MECHANICAL, PHYSICAL AND THERMAL PROPERTIES OF NATURAL FIBRE REINFORCED EPOXY COMPOSITES

BY

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ABSTRACT

There has been expanded effort to offer eco-friendly and biodegradable materials for the next generation of automotive applications due to global environmental concerns and increased awareness of renewable green resources. Currently, polystyrene foam has been used as one of the core insulation material in refrigerated vehicle body which is non-biodegradable and highly polluting resource. There were limited study on utilizing natural fibre in refrigerated vehicle application. Thus, to fill this research gap, current efforts are being made to produce biodegradable and renewable resource composites with the use of palm oil fibre and kenaf fibre in the epoxy resin as a matrix constituent. The objectives of this study were to fabricate palm oil fibre and kenaf fibre reinforced epoxy resin via vacuum infusion techniques based on volume fraction of fibres and alkaline treatment. Then, tensile, water absorption, thermal conductivity and morphologies properties were evaluated and compared with the existing core insulation material (polystyrene foam). As such, the natural fibre composite was fabricated based on two parameters, namely fibre content (20, 30, and 40 vol.%) and 5 w/v% of NaOH solution using vacuum infusion method. The mechanical, physical and thermal properties of fabricated untreated and treated palm oil fibre (UPOF and TPOF) as well as kenaf fibre (UKF and TKF) composites were investigated. From the viewpoint of mechanical performance, 40TPOF showed the highest tensile strength and tensile modulus with the values of 35.89 MPa and 6.39 GPa, respectively. Alkaline treated fibre composite is indeed has increased the values of tensile strength and tensile modulus. It has been proven by the good interfacial adhesion between fibres and matrix detected by SEM morphology. Meanwhile, from the physical perspective, 20TPOF was found to have the lowest water absorption with the values of 1.43%. The use of treated composites increases the number of possible reaction sites on the surface of the fibre and promotes better interfacial bonding within the composite. Fibre adhesion is improved, resulting in dimensionally stable structures. As a result, no voids were observed by using the optical microscope. Besides, the lowest thermal conductivity was 40UPOF with value of 0.079 W/mK. The study of these materials leads to the conclusion that increasing the fibre loading reduces the thermal conductivity of a composite material. The fabrication of the suggested parameters was performed where the obtained values are compared with values of the polystyrene foam. 20TPOF was found to be the most suitable core insulation material with the tensile strength, tensile modulus, water absorption, thermal conductivity values of 25.37 MPa, 3.88 GPa, 1.43% and 0.098 W/mK, respectively. The tensile strength, tensile modulus, and water absorption values have been improved by 97.64%, 99.38%, and 4.67%, respectively compared to the polystyrene foam. Meanwhile, the thermal values obtained for 20TPOF was considered as one of the insulator material. Therefore, this study offers the great potential of the utilization of palm oil fibre and kenaf fibre composites in automotive applications, specifically the core insulation material of refrigerated vehicle body.

