrylonitrile Butadiene Styrene* (ABS) for potential use in Modenas Kriss 110 motorcycle battery housing components.

1.4 Significance of the research

Combining sugar palm fiber with glass fiber with prior chemical treatment of the fibers that were converted into the high-performance composite material can result in a beneficial hybrid effect. When compared to ABS plastics, the proposed new material, termed "partial eco-friendly hybrid composite", possesses better physical and mechanical properties while being less harmful to the environment. This study's findings also give basic information regarding sugar palm and glass fiber reinforced poly(lactic acid) hybrid composite as a material proposed for battery housing of motorcycle components. The utilization of sugar palm fiber would encourage rural people to develop sugar palm tree cultivation. Because of the increased revenue, the economy and people's well-being will benefit even more. The sugar palm and glass fiber reinforced poly(lactic acid) hybrid composites outperformed existing ABS plastic in terms of flame retardance. This new composite is safer for the environment as well as for accidental contact. This new material benefits the local motorcycle manufacturers for the production of battery housing components.

1.5 Research scopes

The research focuses on the characterizations of both treated and untreated fiber, which included density, void content, thickness swelling, moisture content, tensile, flexural, and impact strength, as well as morphological analysis. Using Brabender mixing and the

© COPYRIGHT UPM

hot compression method, sugar palm and glass fiber reinforced poly(lactic acid) hybrid and non-hybrid composites were developed. The hybrid and non-hybrid composites were characterized in accordance with the standards. The physical, mechanical, and morphological properties of the composite were investigated. These tests were carried out to determine its suitability as a material for the battery housing component of the Modenas Kriss 110. Furthermore, the properties of the SPF/GF/PLA hybrid composites, such as rainwater absorption, oil absorption, creep, hardness, compression, and flammability, were determined and compared with existing ABS plastic components, demonstrating that our proposed material is more suitable than the commercially available ABS component.

1.6 Structure of thesis

The following are the specifics of the thesis structure:

Chapter 1

This chapter presents the research background, problem statements, and objectives. This chapter also describes the significance of the research work and the scope of the research, as well as the structure of the thesis.

Chapter 2

This chapter gives a detailed overview of the literature on the title of this research. Further- more, the research gaps identified throughout the study were addressed inside the chapter.

Chapter 3

This chapter is concerned with the methods used in this study for material selection, preparation, fabrication, testing procedures, and data collection.

Chapter 4

This chapter is about results and discussion of the research work and they are divided into four parts. The first part is about physical, mechanical and morphological properties of sugar palm fiber reinforced poly(lactic acid) composites. In this part, the effect of different sugar palm fiber loading (from 0 to 40%SPF loading) on physical (density, thickness swelling, and water absorption), mechanical (tensile, flexural, and impact), and morhological properties of sugar palm fiber reinforced poly(lactic acid) composites were investigated.

This second part presents the effect of alkaline and benzoyl chloride treatments on physical, mechanical and morphological properties of sugar palm fiber-reinforced poly(lactic acid) composites. In this part, the effect of alkaline (4,5 & 6% conc. of NaOH)

© COPYRIGHT UPM

and benzoyl chloride (10, 15 & 20 min.) treatments on physical (density, thickness swelling, and water absorption), mechanical (tensile, flexural, and impact) and morphological properties of sugar palm fiber-reinforced poly(lactic acid) composites were investigated.

The third part of chapter four is about the physical, mechanical, and morphological properties of treated sugar palm/ glass fiber reinforced poly (lactic acid) hybrid composites. In this part, the effect of 30%SP/GF & 70% PLA loading on physical (density, thickness swelling, and water absorption), mechanical (tensile, flexural, and impact), and morhological properties of sugar palm / glass fiber reinforced poly(lactic acid) hybrid composites were investigated.

The last part of chapter four is related to mechanical properties of sugar palm [*Arenga pinnata* (Wurmb.) Merr]/glass fiber-reinforced poly(lactic acid) hybrid composites for potential use in motorcycle components. In this part, mechanical (tensile, flexural, hardness, compressive, impact, and creep) and flammability properties of SPF/GF/PLA hybrid composites were investigated and compared to commercially available motorcycle Acrylonitrile Butadiene Styrene (ABS) plastic components.

Chapter 5

This chapter is the final chapter where the overall conclusions from the whole research as well as future recommendations for further improvement of this research.

© COPYRIGHT UPM

REFERENCES

Abdul Khalil, H. P.S., Suraya, N.L. Atiqah, N, Jawaid, M and Hassan A. 2013. "Mechanical and Thermal Properties of Chemical Treated Kenaf Fibres Reinforced Polyester Composites." *Journal of Composite Materials* 47(26): 3343–50.

Abdul Majid, Rohani, Hanafi Ismail, and Razaina Mat Taib. 2018. "Processing, Tensile, and Thermal Studies of Poly(Vinyl Chloride)/Epoxidized Natural Rubber/Kenaf Core Powder Composites with Benzoyl Chloride Treatment." *Polymer - Plastics Technology and Engineering* 57(15): 1507–17.

Afdzaluddin, Atiqah, Abdul Maleque, and Mohammed Iqbal. 2013. "Synergistic Effect on Flexural Properties of Kenaf-Glass Hybrid Composite." *Advanced Materials Research* 626: 989–92.

Afzaluddin, Atiqah, Mohammad Jawaid, Mohd Sapuan Salit, and Mohamed Ridwan Ishak. 2019. "Physical and Mechanical Properties of Sugar Palm/Glass Fiber Reinforced Thermoplastic Polyurethane Hybrid Composites." *Journal of Materials Research and Technology* 8(1): 950–59.

Agrebi, F. Ghorbel, N Rashid, B Kallel, A and Jawaid,M. 2018. "Influence of Treatments on the Dielectric Properties of Sugar Palm Fiber Reinforced Phenolic Composites." *Journal of Molecular Liquids* 263: 342–48.

Akash, K. G. Girisha, N. S. Venkatesha Gupta, and K. V. Sreenivas Rao. 2017. "A Study on Flammability and Moisture Absorption Behavior of Sisal/Coir Fiber Reinforced Hybrid Composites." *IOP Conference Series: Materials Science and Engineering* 191(1).

AL-Oqla, Faris M., and Mohd S. Salit. 2017. "Natural Fiber Composites." *Materials Selection for Natural Fiber Composites*: 23–48.

Alaaeddin, M H, S M Sapuan, M Y M Zuhri, and E S Zainudin. 2019. "Development of Photovoltaic Module with Fabricated and Evaluated Novel Backsheet-Based."

Alam, Moshiul Mina, M.F. Beg, M.D.H Mamun, A.A. Bledzki, A.K. and Shubhra, Q.T.H.2014. "Thermo-Mechanical and Morphological Properties of Short Natural Fiber Reinforced Poly (Lactic Acid) Biocomposite: Effect of Fiber Treatment." *Fibers and Polymers* 15(6): 1303–9.

Alias, N. F., H. Ismail, and K. M.Ku Ishak. 2019. "The Effect of Kenaf Loading on Water Absorption and Impact Properties of Polylactic Acid/ Natural Rubber/ Kenaf Core Powder Biocomposite." *Materials Today: Proceedings* 17: 584–89.

AlMaadeed, Mariam A., Ramazan Kahraman, P. Noorunnisa Khanam, and Nabil Madi. 2012. "Date Palm Wood Flour/Glass Fibre Reinforced Hybrid Composites of Recycled Polypropylene: Mechanical and Thermal Properties." *Materials and Design* 42: 289–94.

© COPYRIGHT UPM

Alves Fidelis Maria Ernestina, Thatiana Vitorino Castro Pereira, Otávio da Fonseca Martins Gomes, Flávio de Andrade Silva, Romildo Dias Toledo Filho 2013. "The Effect of Fiber Morphology on the Tensile Strength of Natural Fibers." *Journal of Materials Research and Technology* 2(2): 149–57.

Angelova, D Uzunov, I Uzunovaa, S Gigova, A and Minchev, L. 2011. "Kinetics of Oil and Oil Products Adsorption by Carbonized Rice Husks." *Chemical Engineering Journal* 172(1): 306–11.

