PREPARATION, CHARACTERISATION AND MICROMECHANICAL MODELLING OF RESIN TRANSFER MOULDED NONWOVEN KENAF FIBRE/EPOXY COMPOSITES

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by

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
CP300	Biodegradable Starch/PCL Resin
DMA	Dynamic Mechanical Analysis
FEA	Finite element analysis
GF	Glass Fibre
HDPE	High Density Polyethylene
KF	Kenaf Fibre
MAPP	Maleated Polyproylene
NKFE	Nonwoven Kenaf Fibre/Epoxy
PA66	Polyamide-66
PBT	Polybutylene Terephthalate
PHBV	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)
PLLA	Poly-L-Lactide
PP	Polypropylene
ROM	Rule of Mixture
RTM	Resin Transfer Moulding
SEM	Scanning Electron Microscopy
SF	Safety factor
SGW	Stoneground Wood
2D	Two-dimension
3D	Three-dimension

LIST OF SYMBOLS

A_W	Areal Weight
l/d	Aspect Ratio (length/diameter)
cm/day	Centimeter per day
cm^2	Centimeter square
E_C	Composite Elastic Modulus
E_{11}	Composite Longitudinal Modulus
G_C	Composite Shear Modulus
σ_C	Composite Tensile Strength
E_{22}	Composite Transverse Modulus
l_C	Critical Fibre Length
°C	Degree Celcius
ºC/min	Degree Celcius per minute
ρ	Density
η_e	Efficiency Factor (Cox-Krenchel)
η_l	Fibre Length Distribution Factor
K_2	Fibre Length Factor (Bowyer-Bader)
E_{f1}	Fibre Longitudinal Young's modulus
η_o	Fibre Orientation Distribution Factor
K_1	Fibre Orientation Factor (Bowyer-Bader)
α_o	Fibre Orientation Limit Angle
σ_f	Fibre Tensile Strength
E_{f2}	Fibre Transverse Young's Modulus
V_f	Fibre Volume Fraction

K_{IC}	Fracture Toughness
GPa	Gigapascal
T_g	Glass Transition Temperature
g	gram
g/m^3	Gram per cubic meter
h	Hour
l	Length
E_m	Matrix Elastic Modulus
σ_m'	Matrix Stress corresponding to Fibre Failure Strain
σ_m	Matrix Tensile Strength
MJ	Megajoule
MPa	Megapascal
µm	Micrometer
mm^3	Millimeter cubic
min	minute
χ_i	Packing of fibres in the composites
%	Percentage
v	Poisson's Ratio of Matrix
r	Radius
ξ	Shape Fitting Parameter
β	Shear parameter (Coefficient of stress concentration rate at fibre's end)
atm	Standard Atmosphere
η	Stress Partitioning Factor (Tsai-Hahn)
V_V	Void Content

PENGHASILAN, PENCIRIAN DAN PEMODELAN MIKROMEKANIK KOMPOSIT GENTIAN KENAF TIDAK TERANYAM/EPOKSI DISEDIAKAN MELALUI PENGACUAN PEMINDAHAN RESIN

ABSTRAK

Pengunaan gentian semulajadi sebagai penguat di dalam sistem komposit semakin meningkat berikutan peningkatan kesedaran alam sekitar dan kelebihan-kelebihan yang dimiliki seperti kekuatan dan modulus spesifik yang tinggi dan juga bersifat mesra alam. Dalam kajian ini, komposit gentian kenaf tidak teranyam/epoksi (NKFE) telah dihasilkan melalui proses pengacuan pemindahan resin (RTM). Kesan pecahan isipadu gentian (V_f) dan kesan arah jarum-pembenam terhadap sifat-sifat tegangan komposit telah dikaji. Kekuatan dan modulus tertinggi dicapai pada kandungan gentian (V_f) sebanyak 0.42. Kajian juga mendapati komposit menunjukkan tegangan isotropi. Selain itu, kesan pembebanan gentian terhadap sifat fleksur dan ketahanan retakan komposit telah diselidik. Kajian mendapati keputusan tertinggi dicapai pada beban gentian (V_f) sebanyak 0.42. Graf tipikal beban melawan sesaran dan imej-imej mikroskop pengimbas elektron telah menunjukkan bahawa peningkatan kepada ketahanan retakan komposit adalah disebabkan kejadian penyerapan tenaga melalui gentian-gentian kenaf (KF). Disamping itu, kajian ini telah menekankan kepentingan anisotropi sifat kekenyalan gentian didalam menghasilkan ramalan sifat modulus tegangan yang tepat dimana kedua-dua modulus gentian membujur (E_{f1}) dan

