UNIVERSITI PUTRA MALAYSIA

EXPERIMENTAL ANALYSIS OF UNIDIRECTIONAL OIL PALM EMPTY FRUIT BUNCH FIBRE-REINFORCED POLYMER COMPOSITES AND CRASH PERFORMANCE USING FINITE ELEMENT METHOD

CIK SUHANA BINTI HASSAN

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By

CIK SUHANA BINTI HASSAN

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

September 2018

This humble thesis is dedicated to:

My parent;
Hassan Bin Nayan and Patimah Binti Din

My husband;
Adi Akmal Bin Nasrul Hisham

My children;
Nur Adriana Sufi and Adrian Sulhi

whom constantly encouraged me to pursue my dreams and loved me unconditionally.

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

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Chairman : Professor Mohd Sapuan Bin Salit, PhD, Ir.
Faculty : Engineering

The overall objective of this research was to analyze the mechanical properties of unidirectional oil palm empty fruit bunch (OPEFB) fibre reinforced polymer composites and simulating their impact failure response using finite element analysis. The work has primarily focused on the fabrication of unidirectional OPEFB fibre reinforced polymer composites using hand lay-up and compression moulding technique employing Epoxy resin and Polypropylene (PP), respectively. The mechanical properties of the OPEFB fibre/polymer composite have been experimentally characterized by varying the fibre orientation angle by 0°, 45° and 90°. Fibre weight ratio was varied by 25%, 35% and 45% for OPEFB fibre/PP composite. Tensile, flexural and impact strength test conducted in accordance to ASTM D638, ASTM D70 and ASTM D6110, respectively. Superior tensile and flexural strengths were observed for the unidirectional OPEFB fibre/epoxy composite with 0° fibre orientation angle, with increases by of around 30% and 216%, respectively, as compared to pure epoxy. Unidirectional OPEFB fibre/PP composites with fibre loading of 35% and 0° fibre orientation was observed to provide the highest tensile strength. There was an increase of around 130% in the tensile strength as compared to pure PP. The greatest resistance to flexural and impact on the other hand were depicted by the 0° oriented OPEFB fibre/PP composites with fibre loading of 25% and 45%, respectively. The flexural and impact strength were found to be better by 328% and 52%, respectively as compared to pure PP. A finite element modeling was developed for predicting the behavior of the OPEFB fibre/polymer composite using the MAT 54/55 material model that is implemented in the LS-DYNA explicit finite element code. The finite element results were validated against the experimental finding. Good correlations with error lesser by 15% were observed between the simulation and the experimental results. Crash performance of the OPEFB fibre/polymer composite as bumper material has been investigated using finite element analysis. The crash was conducted as frontal impact collision with low velocity impact of 4 km/hr. The specific energy absorption (SEA) of the composites bumper part was found to be comparable with the conventional material

used for the bumper. The SEA performance of the unidirectional OPEFB fibre/epoxy composites bumper beam was found to be improved by of around 52% as compared to the conventional Aluminum bumper beam. It was also found that there was an increase by 8.34% in the SEA performance of the unidirectional OPEFB fibre/PP composites bumper fascia as compared to pure PP bumper fascia.

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

ANALISIS MEKANIKAL UNTUK POLIMER KOMPOSIT DIPERKUAT-GENTIAN TANDAN BUAH KELAPA SAWIT KOSONG SECARA SEARAH DAN PRESTASI PERLANGGARAN MENGGUNAKAN KAEDAH UNSUR TERHINGGA