Ashothaman, A., J. Sudha, and N. Senthilkumar. 2021. "A Comprehensive Review on Biodegradable Polylactic Acid Polymer Matrix Composite Material Reinforced with Synthetic and Natural Fibers." *Materials Today: Proceedings* (xxxx).

Asim, M., M. Jawaid, M. Nasir, and N. Saba. 2018. "Effect of Fiber Loadings and Treatment on Dynamic Mechanical, Thermal and Flammability Properties of Pineapple Leaf Fiber and Kenaf Phenolic Composites." *Journal of Renewable Materials* 6(4): 383–93.

Asim, Mohammad, Mohammad Jawaid, Khalina Abdan, and Mohamad Ridzwan Ishak. 2016. "Effect of Alkali and Silane Treatments on Mechanical and Fibre-Matrix Bond Strength of Kenaf and Pineapple Leaf Fibres." *Journal of Bionic Engineering* 13(3): 426–35.

Assarar Mustapha, Wajdi Zouari, Hamid Sabhi, Rezak Ayad and Jean-Marie Berthelot. 2015. "Evaluation of the Damping of Hybrid Carbon-Flax Reinforced Composites." *Composite Structures* 132: 148–54.

ASTM D570. 2014. "Standard Test Method for Water Absorption of Plastics." *ASTM Standards* 98(Reapproved 2010): 25–28.

ASTM D695 − 15. 2015. "Standard Test Method for Compressive Properties of Rigid Plastics 1 Standard Test Method for Compressive Properties of Rigid Plastics." *American Society for Testing and Materials* (July): 19428–2959.

ASTM D790. 2015. "ASTM D790-03-Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulation Materials." *ASTM D790-3 Standards* 08.01: 1–11.

ASTM D792. 2013. "ASTM D792 − 13: Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement." *ASTM International* 15(3): 145–49.

ASTM Standard D256. 2010. "Determining the Izod Pendulum Impact Resistance of Plastics." : 1–20.

ASTM Standard D2990-09. 2011. "Standard Test Methods for Tensile , Compressive , and Flexural Creep and Creep- Rupture of Plastics." *Annual Book of ASTM Standards* (April): 1–20.

© COPYRIGHT UPM

ASTM Standard D638. 2010. "ASTM Standard D638 (2010), 'Standard Test Method for Tensile Properties of Plastics,'. ASTM International, West Conshohocken, PA."

ASTMD635-18. 2018. "Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position."

Atiqah, A., M. Jawaid, S. M. Sapuan, M. R. Ishak, M.N.M. Ansaria, and R.A. Ilyas 2019. "Physical and Thermal Properties of Treated Sugar Palm/Glass Fibre Reinforced Thermoplastic Polyurethane Hybrid Composites." *Journal of Materials Research and Technology* 8(5): 3726–32.

Atiqah, A., M. Jawaid, M. R. Ishak, and S. M. Sapuan. 2017. "Moisture Absorption and Thickness Swelling Behaviour of Sugar Palm Fibre Reinforced Thermoplastic Polyurethane." *Procedia Engineering* 184: 581–86.

Atiqah, A., M. Jawaid, M. R. Ishak, and S. M. Sapuan. 2018. "Effect of Alkali and Silane Treatments on Mechanical and Interfacial Bonding Strength of Sugar Palm Fibers with Thermoplastic Polyurethane." *Journal of Natural Fibers* 15(2): 251–61.

Atiqah, A., M. Jawaid, S. M. Sapuan, and M. R. Ishak. 2018a. "Physical Properties of Silane-Treated Sugar Palm Fiber Reinforced Thermoplastic Polyurethane Composites." *IOP Conference Series: Materials Science and Engineering* 368(1).

Atiqah, A., M. Jawaid, S. M. Sapuan, and M. R. Ishak. 2019. "Dynamic Mechanical Properties of Sugar Palm/Glass Fiber Reinforced Thermoplastic Polyurethane Hybrid Composites." *Polymer Composites* 40(4): 1329–34.

Atiqah, A., Mohammad Jawaid, S. M. Sapuan, and Mohamad Ridzwan Ishak. 2018b. "Effect of Surface Treatment on the Mechanical Properties of Sugar Palm/Glass Fiber-Reinforced Thermoplastic Polyurethane Hybrid Composites." *BioResources* 13(1): 1174–88.

Atiqah, A, M Jawaid, S. M Sapuan, and M R Ishak. 2017a. "Mechanical and Thermal Properties of Sugar Palm Fiber Reinforced Thermoplastic Polyurethane Composites: Effect of Silane Treatment and Fiber Loading." *Journal of Renewable Materials* 6(5): 477–92.

Azlin, M.N.M, Sapuan S.M., Zainudin E.S., Zuhri M.Y.M., ILyas, R.A. 2020. Advanced Processing, Properties, and Applications of Starch and Other Bio-Based Polymers *Natural Polylactic Acid-Based Fiber Composites: A Review*. Advanced Processing, Properties, and Applications of Starch and Other Bio-based Polymers Elsevier Inc.

B.Z. Jang, J.Y. Liau, W.K. ShihL.R. Hwang. 1990. "Particulate and Whisker Modifications of Matrix Resin for Improved Toughness of Fibrous Composites,." *J. Reinforc. Plast. Compos.* 9: 314–33.

Bachtiar, D. Sapuan S.M., Khalina A, Zainudin E.S., and Dahlan K.Z.M . 2012. "Flexural and Impact Properties of Chemically Treated Sugar Palm Fiber Reinforced High Impact Polystyrene Composites." *Fibers and Polymers* 13(7): 894–98.

© COPYRIGHT UPM

Bachtiar, D. Sapuan S.M., Khalina A, Zainudin E.S., and Dahlan K.Z.M .2011. "Effects of Alkaline Treatment and a Compatibilizing Agent on Tensile Properties of Sugar Palm Fibre reinforced High Impact Polystyrene Composites." *BioResources* 6(4): 4815–23.

Badyankal, Pramod V., T. S. Manjunatha, Gurushanth B. Vaggar, and K. C. Praveen. 2019. "Compression and Water Absorption Behaviour of Banana and Sisal Hybrid Fiber Polymer Composites." *Materials Today: Proceedings* 35: 383–86.

Bajpai, Pramendra Kumar, Inderdeep Singh, and Jitendra Madaan. 2014. "Development and Characterization of PLA-Based Green Composites: A Review." *Journal of Thermoplastic Composite Materials* 27(1): 52–81.

Bajracharya, Rohan M., Dilpreet S. Bajwa, and Sreekala G. Bajwa. 2017. "Mechanical Properties of Polylactic Acid Composites Reinforced with Cotton Gin Waste and Flax Fibers." *Procedia Engineering* 200: 370–76..

Bakar, Noor Haznida, Koay Mei Hyieb, Aidah Jumahatc, Anizah Kalamd, and Z. Salleh 2015. "Effect of Alkaline Treatment on Tensile and Impact Strength of Kenaf/Kevlar Hybrid Composites." *Applied Mechanics and Materials* 763: 3–8.

Balla, Vamsi Krishna, Kunal H. Kate, Jagannadh Satyavolu, Paramjot Singh, Jogi Ganesh Dattatreya Tadimeti. 2019. "Additive Manufacturing of Natural Fiber Reinforced Polymer Composites: Processing and Prospects." *Composites Part B: Engineering* 174(March): 106956.

Bambach, M. R. 2020. "Durability of Natural Fibre Epoxy Composite Structural Columns: High Cycle Compression Fatigue and Moisture Ingress." *Composites Part C: Open Access* 2(August): 100013. https://doi.org/10.1016/j.jcomc.2020.-100013.

Baskaran, Justin Dhiraviyam.F, and Sathish K. 2017. "Design and Fabrication of Two Wheeler Mudguard Using Sisal Natural Fiber." *International Journal of Mechanical Engineering* 4(1): 1–4.