ملخّص البحث

كان هناك جهد موسع لتقديم مواد صديقة للبيئة وقابلة للتحلل الحيوي للجيل القادم من تطبيقات السيارات بسبب المخاوف البيئية العالمية وزيادة الوعي بالموارد الخضراء المتجددة. حاليًا ، تم استخدام رغوة البوليسترين كواحدة من مواد العزل الأساسية في جسم السيارة المبردة ، وهي مورد غير قابل للتحلل البيولوجي وشديد التلوث. كانت هناك دراسة محدودة حول استخدام الألياف الطبيعية في تطبيقات المركبات المبردة. وبالتالي لسد هذه الفجوة البحثية ، تُبذل الجهود الحالية لإنتاج مركبات الموارد القابلة للتحلل والمتجددة باستخدام ألياف زيت النخيل وألياف التيل في راتنجات الايبوكسي كمكون مصفوفة. هدفت هذه الدراسة إلى تصنيع ألياف زيت النخيل وراتنج الإيبوكسي المعزز بألياف التيل من خلال تقنيات التسريب بالتفريغ بناءً على الجزء الحجمي للألياف والمعالجة القلوية. بعد ذلك ، تم تقييم خصائص الشد وامتصاص الماء والتوصيل الحراري والتشكيلات ومقارنتها مع مادة العزل الأساسية الموجودة (رغوة البوليسترين). تم تصنيع مركب الألياف الطبيعية بناءً على معاملين ، وهما محتوى الألياف (20 ، 30 ، و 40 حجمًا٪) و 5 وزن / حجم٪ من محلول هيدروكسيد الصوديوم باستخدام طريقة التسريب بالتفريغ. تم فحص الخواص الميكانيكية والفيزيائية والحرارية لألياف زيت النخيل المصنعة غير المعالجة والمعالجة (UPOF و TPOF) ، وكذلك مركبات ألياف التيل (UKF و TKF). من وجهة نظر الأداء الميكانيكي ، أظهر 40TPOF أعلى قوة شد ومعامل شد بقيمتين 35.89 ميجا باسكال و 6.39 جيجا باسكال على التوالي. مركب الألياف القلوية المعالج بالفعل قد زاد من قيم قوة الشد ومعامل الشد. لقد تم إثبات ذلك من خلال الالتصاق البيني الجيد بين الألياف والمصفوفة التي تم الكشف عنها بواسطة مورفولوجيا SEM. وفي الوقت نفسه ، من الناحية الفيزيائية ، وجد أن 20TPOF لديها أقل امتصاص للماء بقيم 1.43٪. يزيد استخدام المركبات المعالجة من عدد مواقع التفاعل المحتملة على سطح الألياف ويعزز الترابط البيني داخل المركب. نتيجة لذلك ، تم تحسين الالتصاق بالألياف ، مما ينتج عنه هياكل ثابتة الأبعاد. نتيجة لذلك ، لم يتم ملاحظة أي فراغات باستخدام المجهر

الضوئي. إلى جانب ذلك ، كان 40UPOF أقل موصلية حرارية بقيمة 0.079 واط / مللي كلفن. خلصت دراسة هذه المواد إلى أن زيادة تحميل الألياف يقلل من التوصيل الحراري للمادة المركبة. تم إجراء تصنيع المعلمات المقترحة حيث تمت مقارنة القيم التي تم الحصول عليها مع قيم رغوة البوليسترين. 20TPOF كانت أنسب مادة عازلة أساسية مع قوة الشد ، معامل الشد ، امتصاص الماء ،و قيم التوصيل الحراري 25.37 ميجا باسكال ، 3.88 جيجا باسكال ، 1.43٪ و 0.098 واط / مللي كلفن على التوالي. بالمقارنة مع رغوة البوليسترين ، تم تحسين قيم مقاومة الشد ومعامل الشد وامتصاص الماء بنسبة 97.64٪ و 99.38٪ و 4.67٪ على التوالي. وفي الوقت نفسه ، تم اعتبار القيم الحرارية التي تم الحصول عليها لـ 20TPOF كواحدة من مواد العازل. لذلك ، توفر هذه الدراسة إمكانات كبيرة لاستخدام ألياف زيت النخيل ومركبات ألياف التيلف في تطبيقات السيارات ، وتحديداً مادة العزل الأساسية لهيكل المركبات المبردة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Mechanical Engineering)

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
DSC	Differential Scanning Calorimetry
FTIR	Fourier Transform Infra-Red
EFB	Empty Fruit Bunch
EPA	Environmental Protection Agency
EPS	Expanded Polystyrene
H_2O	Chemical formula of water
HIPS	High Impact Polystyrene
MPOB	Malaysian Palm Oil Board
Na	Sodium
N_2	Chemical formula of nitrogen
NaOH	Sodium Hydroxide
OH	Hydroxide
OPEFB	Oil Palm Empty Fruit Bunch
OPPF	Oil Palm Press Fibre
Pd	Palladium
PLA	Polylactic Acid
PU	Polyurethane
PS	Polystyrene
RM	Ringgit Malaysia
RTM	Resin Transfer Moulding
TPOF	Treated Palm Oil Fibre
TKF	Treated Kenaf Fibre
T_c	Crystallisation Temperature