Oleh

CIK SUHANA BINTI HASSAN

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Pengerusi : Professor Mohd Sapuan Bin Salit, PhD, Ir.
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Secara keseluruhan, kajian ini bertujuan mengkaji ciri-ciri mekanikal polimer komposit diperkuat gentian tandan buah kelapa sawit kosong (OPEFB) secara searah dan mensimulasikan tindak balas bahan tersebut kepada hentaman menggunakan kaedah unsur terhingga. Kajian ini melibatkan penghasilan komposit polimer diperkuat gentian OPEFB menggunakan teknik bengkalai tangan untuk komposit berdasarkan Epoxy dan acuan mampatan untuk komposit berdasarkan Polypropylene (PP). Ciri-ciri mekanikal untuk komposit gentian OPEFB/polimer telah dikaji secara eksperimen dengan sudut darjah orientasi yang berbeza iaitu 0°, 45° dan 90°. Nisbah berat kandungan gentian OPEFB untuk komposit gentian OPEFB/PP bervariasi 25%, 35% dan 45%. Ujian kekuatan tegangan, lenturan dan impak masing-masing telah dijalankan mengikut dimensi yang ditentukan dalam ASTM D638, ASTM D70 dan ASTM D6110. Kekuatan tegangan dan lenturan lebih unggul diperhatikan untuk komposit dengan sudut darjah 0° bagi gentian OPEFB/epoxy dengan pertambahan lebih kurang 30% dan 216%, masing-masing, dibandingkan dengan epoxy tulen. Bagi komposit gentian OPEFB/PP, kandungan gentian 35% didapati menghasilkan kekuatan tegangan tertinggi. Terdapat pertambahan sebanyak lebih kurang 130% pada komposit kekuatan tegangan dibandingkan dengan PP tulen. Sementara itu, kandungan gentian sebanyak 25% dan 45% juga dengan sudut darjah 0°, masing-masing, didapati memberikan rintangan terbesar kepada beban lenturan dan impak. Kekuatan lenturan dan impak didapati lebih baik sebanyak lebih kurang 328% dan 52%, masing-masing dibandingkan dengan PP tulen. Pemodelan telah dihasilkan untuk meramalkan perilaku gentian komposit OPEFB/polimer menggunakan model bahan MAT 54/55 yang telah dicipta dalam perisian LS-DYNA. Keputusan simulasi telah dibandingkan dengan keputusan eksperimen. Kolerasi yang baik telah diperhatikan di antara keputusan simulasi dan eksperimen dengan peratusan ralat kurang dari 15%. Prestasi perlanggaran komposit gentian OPEFB/polimer sebagai bahan untuk bampar telah dikaji menggunakan kaedah unsur terhingga. Simulasi perlanggaran tersebut telah dijalankan

sebagai perlanggaran berhadapan dengan halaju rendah sebanyak 4 km/jam. Penyerapan tenaga khusus (SEA) oleh komposit bampar tersebut didapati setanding dengan bahan konvensional yang digunakan sebagai bampar. Prestasi SEA untuk komposit gentian OPEFB/epoxy didapati lebih baik sebanyak lebih kurang 52% dibandingkan dengan rasuk bampar Aluminum. Prestasi SEA pada papan pemuka bampar juga didapati lebih baik sebanyak lebih kurang 8.34% bagi komposit gentian OPEFB/PP dibandingkan dengan papan pemuka bampar menggunakan PP tulen.

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I certify that a Thesis Examination Committee has met on 26 September 2018 to conduct the final examination of Cik Suhana binti Hassan on her thesis entitled "Experimental Analysis of Unidirectional Oil Palm Empty Fruit Bunch Fibre-Reinforced Polymer Composites and Crash Performance Using Finite Element Method" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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Name of Member of Supervisory Committee: Dr. Mohd Zuhri Bin Mohamed Yusoff

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
ABS	Anti-lock Braking System
CFE	Crash Force Efficiency
CFRP	Carbon Fibre Reinforced Plastic
E	Modulus of Elasticity
EA	Energy Absorption
EEVSC	European Enhanced Vehicle-safety Committee
ESC	Electronic Stability Control
FEA	Finite Element Analysis
FEM	Finite Element Method
FMVSS	Federal Motor Vehicle Safety Standards
HDPE	High Density Polyethylene
HLU	Hand Lay-up
MAPE	Maleic anhydride-g-polyethylene
NaOH	Sodium Hydroxide
NCAP	New Car Assessment Program
NHTSA	National Highway Traffic Safety Administration
OPEFB	Oil Palm Empty Fruit Bunch
PC	Polycarbonate
PLA	Polylactic Acid
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
ROM	Rules of Mixture
SEA	Specific Energy Absorption
SEM	Scanning Electron Microscopy
F_{mcf}	Mean Crash Forces
F_{peak}	Peak Crash Force

CHAPTER 1

INTRODUCTION

1.1 Background

Composite is defined as a mixture of dissimilar constituents. The combination results in a material that maximizes specific performance properties. The constituents do not dissolve or merge completely and therefore exhibit an interface between one another. In this form, both reinforcing agents and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone.