Bax, Benjamin, and Jörg Müssig. 2008. "Impact and Tensile Properties of PLA/Cordenka and PLA/Flax Composites." *Composites Science and Technology* 68(7–8): 1601–7.

Bera, Tanusree, Niharika Mohanta, Ved Prakash, Subhrajit Pradhan and Samir K Acharya."Moisture Absorption and Thickness Swelling Behaviour of Luffa Fibre/Epoxy Composite." *Journal of Reinforced Plastics and Composites* 38(19–20): 923–37.

Bharanichandar, J. 2014. "Natural Fiber Reinforced Polymer Composites for Automobile Accessories." *American Journal of Environmental Science* 9(6): 494–504.

Bharath, K.N., and S. Basavarajappa. 2014. "Flammability Characteristics of Chemical Treated Woven Natural Fabric Reinforced Phenol Formaldehyde Composites." *Procedia Materials Science* 5: 1880–86.

© COPYRIGHT UPM

Binti Mohd Hafidz, N.S., M.S. Bin Mohamed Rehan, and H. Binti Mokhtar. 2021. "Effect of Alkaline Treatment on Water Absorption and Thickness Swelling of Natural Fibre Reinforced Unsaturated Polyester Composites." *Materials Today: Proceedings*.

Braden, M., E. E. Causton, and R. L. Clarke. 1976. "Diffusion of Water in Composite Filling Materials." *Journal of Dental Research* 55(5): 730–32.

Chalid, Mochamad, and Imam Prabowo. 2015. "The Effects of Alkalization to the Mechanical Properties of the Ijuk Fiber Reinforced PLA Biocomposites." *International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering* 9(2): 342–46.

Chapple, S., and R. Anandjiwala. 2010. "Flammability of Natural Fiber-Reinforced Composites and Strategies for Fire Retardancy: A Review." *Journal of Thermoplastic Composite Materials* 23(6): 871–93.

Chen, Chen Xiaoyu Gu, Xiaodong Jin, Jun Sun and Sheng Zhang 2017. "The Effect of Chitosan on the Flammability and Thermal Stability of Polylactic Acid/Ammonium Polyphosphate Biocomposites." *Carbohydrate Polymers* 157: 1586–93.

Curosu, Iurie Marco Liebscher, Sarah Burk, Huanyu Li, Simone Hempel, Norbert Raak, Harald Rohm and Viktor Mechtcherine. 2021. "Influence of Fiber Type on the Tensile Behavior of High-Strength Strain-Hardening Cement-Based Composites (SHCC) at Elevated Temperatures." *Materials and Design* 198: 109397.

Danladi, A, and J Shu'aib. 2014. "Fabrication and Properties of Pineapple Fibre / High Density Polyethylene Composites." *American Journal of Materials Science* 2014(3): 139–43.

Davis, P.D., G.D. Parbrook, and G.N.C. Kenny. 1995. "Diffusion and Osmosis." *Basic Physics and Measurement in Anaesthesia*: 89–102.

Devi, L. Uma, Kuruvila Joseph, K. C.Manikandan Nair, and Sabu Thomas. 2004. "Ageing Studies of Pineapple Leaf Fiber-Reinforced Polyester Composites." *Journal of Applied Polymer Science* 94(2): 503–10.

Dong, Chensong, and Ian J. Davies. 2015. "Flexural Strength of Bidirectional Hybrid Epoxy Composites Reinforced by e Glass and T700S Carbon Fibres." *Composites Part B: Engineering* 72: 65–71.

Du, Siqi, Xiongqi Peng, and Hailin Gu. 2019. "Experimental Investigation on Fabrication and Thermal-Stamping of Woven Jute/Polylactic Acid Biocomposites." *Journal of Composite Materials* 53(7): 851–61.

Du, Yicheng, Ning Yan, and Mark T. Kortschot. 2013. "An Experimental Study of Creep Behavior of Lightweight Natural Fiber-Reinforced Polymer Composite/Honeycomb Core Sandwich Panels." *Composite Structures* 106: 160–66.

© COPYRIGHT UPM

Durante, Massimo, Antonio Formisano, Luca Boccarusso, Antonio Langella and Luigi Carrino. 2017. “Creep Behaviour of Polylactic Acid Reinforced by Woven Hemp Fabric.” *Composites Part B: Engineering* 124: 16–22.

Edu H. Agung, M. H. M. Hamdan, J. P. Siregar. 2005. “Water Absorption Behaviour and Mechanical Performance of Pineapple Leaf Fibre Reinforced Polylactic Acid Composites E.” *NASPA Journal* 42(4): 1.

Edhirej, Ahmed, S. M. Sapuan, Mohammad Jawaid, and Nur Ismarrubie Zahari. 2017. “Cassava/Sugar Palm Fiber Reinforced Cassava Starch Hybrid Composites: Physical, Thermal and Structural Properties.” *International Journal of Biological Macromolecules* 101: 75–83.

Ferdiansyah, T., and H. Abdul Razak. 2011. “Mechanical Properties of Black Sugar Palm Fiber-Reinforced Concrete.” *Journal of Reinforced Plastics and Composites* 30(11): 994–1004.

Fiore, V, G Di Bella, and A Valenza. 2015. “The Effect of Alkaline Treatment on Mechanical Properties of Kenaf Fibers and Their Epoxy Composites.” *Composites part B* 68: 14–21.

Francis Luther King, M., Arul Jeyakumar, A., Srinivasan, V. 2018. “Investigation of Mechanical Behaviour on Bagasse/ Basalt Reinforced Poly Lactic Acid Hybrid Composites: Tensile, Flexural, Impact and Water Absorption.” *Journal of Advanced Microscopy*.

George, Gejo, Kuruvilla Joseph, Abderrahim Boudenne, and Sabu Thomas. 2010. “Recent Advances in Green Composites.” *Key Engineering Materials* 425: 107–66.

Girisha, C., Sanjeevamurthy, and Gunti Ranga Srinivas. 2012. “Sisal/Coconut Coir Natural Fibers-Epoxy Composites: Water Absorption and Mechanical Properties.” *International Journal of Engineering and Innovative Technology (IJEIT)* 2(3): 166–70.

Gupta, Arun Kumar, Manoranjan Biswal, S. Mohanty, and S. K. Nayak. 2012. “Mechanical, Thermal Degradation, and Flammability Studies on Surface Modified Sisal Fiber Reinforced Recycled Polypropylene Composites.” *Advances in Mechanical Engineering* 2012.

Haleem, Abid, Vineet Kumar, and Lalit Kumar. 2017. “Mathematical Modelling & Pressure Drop Analysis of Fused Deposition Modelling Feed Wire.” *International Journal of Engineering and Technology* 9(4): 2885–94.

Hassan, C. S. Yeo, C W. Sahari B, Salit S.M and Abdul Aziz,N. 2017. “Mechanical Properties of Unidirectional Oil Palm Empty Fruit Bunch (OPEFB) Fiber Reinforced Epoxy Composite.” *IOP Conference Series: Materials Science and Engineering* 206(1).

© COPYRIGHT UPM

Hazrati, K.Z., S.M. Sapuan, M.Y.M. Zuhri, and R. Jumaidin. 2021. "Effect of Plasticizers on Physical, Thermal, and Tensile Properties of Thermoplastic Films Based on Dioscorea Hispida Starch." *International Journal of Biological Macromolecules* 185(June): 219–28.

Hinchcliffe, Sean A., Kristen M. Hess, and Wil V. Srubar. 2016. "Experimental and Theoretical Investigation of Prestressed Natural Fiber-Reinforced Polylactic Acid (PLA) Composite Materials." *Composites Part B: Engineering* 95: 346–54.

Holbery, James, and Dan Houston. 2006. "Natural-Fiber-Reinforced Polymer Composites in Automotive Applications." *Jom* 58(11): 80–86.

Huda, M. S. Mohanty, A. K. Drzal, L. T. Schut, E.Misra, M. 2005. "'green' Composites from Recycled Cellulose and Poly(Lactic Acid): Physico-Mechanical and Morphological Properties Evaluation." *Journal of Materials Science* 40(16): 4221–29.