T_g	Glass Transition Temperature
T_m	Melting Temperature
UPOF	Untreated Palm Oil Fibre
UKF	Untreated Kenaf Fibre
UTM	Universal Testing Machine
SEM	Scanning Electron Microscope

LIST OF SYMBOLS

%	Percentage
ρ	Density
cm	Centimetre
λ	Thermal conductivity
cm^3	Centimetre cube
℃	Degree Celsius
C	Carbon
G	Gram
GPa	Giga Pascal
g/cm^3	Gram per centimetre cube
h	Hour
H	Hydrogen
kg/m^3	Kilogram per metre cube
kPa	Kilo Pascal
kV	Kilo Voltage
kN	Kilo Newton
K	Thermal conductivity
m	Meter
ml	Millilitre
mm	Millimetre
ml/min	Millimetre per minute
MPa	Mega Pascal
O	Oxygen
Psi	Pounds per square inch

vol.%	Volume percent
W	Watt
w/v%	Weight by volume percent
wt.%	Weight percent

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

In recent years, natural fibre as reinforcement which include plant fibres and wood fibres has increased dramatically and has become more essential. This is due to natural fibre is a renewable resource and it has been discovered and used because non-renewable resources are becoming scarce (Gholampour & Ozbakkaloglu, 2020). Animals, vegetables as well as minerals are obtained and they are produced into a class of hair-like materials and they are called natural fibres. Some of them spun into filaments, thread, or rope. Besides that, they can be utilized as reinforcements and will be embedded in matrix to form fibrous composites (Bhardwaj et al., 2015). A composite material is defined as materials that are made up off two or more materials, each of them has various type of physical as well as chemical properties. However, when it is combined, it will form a new material with some different characteristics from the individual material (Nagavally, 2017).

Currently, producing automotive components from natural fibre composites are already exists in the manufacturing industry (Ramli et al., 2018). Germany was one of the pioneer in utilizing natural fibre composites for interior and exterior of car applications. For instance, the inner door panel was first introduced in 1999 of the S-Class MercedezBenz (Koronis et al., 2013). Furthermore, epoxy matrix with the addition of jute was used for the door panels in its E-class vehicles of the Mercedez Benz back in 1996 (Foisal et al., 2009). In 2008, another development was announced at the EcoInnovAsia 2008 event held in Bangkok, Thailand which was related to Mazda

5. The manufacturer used polylactic acid (PLA) for the interior consoles with PLA and kenaf fibre in the seat covers (Broeren et al., 2017). Besides that, door panels of the car Ford Mondeo in UK, are made of kenaf fibre and polypropylene resins. Hence, by utilizing kenaf fibre as a door panel could reduce the mass of the door from 5% to 10% (Jović & Milićević, 2017). However, there were limited research on utilizing natural fibre composites in exterior automotive components especially in the refrigerated vehicle wall.

The temperature controlled vehicles are called refrigerated vehicles that are used to transport raw food and food products for instance, dairy products, meats and ice-creams from the farm of producer to the market customers (Baartmans, 2015; Isaksson et al., 2016;). The purpose of refrigerated vehicles is to maintain the chilling temperature that avoids shelf life spoilage while cooling chamber provides cooling. Refrigerated vehicle's body is made up of insulating material sandwiched in two metal sheets of aluminium or steel (Beukers et al., 1999; Heisler, 2002; Tassou et al., 2009). Insulation material such as polyurethane foam and polystyrene foam are mostly used as insulation material because it helps to preserve the temperature in the panel outer surface (Al-Homoud, 2005; Baetens et al., 2010; Yang et al., 2015; Ravago, 2020). However, polyurethane and polystyrene are non-renewable and non-biodegradable resources. Polyurethanes (PU) are derived from the petrochemical industry and are generally synthesized by the polyols (Lligadas et al., 2010; Kong et al., 2012; Cinelli et al., 2013) while polystyrene (PS) is a durable thermoplastic that is generally believed to be non-biodegradable (Kaplan et al., 1979; Ho et al., 2018). It is always a critical job for researchers to overcome the environmental issues by using non-biodegradable materials (Chang and Lu, 2012; Fan et al., 2012; Spontón et al., 2013). Thus, in this research, natural fibres such as kenaf fibres and palm oil fibres were used as one of the potential insulation materials due to their biodegradable and renewable resources.