The use of composite reinforced with natural fibre has grown significantly in recent years because of their superior properties and also due to the growing search for low cost materials from renewable sources that is able to substitute the traditional material. Composites are termed as bio-composite materials when one of its phases comes from natural source such as wood fibre, hemp fibre, flax fibre, oil palm fibre and many others. Fibre-reinforced composite materials consist of fibre embedded in a matrix. In fibre - reinforced composites, fibres are the principal load carrying members, while the surrounding matrix keeps them in the desired location and orientation. Matrix also acts as a load transfer medium between the fibres, and protects them from environmental damages due to elevated temperatures, humidity and corrosion. Fibre-reinforced composite inherit the high stiffness and strength of the fibre while retaining the elevated temperature capabilities of the matrix material. In addition, the fibre-reinforced materials are more resistant to damages and defects.

1.2 Problem Statements

Malaysia has about 3.5 million hectares of oil palm producing annually over 10 million tons of crude palm oil. However, crude palm oil and its economic products such as palm kernel oil and palm kernel cake constitute only 10% of the crop, leaving the rest of the biomass to waste. This biomass also includes oil palm empty fruit bunch (OPEFB) fibre, being the residual bunch after removal of the fruit constituting 20% to 22% of the weight of the fresh fruit bunches (Ramli et al., 2002). Utilization of OPEFB fibre therefore not only create value added product but will also solve disposal problem.

Various research have been conducted to produce OPEFB fibre reinforced epoxy (Bakri et al., 2015; Yusoff et al., 2010) and PP composite (Ahmed et al., 2010; Khalid et al., 2008; Razak & Kalam, 2012). Although many research have been conducted, these research work are limited to the usage of discontinuous OPEFB fibre. Discontinuous-fibre composite are normally random in alignment, while continuous-

fibre generally have preferred orientation. The random alignment of the discontinuous-fibre dramatically reduces their strength and modulus (Tanwer, 2014).

One method of reinforcing continuous-fibre is by unidirectional fibre alignment. Unidirectional fibres could be distinguished between its reinforcement angles. The reinforcement angles vary in the direction of load applied. The composites are said to be reinforced with 0° fibre alignment if the orientation of the fibre is parallel with the direction of applied load or to be reinforced with 90° fibre alignment if the fibre orientation is perpendicular to the applied load, normally defined using tensile loading.

It is expected that the unidirectional composite with 0° fibre alignment to be stronger and stiffer as compared to composite with other fibre alignment angles. As fibre orientation changes from 0° to 90°, the properties of the fibres decline and the properties of the matrix dominate (Hedge 2015), hence, the load will be carried by the much weaker polymeric matrix (Campbell 2010).

This research also aims to evaluate the potential application of the unidirectional OPEFB fibre reinforced epoxy and OPEFB fibre reinforced PP composites as the material for car bumper. The incorporation of OPEFB fibre is expected to significantly increase the impact strength of the bumper as OPEFB fibre will play the role to absorb the impact energy in the event of collision.

Three main criteria are considered when selecting material to be adapted in automotive parts. The material should be able to offer lightweight properties, cost-effectiveness and crashworthiness. Metals used to be used extensively to make up bumper structure due to their high strength and stiffness. However, due to considerable demand of lightweight properties for automotive parts, which can contribute to lower fuel consumption, engineers began to replace metals with plastic and synthetic fibre polymer composite.

Due to the lightweight criteria of fibre reinforced polymer composites, the material has been employed vastly as front and rear bumpers, instrument panels and side mountings. The other criterion that makes the material highly in demand is because of its manufacturability. Plastic material can be moulded into various designs and shapes to suit the market demands, as opposed to metal that have many constraints.