Huda, M. S., L. T. Drzal, M. Misra, and A. K. Mohanty. 2006. "Wood-Fiber-Reinforced Poly(Lactic Acid) Composites: Evaluation of the Physicomechanical and Morphological Properties." *Journal of Applied Polymer Science* 102(5): 4856–69.

Huda, Masud S., Lawrence T. Drzal, Amar K. Mohanty, and Manjusri Misra. 2008. "Effect of Fiber Surface-Treatments on the Properties of Laminated Biocomposites from Poly(Lactic Acid) (PLA) and Kenaf Fibers." *Composites Science and Technology* 68(2): 424–32.

Huzaifah, M. R.M., Sapuan, S. M. Leman, Z. Ishak, M. R. Maleque, M. A.2017. "A Review of Sugar Palm (Arenga Pinnata): Application, Fibre Characterisation and Composites." *Multidiscipline Modeling in Materials and Structures* 13(4): 678–98.

Huzaifah, Muhammad Roslim, Mohd Sapuan, S MLeman, Z Ishak, Mohamad Ridzwan 2018. "A Review on Sugar Palm (Arenga Pinnata): Characterization of Sugar Palm Fibre."

Ibrahim, M. I.J., S. M. Sapuan, E. S. Zainudin, and M. Y.M. Zuhri. 2020. "Preparation and Characterization of Cornhusk/Sugar Palm Fiber Reinforced Cornstarch-Based Hybrid Composites." *Journal of Materials Research and Technology* 9(1): 200–211.

Ibrahim, Nor Azowa Md Zin Wan Yunus, Wan Othman, Maizatulnisa Abdan, Khalina Hadithon, Kamarul Arifin 2010. "Poly(Lactic Acid) (PLA)-Reinforced Kenaf Bast Fiber Composites: The Effect of Triacetin." *Journal of Reinforced Plastics and Composites* 29(7): 1099–1111.

Idris, U. D., V. S. Aigbodion, I. J. Abubakar, and C. I. Nwoye. 2015. "Eco-Friendly Asbestos Free Brake-Pad: Using Banana Peels." *Journal of King Saud University - Engineering Sciences* 27(2): 185–92. http://dx.doi.org/10.1016/j.jksues.-2013.06.006.

© COPYRIGHT UPM

Ilyas, R. A., S. M. Sapuan, M. R. Ishak, and E. S. Zainudin. 2017. "Effect of Delignification on the Physical, Thermal, Chemical, and Structural Properties of Sugar Palm Fibre." *BioResources* 12(4): 8734–54.

Ilyas, R. A., S. M. Sapuan, M. R. Ishak, and E. S. Zainudin. 2019. "Sugar Palm Nanofibrillated Cellulose (Arenga Pinnata (Wurmb.) Merr): Effect of Cycles on Their Yield, Physic-Chemical, Morphological and Thermal Behavior." *International Journal of Biological Macromolecules* 123: 379–88.

Ilyas, R. A., S. M. Sapuan, M. R. Ishak, and E. S. Zainudin. 2018 Development and characterization of sugar palm nanocrystalline cellulose reinforced sugar palm starch bionanocomposites. *Carbohydrate Polymers* 202(May): 186–202.

Ilyas, R. A., S. M. Sapuan, M. R. Ishak, and E. S. Zainudin. 2018. "Nanocrystalline Cellulose as Reinforcement for Polymeric Matrix Nanocomposites and Its Potential Applications: A Review." *Current Analytical Chemistry* 14(3): 203–25.

Ilyas, R.A., and S.M. Sapuan. 2020a. "Biopolymers and Biocomposites: Chemistry and Technology." *Current Analytical Chemistry* 16(5): 500–503.

Ilyas, R.A., and S.M. Sapuan. 2020b. "The Preparation Methods and Processing of Natural Fibre Bio-Polymer Composites." *Current Organic Synthesis* 16(8): 1068–70.

Ilyas, RA Sapuan, S. M. Atikah, M. S.N. Asyraf, M. R.M. Rafiqah, S. Ayu Aisyah, H. A. Nurazzi, N. Mohd Norrrahim, M. N.F. 2020. "Effect of Hydrolysis Time on the Morphological, Physical, Chemical, and Thermal Behavior of Sugar Palm Nanocrystalline Cellulose (Arenga Pinnata (Wurmb.) Merr)." *Textile Research Journal*: 004051752093239.

Ilyas, Rushdan Ahmad Sapuan, S. M. Atikah, M. S.N. Asyraf, M. R.M. Rafiqah, S. Ayu Aisyah, H. A. Nurazzi, N. Mohd Norrrahim, M. N.F et al. 2019. "Sugar Palm (Arenga Pinnata (Wurmb.) Merr) Cellulosic Fibre Hierarchy: A Comprehensive Approach from Macro to Nano Scale." *Journal of Materials Research and Technology* 8(3): 2753–66.

Imran, M. K. B. M. 2015. "Sound Insulation and Vibration Reduction of Modified Zinc Roof Using Natural Fiber (Arenga Pinnata)." Universiti.

Ishak, M. R. Sapuan, S. M. Leman, Z. Rahman, M. Z.A. Anwar, U. M.K. Siregar, J. P. 2013. "Sugar Palm (Arenga Pinnata): Its Fibres, Polymers and Composites." *Carbohydrate Polymers* 91(2): 699–710.

Jiang, Ying, Penghu Deng, Lingxiao Jing, and Tonghua Zhang. 2019. "Tensile Properties and Structure Characterization of Palm Fibers by Alkali Treatment." 20(5): 1029–35.

© COPYRIGHT UPM

Jones, Frank R., and Norman T. Huff. 2009. "Structure and Properties of Glass Fibres." *Handbook of Tensile Properties of Textile and Technical Fibres*: 529–73.

Jumaidin, Ridhwan Sapuan, Salit M. Jawaid, Mohammad Ishak, Mohamad R. Sahari, Japar 2017. "Thermal, Mechanical, and Physical Properties of Seaweed/Sugar Palm Fibre Reinforced Thermoplastic Sugar Palm Starch/Agar Hybrid Composites." *International Journal of Biological Macromolecules* 97: 606–15.

Kabir, M.M., H. Wang, K.T. Lau, and F. Cardona. 2012. "Chemical Treatments on Plant-Based Natural Fibre Reinforced Polymer Composites: An Overview." *Composites Part B: Engineering* 43(7): 2883–92.

Kandola, B. K., M. H. Akonda, and A. R. Horrocks. 2005. "Use of High-Performance Fibres and Intumescents as Char Promoters in Glass-Reinforced Polyester Composites." *Polymer Degradation and Stability* 88(1): 123–29.

Karimah, Azizatul Ridho, Muhammad Rasyidur Munawar, Sasa Sofyan Adi, Danang Sudarwoko Ismadi Damayanti, Ratih Subiyanto, Bambang Fatriasari, Widya Fudholi, Ahmad. 2021. "A Review on Natural Fibers for Development of Eco-Friendly Bio-Composite: Characteristics, and Utilizations." *Journal of Materials Research and Technology* 13: 2442–58.

Khalid, Muhamad Faris Syafiq, and Abdul Hakim Abdullah. 2013. "Storage Modulus Capacity of Untreated Aged Arenga Pinnata Fibre-Reinforced Epoxy Composite." *Applied Mechanics and Materials* 393: 171–76.

Khalid, Muhammad Yasir Al Rashid, Arif, Zia Ullah Ahmed, Waqas Arshad, Hassan Zaidi, Asad Ali. 2021. "Natural Fiber Reinforced Composites: Sustainable Materials for Emerging Applications." *Results in Engineering* 11(April): 100263.

Kumar, Gujja Sunil, B Naresh, and Ch Sunil. 2015. "Fabrication of Carbon Fibre Bike Mudguard." *International Journal of Innovative Science, Engineering & Technology* 2(11): 776–82.