There are various of factors that needed to be taken into account when designing insulation core material of refrigerated truck bodies. The vehicles must be insulated effectively by having low thermal conductivity as they are designed to transport easily-perishable food (Uwa. et al., 2019; Ravago, 2020). Besides that, the core material must be capable to withstand high mechanical force when loaded with heavy cargo loads, during loading and unloading (Ravago, 2020). In addition, refrigerated vehicle walls required low moisture pick up in order to prevent any damages to the exterior or interior that may occur during on or off-loading as well as daily services. The moisture resistance of the core insulation material can have a significant impact on long term insulation performance of truck panels (Ravago, 2020). As a result, the goal of this study is to use kenaf fibre composites and palm oil fibre composites as a replacement for polystyrene foam used for core insulation materials in refrigerated vehicles, with the potential for low thermal conductivity, high tensile properties, and low water absorption behaviour.

1.2 PROBLEM STATEMENT

More sustainable developments in automotive industry was in demands due to fuel-efficient and low polluting vehicles revolutions. A lot of studies indicated that the car industry had utilized natural fibres as the developments in the automotive industry. For instance, flax, kenaf, hemp and jute and these were basically used and to be applied within the passenger cars (Dammer et al., 2013). On top of that, natural fibre composites have been used in interior automotive components for instance interior door panel, headliners, seatbacks and package trays (Tholibun et al., 2019). However, there were limited research on utilizing natural fibre composites in exterior automotive components especially in the refrigerated vehicle wall.

Generally, refrigerated vehicle wall which takes the shape of a box and is made up of insulating material sandwiched in two metal sheets of aluminium or steel (Heisler, 2002; Tassou et al., 2009; Ravago, 2020). Insulation material that is being used the most is polystyrene foam or is also known as a core material (Yang et al., 2015; Ravago, 2020). Polystyrene (PS) is a petroleum-based plastic made from styrene (vinyl benzene) monomer and it is generally believed to be non-biodegradable (Ho et al., 2018). Otake

Therefore, in this work, kenaf fibre and oil palm empty fruit bunch fibre (EFB) were used due to their low cost, biodegradable and found abundance in Malaysia (Yousif et al., 2012; Faruk et al., 2012). Moreover, the utilization of EFB which is a by-product of palm oil refinery can ease the agricultural waste disposal issue and kenaf fibre has been well known for its long history as reinforcement in polymer composites (Akil et al., 2011). However, the susceptibility of natural fibre towards moisture absorption is one of the drawbacks that restricts the use of natural fibre as reinforcement in composites (Alamri et al., 2012). This is due to their hydrophilic characteristic as they tend to absorb moisture from the environment and swell. Hence, the presence of voids at the fibre-matrix interface which consequently lead to reduction of mechanical and physical properties (Ngo et al., 2014). Alkaline treatment by using sodium hydroxide was used in this work to treat the fibres in order to improve the interfacial adhesion between the fibre and matrix (Majid et al., 2016).

Besides that, the mechanical and physical properties of producing insulating core material from the refrigerated truck bodies were good thermal insulation, low water absorption and high mechanical strength properties (Ravago, 2020). Thus, in this study, the mechanical and physical properties of natural fibre composites were investigated in