The overblown price of plastic these days has urged the needs for searching alternative materials that can offer cost reduction but still retaining the beneficial properties of plastic. The most commonly utilized reinforcement material is glass fibre. However, glass fibre has shown significant disadvantages in terms of cost, density, renewability, recyclability, abrasiveness and biodegradability. Thus, the use of natural fibre to reinforce plastic is preferable. Besides enhancing the degradability and recyclability, the utilization of natural fibre further offer significant cost and weight reduction. In addition, as compared to the glass fibre, natural fibres have better sound absorbing efficiency, more shatter resistant and have better energy management characteristics. In

automotive parts, bio-composites not only reduce the mass of the component but also lower the energy needed for production by 80% (Malkapuram et al., 2008).

To augment the needs for a lightweight yet low cost material, OPEFB fibre reinforced polymer composite is proposed through this research. The mechanical properties of the bio-composite material defined through experimental works and its behaviour when being subjected to impact application in automotive industry, specifically when being used as car bumper material is analysed using finite element.

Car bumper system could consist of three parts called as bumper fascia (cover), foam and bumper beam. The usage of polymer material currently is focused mainly to the bumper fascia as the non-structural component. Bumper fascia conventionally fabricated using polypropylene (PP). Among the drawback of the PP bumper fascia is their low impact and compressive strength.

As polymer material has been adopted for car bumper fascia, the application to bumper beam however is still limited. Bumper beam conventionally made from Aluminum which is lighter than steel but expensive. Aluminum is utilized for bumper beam mainly due to its crashworthiness properties. Aluminum is able to absorb the low-impact energy by bending resistance and dissipates the high-impact energy by collision (Davoodi et al., 2008). Due to the environmental awareness and sustainability concept, the use of bio-composite material as bumper material is hence worthy of analysis.

1.3 Objectives

Present work investigates the suitability of OPEFB fibre reinforced polymer composite to be adapted as material for car bumper. The objectives of this research are:

1. To determine the mechanical properties of unidirectional OPEFB fibre reinforced epoxy composites.
2. To determine the mechanical properties of unidirectional OPEFB fibre reinforced PP composites.
3. To analyze the mechanical behavior of the unidirectional OPEFB fibre reinforced polymer composites using finite element analysis.
4. To analyze the crash performance of composites subjected to low velocity impact of automotive bumper system.

1.4 Scope of Work

The research work involved experimental characterization of the unidirectional OPEFB fibre/polymer composites material properties. The mechanical properties investigated were tensile, flexural and impact strengths. The composites were categorized into three

different fibre orientation angles of 0°, 45° and 90° with two different matrixes: Epoxy and Polypropylene. In addition, this research also involved the development of finite element modelling that predicts the behaviour of the composites under tensile and flexural load. Calibration and validation of the finite element material models were performed to the finite element material model in order to obtained accurate representation of the composites behaviour. Crash performance of the composites material as car bumper beam and bumper fascia was sequentially investigated *via* finite element analysis. The crash performances were evaluated under low velocity impact of 4 km/h.

1.5 Thesis Outline

This thesis is divided into five chapters. Following this introduction, the thesis is composed as follows:

Chapter 2 encompasses a comprehensive review of the literature on the state of the art in unidirectional bio-composites properties and finite element modeling of the impact behavior of bio-composites car bumper. The literature review is divided into four main sections, i.e., (i) overview and state-of-the-art of the natural fibre reinforced polymer composites, (ii) mechanical properties of unidirectional bio-composite materials, (iii) material behavior model and failure criteria for composites, and (iv) automobile safety system including the assessment of the composites material for bumper application.

Chapter 3 presents the methodology for experimental works conducted to investigate the mechanical properties of the unidirectional OPEFB fiber reinforced polymer composites including the composites preparation and the tests conducted onto the composites. The finite element analysis for development of predictive modeling technique of the composite behavior and their crash behavior as car bumper material also presented here.

Chapter 4 is devoted to the findings obtained through the mechanical test and finite element analysis. The experimental results of tensile, flexural and impact properties of the OPEFB fibre/polymer composites is presented here. This is followed by comparison of the experimental findings with finite element analysis result which is developed using material model within the LS_DYNA explicit finite element code. Calibration and validation of the finite element material model is presented. This chapter also presents the modelling results for the application of the bio-composite material as car bumper subjected to impact.

Chapter 5 presents the conclusion of the present research summarising the attainment of objectives for this research. Recommendations for future work are also outlined.

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