Kurniawan Kim, Min seuk Woo Chung, Kyeong Kim, Rina Lee, Jae chun. 2021. "Simple and Complete Separation of Copper from Nickel in the Ammoniacal Leach Solutions of Metal Coated ABS Plastic Waste by Antagonistic Extraction Using a Mixture of LIX 84-I and TBP." *Separation and Purification Technology* 255(September 2020): 117712.

Kushwaha, Pradeep K., and Rakesh Kumar. 2011. "Influence of Chemical Treatments on the Mechanical and Water Absorption Properties of Bamboo Fiber Composites." *Journal of Reinforced Plastics and Composites* 30(1): 73–85.

L. Uma Devi, S.S. Bhagawan, S. Thomas. 2012. "Polyester Composites of Short Pineapple Fiber and Glass Fiber: Tensile and Impact Properties." *Polymer Composites* 16(2): 1–6.

© COPYRIGHT UPM

Leman, Z. Sapuan, S. M. Saifol, A. M. Maleque, M. A. Ahmad, M. M.H.M.. 2008. "Moisture Absorption Behavior of Sugar Palm Fiber Reinforced Epoxy composites." *Materials and Design* 29(8): 1666–70.

Maisara, A. M.N. Ilyas, R. A. Sapuan, S. M. Huzaifah, M. R.M. Mohd Nurazzi, N. Saifulazry, S. O.A. 2019. "Effect of Fibre Length and Sea Water Treatment on Mechanical Properties of Sugar Palm Fibre Reinforced Unsaturated Polyester Composites." *International Journal of Recent Technology and Engineering* 8(2 Special Issue 4): 510–14.

Majid, R.A., Ismail, H. and Taib, R.M. 2016. "Benzoyl Chloride Treatment of Kenaf Core Powder: The Effects on Mechanical and Morphological Properties of PVC/ENR/Kenaf Core Powder Composites." *Procedia Chemistry* 19: 803–9.

Maleque, M. A., and A. Atiqah. 2013. "Development and Characterization of Coir Fibre Reinforced Composite Brake Friction Materials." *Arabian Journal for Science and Engineering* 38(11): 3191–99.

Maleque, M. A., Atiqah, A. and Iqbal, M. 2012. "Flexural and Impact Properties of Kenaf-Glass Hybrid Composite." *Advanced Materials Research* 576: 471–74.

Mancini, Sandro Donnini, Antídio De Oliveira Santos Neto, Maria Odila Hilário Cioffi, and Eduardo Carlos Bianchi. 2017. "Replacement of Metallic Parts for Polymer Composite Materials in Motorcycle Oil Pumps." *Journal of Reinforced Plastics and Composites* 36(2): 149–60.

Manral, Ankit, Furkan Ahmad, and Vijay Chaudhary. 2019. "Static and Dynamic Mechanical Properties of PLA Bio-Composite with Hybrid Reinforcement of Flax and Jute." *Materials Today: Proceedings* 25: 577–80.

Martini, Endri Roshetko, James M. van Noordwijk, Meine Rahmanulloh, Arif Mulyoutami, Elok Joshi, Laxman Budidarsono, Suseno. 2012. "Sugar Palm (Arenga Pinnata (Wurmb) Merr.) for Livelihoods and Biodiversity Conservation in the Orangutan Habitat of Batang Toru, North Sumatra, Indonesia: Mixed Prospects for Domestication." *Agroforestry Systems* 86(3): 401–17.

Mazani, N. Sapuan, S. M. Sanyang, M. L. Atiqah, A. Ilyas, R. A.. 2019. "Design and Fabrication of a Shoe Shelf from Kenaf Fiber Reinforced Unsaturated Polyester Composites." *Lignocellulose for Future Bioeconomy* (May): 315–32.

Meon, Mohd Suhairil Othman, Muhamad Fauzi Husain, Hazran Remeli, Muhammad Fairuz Syawal, Mohd Syahar Mohd. 2012. "Improving Tensile Properties of Kenaf Fibers Treated with Sodium Hydroxide." *Procedia Engineering* 41(December): 1587–92.

Merlini, Claudia, Valdir Soldi, and Guilherme M.O. Barra. 2011. "Influence of Fiber Surface Treatment and Length on Physico-Chemical Properties of Short Random Banana Fiber-Reinforced Castor Oil Polyurethane Composites." *Polymer Testing* 30(8): 833–40.

© COPYRIGHT UPM

Miller, Sabbie A. 2018. “Natural Fiber Textile Reinforced Bio-Based Composites: Mechanical Properties, Creep, and Environmental Impacts.” *Journal of Cleaner Production* 198: 612–23.

Mishra, S. Mohanty, A. K. Drzal, L. T. Misra, M. Parija, S. Nayak, S. K. Tripathy, S. S.. 2003. “Studies on Mechanical Performance of Biofibre/Glass Reinforced Polyester Hybrid Composites.” *Composites Science and Technology* 63(10): 1377–85.

Misri, S, Leman, Z. Sapuan, S.M. and Ishak, M R. 2010. “Mechanical Properties and Fabrication of Small Boat Using Woven Glass/Sugar Palm Fibres Reinforced Unsaturated Polyester Hybrid Composite.” *IOP Conference Series: Materials Science and Engineering* 11: 012015.

Mogea, J., Seibert, B and Smits, W. 1991. “Multipurpose Palms: The Sugar Palm (Arenga Pinnata (Wurmb) Merr.).” *Agroforestry Systems* 13(2): 111–29.

Mohammed, A. A., D. Bachtiar, M. R.M. Rejab, and J. P. Siregar. 2018. “Effect of Microwave Treatment on Tensile Properties of Sugar Palm Fibre Reinforced Thermoplastic Polyurethane Composites.” *Defence Technology* 14(4): 287–90.

Mohanty, A K, M Misra, and L T Dreal. 2001. “Surface Modifications of Natural Fibres and Peformance of the Resulting Biocomposite.” *Composite Interfaces* 8(5): 313–43.

Mohd Hanafee Zin, Khalina Abdan, Mohd Nurazzi Norizan. 2019. “The Effect of Different Fiber Loading on Flexural and Thermal Properties of Banana/Pineapple Leaf (PALF)/Glass Hybrid Composite.” In *Structural Health Monitoring of Biocomposites, Fiber-Reinforced Composites and Hybrid Composites*, ed. Naheed Sab Mohammad Jawaid, Mohamed Thariq. United Kingdom.

Mohd Izwan, S., S. M. Sapuan, M. Y.M. Zuhri, and A. R. Mohamed. 2020. “Effects of Benzoyl Treatment on NaOH Treated Sugar Palm Fiber: Tensile, Thermal, and Morphological Properties.” *Journal of Materials Research and Technology* 9(3): 5805–14.

Mohd Nurazzi, N. Khalina, A. Sapuan, S. M. Ilyas, R. A. Ayu Rafiqah, S. Hanafee, Z. M.. 2019. “Thermal Properties of Treated Sugar Palm Yarn/Glass Fiber Reinforced Unsaturated Polyester Hybrid Composites.” *Journal of Materials Research and Technology* 9(2): 1606–18.

Mukaffa, Hubby Asrofi, Mochamad Sujito Asnawi Hermawan, Yuni Sumarji Qoryah, Rika Dwi Hidayatul Sapuan, S.M. Ilyas, R.A. Atiqah, A. 2021. “Effect of Alkali Treatment of Piper Betle Fiber on Tensile Properties as Biocomposite Based Polylactic Acid: Solvent Cast-Film Method.” *Materials Today: Proceedings*.

Mukhtar, Isma’ila, Zulkiflle Leman, Mohamad Ridzwan Ishak, and Edi Syams Zainudin. 2016. “Sugar Palm Fibre and Its Composites: A Review of Recent Developments.” *BioResources* 11(4): 10756–82.

© COPYRIGHT UPM

Mukhtar, Ismaila, Zulkiflle Leman, Edi Syams Zainudin, and Mohamad Ridzwan Ishak. 2019. "Hybrid and Nonhybrid Laminate Composites of Sugar Palm and Glass Fibre-Reinforced Polypropylene: Effect of Alkali and Sodium Bicarbonate Treatments." *International Journal of Polymer Science* 2019.

Munikenche Gowda, T., A. C.B. Naidu, and Rajput Chhaya. 1999. "Some Mechanical Properties of Untreated Jute Fabric-Reinforced Polyester Composites." *Composites Part A: Applied Science and Manufacturing* 30(3): 277–84.

Muthalagu, R., J. Murugesan, S. Sathees Kumar, and B. Sridhar Babu. 2021. "Tensile Attributes and Material Analysis of Kevlar and Date Palm Fibers Reinforced Epoxy Composites for Automotive Bumper Applications." *Materials Today: Proceedings* 46(xxxx): 433–38.

N. Mohd Nurazzi1, A. Khalina, S. M Sapuan, M. Rahmah. 2018. "Development of sugar palm yarn/glass fibre reinforced unsaturated polyester hybrid composites." *Materials Research Express* (IOP Publishing).

Nagaraja Ganesh B and Muralikannan R. 2016. "Physico-Chemical, Thermal, and Flexural Characterization of Cocos Nucifera Fibers Int. J. Polym. Anal. Charact." 21: 244–50.

Nampitch, Tarinee, Chanon Wiphanurat, Thiti Kaisone, and Pran Hanthanon. 2016. "Mechanical and Morphological Properties of Poly(Lactic Acid)/Bagasse Fiber Composite Foams." *Applied Mechanics and Materials* 851: 31–36.

Nanthakumar, Kuhananthan, Chan Ming Yeng, and Koay Seong Chun. 2020. "Tensile and Water Absorption Properties of Solvent Cast Biofilms of Sugarcane Leaves Fibre-Filled Poly(Lactic) Acid." *Journal of Thermoplastic Composite Materials* 33(3): 289–304.

Nayak, Subhakanta, and Jyotiranjan Mohanty. 2020. "Erosion Wear Behavior of Benzoyl Chloride Modified Areca Sheath Fiber Reinforced Polymer Composites." *Composites Communications* 18(July 2019): 19–25.

Negawo, Tolera A. et al. 2021. "Mechanical and Dynamic Mechanical Thermal Properties of Ensete Fiber/Woven Glass Fiber Fabric Hybrid Composites." *Composite Structures* 259(July 2020): 113221.

Norizan, Mohd Nurazzi, Khalina Abdan, Mohd Sapuan Salit, and Rahmah Mohamed. 2017. "Physical, Mechanical and Thermal Properties of Sugar Palm Yarn Fibre Loading on Reinforced Unsaturated Polyester Composites." *Journal of Physical Science* 28(3): 115–36.

Norizan, N. M., A. Atiqah, M. N. M. Ansari, and M. Rahmah. 2019. "Green Materials in Hybrid Composites for Automotive Applications." (December): 56–76.

Ochi, Shinji. 2008. "Mechanical Properties of Kenaf Fibers and Kenaf/PLA Composites." *Mechanics of Materials* 40(4–5): 446–52.

© COPYRIGHT UPM

Oksman, K., M. Skrifvars, and J. F. Selin. 2003. "Natural Fibres as Reinforcement in Polylactic Acid (PLA) Composites." *Composites Science and Technology* 63(9): 1317–24.

Prabowo, Anditya Endar, Kuncoro Diharjo, Ubaidillah, and Iwan Prasetiyo. 2019. "Sound Absorption Performance of Sugar Palm Trunk Fibers." *E3S Web of Conferences* 130: 1–9.

Prasad, Sodisetty V N B, G Akhil Kumar, K V Prudhvi Sai, and B Nagarjuna. 2019. "Design and Optimization of Natural Fibre Reinforced Epoxy Composites for Automobile Application Design and Optimization of Natural Fibre Reinforced Epoxy Composites for Automobile Application." 020016 (July).

Puspita, D., L. Musyarofah, E. Hidayah, and Sujito. 2019. "Fabrication and Tensile Properties of Bamboo Micro-Fibrils (BMF)/Poly-Lactic Acid (PLA) Green Composite." *Journal of Physics: Conference Series* 1217(1).

Qian, Mengxia Yang, Fangfang Li, Nan Gao, Junting Chen, Xiufang Xu, Tiefeng Zhu, Zhexin Lu, Wangyang Chen, Wenxing. 2021. "A Novel Biodegradable Porous Graphitic Carbon Nitride/Poly(Lactic Acid) Fiber Photocatalyst for Efficient Elimination of Carbamazepine under Solar Irradiation." *Chemical Engineering Journal* 414(February): 128845.

Radzi, A. M., S. M. Sapuan, M. Jawaid, and M. R. Mansor. 2019a. "Effect of Alkaline Treatment on Mechanical, Physical and Thermal Properties of Roselle/Sugar Palm Fiber Reinforced Thermoplastic Polyurethane Hybrid Composites." *Fibers and Polymers* 20(4): 847–55.

Radzi, A. M., S. M. Sapuan, M. Jawaid, and M. R. Mansor.. 2019b. "Water Absorption, Thickness Swelling and Thermal Properties of Roselle/Sugar Palm Fibre Reinforced Thermoplastic Polyurethane Hybrid Composites." *Journal of Materials Research and Technology* 8(5): 3988–94.

Radzi, A M, S M Sapuan, and M Jawaid. 2017. "Influence of Fibre Contents on Mechanical and Thermal Properties of Roselle Fibre Reinforced Polyurethane Composites." 18(7): 1353–58.

Rajesh, M, and Jeyaraj Pitchaimani. 2017. "Mechanical Characterization of Natural Fiber Intra-Ply Fabric Polymer Composites : Influence of Chemical Modifications."

Ramesh, P., B. Durga Prasad, and K. L. Narayana. 2020. "Effect of MMT Clay on Mechanical, Thermal and Barrier Properties of Treated Aloevera Fiber/ PLA-Hybrid Biocomposites." *Silicon* 12(7): 1751–60.

Rashid, Bushra et al. 2016. "Physicochemical and Thermal Properties of Lignocellulosic Fiber from Sugar Palm Fibers: Effect of Treatment." *Cellulose* 23(5): 2905–16.

© COPYRIGHT UPM

Rashid, Bushra Leman, Z. Jawaid, M.Ghazali, M. J. Ishak, M. R.. 2017. "Effect of Treatments on the Physical and Morphological Properties of SPF/Phenolic Composites." *Journal of Natural Fibers* 14(5): 645–57.

Ravi Theja Reddy, S., A. V. Ratna Prasad, and K. Ramanaiah. 2021. "Tensile and Flexural Properties of Biodegradable Jute Fiber Reinforced Poly Lactic Acid Composites." *Materials Today: Proceedings* 44: 917–21.

Ray, Krutibash Patra, Hemalata Swain, Anup Kumar Parida, Bibhudatta Mahapatra, Sourabh Sahu, Asit Rana, Suryakanta. 2020. "Glass/Jute/Sisal Fiber Reinforced Hybrid Polypropylene Polymer Composites: Fabrication and Analysis of Mechanical and Water Absorption Properties." *Materials Today: Proceedings* 33: 5273–78.

Road, Northumberland. 1989. "Diffusion of Moisture into Two-Phase Polymers Styrenated Polyester Resins." 24: 2343–47.

Roy, Rahul, and Abhijit Mukhopadhyay. 2020. "Tribological Studies of 3D Printed ABS and PLA Plastic Parts." *Materials Today: Proceedings* 41: 856–62.

Rozilah, A et al. 2020. "The Effects of Silver Nanoparticles Compositions on and Morphology Properties of Sugar Palm Starch Biocomposites for Antibacterial Coating." *MDPI, polymers*.

Ruzaidi, C. M., H. Kamarudin, J. B. Shamsul, and M. M.A. Abdullah Rafiza. 2012. "Mechanical Properties and Wear Behavior of Brake Pads Produced from Palm Slag." *Advanced Materials Research* 341–342(March 2021): 26–30.

Sapuan, S.M. R.A. Ilyas and S.F.K. Sherwani. "Advanced applications of sugar palm reinforced polymer composites." Tropicana, UPM. 2021

Saba, N., Mohammad Jawaid, M. T. Paridah, and O. Y. Al-othman. 2016. "A Review on Flammability of Epoxy Polymer, Cellulosic and Non-Cellulosic Fiber Reinforced Epoxy Composites." *Polymers for Advanced Technologies* 27(5): 577–90.

Safiee, Sahnizam Mazuki, Adlan Akram Mohammad Ishak, Zainal Ariffin Mohd Bakar, Azhar Abu. 2011. "Properties of Pultruded Jute Fiber Reinforced Unsaturated Polyester Composites." *Advanced Composite Materials* 20(3): 231–44.

Safri, Syafiqah N.A., Mohamed T.H. Sultan, Naheed Saba, and Mohammad Jawaid. 2018. "Effect of Benzoyl Treatment on Flexural and Compressive Properties of Sugar Palm/Glass Fibres/Epoxy Hybrid Composites." *Polymer Testing* 71(August): 362–69.

Safri, Syafiqah Nur Azrie, Mohamed Thariq Hameed Sultan, and Ain Umaira Md Shah. 2020. "Characterization of Benzoyl Treated Sugar Palm/Glass Fibre Hybrid Composites." *Journal of Materials Research and Technology* 9(5): 11563–73.

© COPYRIGHT UPM

Sahari, J., S. M. Sapuan, E. S. Zainudin, and M. A. Maleque. 2013. "Mechanical and Thermal Properties of Environmentally Friendly Composites Derived from Sugar Palm Tree." *Materials and Design* 49: 285–89.

Salisu, A. A., Musa, H., Yakasai, M. Y. and Aujara, K. M. 2015. "Effects of Chemical Surface Treatment on Mechanical Properties of Sisal Fiber Unsaturated Polyester Reinforced Composites." *ChemSearch Journal* 6(2): 8–13.

Sanyang, M L Sapuan, S. M. Jawaid, M. Ishak, M. R. Sahari, J.. 2016. "Recent Developments in Sugar Palm (Arenga Pinnata) Based Biocomposites and Their Potential Industrial Applications : A Review." *Renewable and Sustainable Energy Reviews* 54: 533–49.

Sapiai, Napisah, Aidah Jumahat, and Jamaluddin Mahmud. 2015. "Flexural and tensile properties of kenaf /glass fibres hybrid composites." *Jurnal Teknologi* 3: 115–20.

Sapuan, S. M., and R.A. Ilyas. 2018a. "Characterization of Sugar Palm Nanocellulose and Its Potential for Reinforcement with a Starch-Based Composite." *Sugar Palm Biofibers, Biopolymers, and Biocomposites*: 189–220.

Sapuan, S. M., and R.A. Ilyas. 2018b. "Development of Sugar Palm–Based Products: A Community Project." *Sugar Palm Biofibers, Biopolymers, and Biocomposites*: 245–66.

Sapuan, S.M., and D. Bachtiar. 2012. "Mechanical Properties of Sugar Palm Fibre Reinforced High Impact Polystyrene Composites." *Procedia Chemistry* 4(May 2014): 101–6.

Saxena, Dipti, and Pralay Maiti. 2021. "Utilization of ABS from Plastic Waste through Single-Step Reactive Extrusion of LDPE/ABS Blends of Improved Properties." *Polymer* 221(December 2020).

Schnurr, Riley E.J. Alboiu, Vanessa Chaudhary, Meenakshi Corbett, Roan A. Quanz, Meaghan E. Sankar, Karthikeshwar Srain, Harveer S. Thavarajah, Venukasan Xanthos, Dirk Walker, Tony R.. 2018. "Reducing Marine Pollution from Single-Use Plastics (SUPs): A Review." *Marine Pollution Bulletin* 137(May): 157–71.

Serizawa, Shin, Kazuhiko Inoue, and Masatoshi Iji. 2006. "Kenaf-Fiber-Reinforced Poly(Lactic Acid) Used for Electronic Products." *Journal of Applied Polymer Science* 100(1): 618–24.

Shalwan, A., and B. F. Yousif. 2013. "In State of Art: Mechanical and Tribological Behaviour of Polymeric Composites Based on Natural Fibres." *Materials and Design* 48: 14–24.

Shaniba, V. Sreejith, M. P. Aparna, K. B. Jinitha, T. V. Purushothaman, E.. 2017. "Mechanical and Thermal Behavior of Styrene Butadiene Rubber Composites Reinforced with Silane-Treated Peanut Shell Powder." *Polymer Bulletin* 74(10): 3977–94.

© COPYRIGHT UPM

Sharba, Mohaiman J. Leman, Zulkiflle Sultan, M. T.H. Ishak, Mohamad R. Azmah Hanim, Mohammad A.. 2016. "Effects of Kenaf Fiber Orientation on Mechanical Properties and Fatigue Life of Glass/Kenaf Hybrid Composites." *BioResources* 11(1): 1448–65.

Shibata, Mitsuhiro Ozawa, Koichi Teramoto, Naozumi Yosomiya, Ryutoku Takeishi, Hiroyuku. 2003. "Biocomposites Made from Short Abaca Fiber and Biodegradable Polyesters." *Macromolecular Materials and Engineering* 288(1): 35–43.

Shih, Yeng Fong Chang, Wen Chieh Liu, Wei Chen Lee, Chuan Chen Kuan, Ching San Yu, Yi Hsiuan. 2014. "Pineapple Leaf/Recycled Disposable Chopstick Hybrid Fiber-Reinforced Biodegradable Composites." *Journal of the Taiwan Institute of Chemical Engineers* 45(4): 2039–46.

Shivamurthy, B., K. Murthy, P. C. Joseph, K. Rishi, K. U. Bhat, and S. Anandhan. 2015. "Waste Management Mechanical Properties and Sliding Wear Behavior of Jatropha Seed Cake Waste/Epoxy Composites." *Journal of Material Cycles* 17:144–56.

Shrivastava, Nilesh Kumar, Ooi Shu Wooi, Azman Hassan, and Ibrahim Mohammed Inuwa. 2018. "Mechanical and Flammability Properties of Poly(Lactic Acid)/Poly(Butylene Adipate-Co-Terephthalate) Blends and Nanocomposites: Effects of Compatibilizer and Graphene." *Malaysian Journal of Fundamental and Applied Sciences* 14(4): 425–31.

Shukor, Faseha Hassan, Azman Hasan, Mahbub Islam, Md Saiful Mokhtar, Munirah. 2014. "PLA/Kenaf/APP Biocomposites: Effect of Alkali Treatment and Ammonium Polyphosphate (APP) on Dynamic Mechanical and Morphological Properties." *Polymer - Plastics Technology and Engineering* 53(8): 760–66.

Siakeng, R. Jawaid, M. Asim, M. Saba, N. Sanjay, M. R. Siengchin, S. Fouad, H.. 2020. "Alkali Treated Coir/Pineapple Leaf Fibres Reinforced Pla Hybrid Composites: Evaluation of Mechanical, Morphological, Thermal and Physical Properties." *Express Polymer Letters* 14(8): 717–30.

Siakeng, Ramengmawii Jawaid, Mohammad Ariffin, Hidayah Sapuan, S. M. Asim, Mohammad Saba, Naheed. 2019. "Natural Fiber Reinforced Polylactic Acid Composites: A Review." *Polymer Composites* 40(2): 446–63.

Singha, A. S., and Ashvinder K. Rana. 2012. "A Study on Benzoylation and Graft Copolymerization of Lignocellulosic Cannabis Indica Fiber." *Journal of Polymers and the Environment* 20(2): 361–71.

Singhaa, Amar Singh, and Vijay Kumar Thakura. 2008. "Fabrication and Study of Lignocellulosic Hibiscus Sabdariffa Fiber Reinforced Polymer Composites." *BioResources* 3(4): 1173–86.

Siregar, J.P. Zalinawati, M. Cionita, T. Rejab, M.R.M. Mawarnie, I. Jaafar, J. Hamdan, M.H.M. 2021. "Mechanical Properties of Hybrid Sugar Palm/Ramie Fibre Reinforced Epoxy Composites." *Materials Today: Proceedings* 46: 1729–34.

© COPYRIGHT UPM

Siregar, Januar Parlaungan. 2015. “Tensile and Flexural Properties of Arenga Pinnata Filament (Ijuk Filament) Reinforced Epoxy Composites tensile and flexural properties of arenga pinnata filament (ijuk filament) reinforced epoxy composites By Thesis Submitted to the School of Graduate.” (January 2005).

Sreekumar, P. A., Kuruvilla Joseph, G. Unnikrishnan, and Sabu Thomas. 2007. “A Comparative Study on Mechanical Properties of Sisal-Leaf Fibre-Reinforced Polyester Composites Prepared by Resin Transfer and Compression Moulding Techniques.” *Composites Science and Technology* 67(3–4): 453–61.

Sukmawan, Romi, Hitoshi Takagi, and Antonio Norio Nakagaito. 2016. “Strength Evaluation of Cross-Ply Green Composite Laminates Reinforced by Bamboo Fiber,” Compos. Part B Eng., Vol. 84, Pp. 9–16, 2016.Trength Evaluation of Cross-Ply Green Composite Laminates Reinforced By.” *Composites Part B: Engineering* 84: 9–16.

Suriani, M. J. Sapuan, S. M. Ruzaidi, C. M. Nair, D. S. Ilyas, R. A.. 2021. “Flammability, Morphological and Mechanical Properties of Sugar Palm Fiber/Polyester Yarn-Reinforced Epoxy Hybrid Biocomposites with Magnesium Hydroxide Flame Retardant Filler.” *Textile Research Journal*.

Swain, Priyadarshi Tapas Ranjan, and Sandhyarani Biswas. 2017. “Influence of Fiber Surface Treatments on Physico-Mechanical Behaviour of Jute/Epoxy Composites Impregnated with Aluminium Oxide Filler.” *Journal of Composite Materials* 51(28): 3909–22.

Swain, Priyadarshi Tapas Ranjan, Sankar Narayan Das, and Shakti Prakash Jena. 2018. “Manufacturing and Study of Thermo-Mechanical Behaviour of Surface Modified Date Palm Leaf/Glass Fiber Reinforced Hybrid Composite.” *Materials Today: Proceedings* 5(9): 18332–41.

Syafiq, Razali M.O., Salit M. Sapuan, and Mohd R.M. Zuhri. 2020. “Effect of Cinnamon Essential Oil on Morphological, Flammability and Thermal Properties of Nanocellulose Fibre-Reinforced Starch Biopolymer Composites.” *Nanotechnology Reviews* 9(1): 1147–59.

Tawakkal, Intan Syafinaz M.A., Rosnita A. Talib, Khalina Abdan, and Chin Nyuk Ling. 2012. “Mechanical and Physical Properties of Kenaf-Derived Cellulose (KDC)-Filled Polylactic Acid (PLA) Composites.” *BioResources* 7(2): 1643–55.

Thiruchitrambalam, M., and D. Shanmugam. 2012. “Influence of Pre-Treatments on the Mechanical Properties of Palmyra Palm Leaf Stalk Fiber-Polyester Composites.” *Journal of Reinforced Plastics and Composites* 31(20): 1400–1414.

Uzunov, I., S. Uzunova, D. Angelova, and A. Gigova. 2012. “Effects of the Pyrolysis Process on the Oil Sorption Capacity of Rice Husk.” *Journal of Analytical and Applied Pyrolysis* 98: 166–76.

© COPYRIGHT UPM

Venkateshwaran, N., A. Elayaperumal, and G. K. Sathiya. 2012. "Prediction of Tensile Properties of Hybrid-Natural Fiber Composites." *Composites Part B: Engineering* 43(2): 793–96.

Verma, Rajneesh, Mukul Shukla, and Dharmendra Kumar Shukla. 2021. "Effect of Glass Fibre Hybridization on the Water Absorption and Thickness of Alkali Treated Kenaf-Epoxy Composites." *Materials Today: Proceedings* 44: 2093–96.

Vigneshwaran, S. Sundarakannan, R. John, K. M. Joel Johnson, R. Deepak Prasath, K. Arun Ajith, S. Arumugaprabu, V. Uthayakumar, M.. 2020. "Recent Advancement in the Natural Fiber Polymer Composites: A Comprehensive Review." *Journal of Cleaner Production* 277: 124109.

Vinod, A. Vijay, R. Manoharan, S. Vinod, A. Lenin Singaravelu, D. Sanjay, M. R. Siengchin, Suchart. 2019. "Characterization of Raw and Benzoyl Chloride Treated Impomea Pes-Caprae Fibers and Its Epoxy Composites." *Materials Research Express* 6(9).

Wahyuni, Ade Sri, and Elhusna. 2016. "The Tensile Behaviour of Concrete with Natural Fiber from Sugar Palm Tree." *International Conference on Engineering and Science for Research and Development (ICESReD)*: 15–18.

Wang, Guilong, Dongmei Zhang, Gengping Wan, 2019. "Glass Fiber Reinforced PLA Composite with Enhanced Mechanical Properties, Thermal Behavior, and Foaming Ability." *Polymer* 181(July).

Wang, Guilong, Dongmei Zhang, Bo Li, 2019. "Strong and Thermal-Resistance Glass Fiber-Reinforced Polylactic Acid (PLA) Composites Enabled by Heat Treatment." *International Journal of Biological Macromolecules* 129: 448–59.

Wang, Xiaomeng, Michal Petrů, and Hang Yu. 2019. "The Effect of Surface Treatment on the Creep Behavior of Flax Fiber Reinforced Composites under Hygrothermal Aging Conditions." *Construction and Building Materials* 208: 220–27.

Wattanachai, Piyachat, Benjawan Buasathain, Christian Antonio, and Susan Roces. 2017. "Open Loop Recycling of Recycled Polypropylene for Motorcycle Saddle Application." *ASEAN Journal of Chemical Engineering* 17(2): 60–76.

Wu, Yingji Xia, Changlei Cai, Liping Garcia, Andres C. Shi, Sheldon Q.. 2018. "Development of Natural Fiber-Reinforced Composite with Comparable Mechanical Properties and Reduced Energy Consumption and Environmental Impacts for Replacing Automotive Glass-Fiber Sheet Molding Compound." *Journal of Cleaner Production* 184: 92–100.

Xu, Zhenzhen Yang, Li Ni, Qignqing Ruan, Fangtao Wang, Hao. 2019. "Fabrication of High-Performance Green Hemp/Polylactic Acid Fibre Composites." *Journal of Engineered Fibers and Fabrics* 14.

© COPYRIGHT UPM

Yusoff, Rosni Binti, Hitoshi Takagi, and Antonio Norio Nakagaito. 2016. “Tensile and Flexural Properties of Polylactic Acid-Based Hybrid Green Composites Reinforced by Kenaf, Bamboo and Coir Fibers.” *Industrial Crops and Products* 94: 562–73.

Zahari, W. Z.W. Badri, R. N.R.L. Ardyananta, H. Kurniawan, D. Nor, F. M.. 2015. “Mechanical Properties and Water Absorption Behavior of Polypropylene / Ijuk Fiber Composite by Using Silane Treatment.” *Procedia Manufacturing* 2(February): 573–78.

Zamri, Mohd Hafiz Akil, Hazizan Md Bakar, Azhar Abu Ishak, Zainal Arifin MohdCheng, Leong Wei. 2012. “Effect of Water Absorption on Pultruded Jute/Glass Fiber-Reinforced Unsaturated Polyester Hybrid Composites.” *Journal of Composite Materials* 46(1): 51–61.

Zhang, Yuan Yuan Sun, Zheng Li, Yuan Qing Huang, Pei Chen, Qing Fu, Shao Yun. 2021. “Tensile Creep Behavior of Short-Carbon-Fiber Reinforced Polyetherimide Composites.” *Composites Part B: Engineering* 212(September 2020): 108717.

© COPYRIGHT UPM