melintang (E_{f2}) telah dikenalpasti. Kajian mendapati gentian kenaf mempunyai anisotropi modulus yang tinggi dimana E_{f1} adalah sebanyak 26.06 GPa manakala E_{f2} sebanyak 2.50 GPa. Analisa mikromekanik menggunakan model Cox-Krenchel pula membolehkan parameter-paramater mikromekanik dikenalpasti. Analisa tersebut telah membuktikan kesusaian model tersebut ke atas komposit NKFE dimana faktor-faktor kecekapan yang dihitung adalah sebanding dengan nilai keputusan kajian-kajian sebelum ini. Analisa tersebut juga telah membuktikan bahawa gentian kenaf (KF) tidak teranyam terdiri daripada gentian-gentian berhaluan rambang yang bertanggungjawab kepada isotropi tegangan komposit. Tambahan pula, jumlah kandungan gentian dan juga mod ujian (tegangan ataupun fleksur) tidak mempunyai sebarang pengaruh yang ketara terhadap faktor kecekapan komposit. Akhir sekali, analisis tegangan penutup tayar ganti menggunakan program komputer analisis unsur terhingga menunjukkan komposit NKFE pada kandungan gentian sebanyak 0.42 (V_f) mempunyai faktor keselamatan, kekuatan spesifik dan modulus spesifik yang tertinggi sekali.

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ABSTRACT

There has been a rapid growth in the utilisation of natural fibre as reinforcement in composites driven by environmental concerns and the advantages they offer such as high specific strength and moduli, and also are environment-friendly. In this study, nonwoven kenaf fibre/epoxy (NKFE) composites have been fabricated using resin transfer moulding (RTM). The effect of kenaf fibre (KF) volume fraction (V_f) and needle-punching directions on the mechanical properties of the composites have been investigated. The highest tensile strength and modulus were attained at 0.42 V_f and it was found that the composites exhibit tensile isotropy. Optimum flexural properties and fracture toughness were also achieved at 0.42 V_f. The typical load versus displacement graph and scanning electron microscopy (SEM) images of epoxy and NKFE composites revealed that the improvements in the fracture toughness was due to the energy absorbing events caused by the addition of fibres. This study also addresses the importance of fibre elastic anisotropy in the accurate predictions of composite tensile modulus in which both longitudinal (E_{f1}) and transverse (E_{f2}) fibre modulus were identified. KF has proven to be highly anisotropic whereby E_{f1} and E_{f2} were found to be 26.06 GPa and 2.50 GPa, respectively.

Meanwhile, micromechanics analysis by Cox-Krenchel model allows the determination of micromechanical parameters of the composites. The analysis also proved the applicability of the model for NKFE composites as the calculated efficiency factors were comparable to the values from previous literatures. Moreover, the analysis verified that the nonwoven KF consists of randomly-oriented fibres which were responsible for the tensile isotropy. In addition, V_f and testing modes (tensile or flexural) show no significant effect on the composite's efficiency factors. Lastly, the static stress analysis of spare wheel cover by using finite element analysis (FEA) computer program showed that the highest safety factor (SF) was exhibited by NKFE composites at 0.42 V_f, which also possessed the highest specific strength and modulus.

CHAPTER ONE

INTRODUCTION

1.1 Overview

For thousands of years, humans have taken objects from nature to create a better world for themselves. From huts of mud and straw, to towers of rock and steel, the rise of modern civilization has been paced by our development of new materials. In line with the huge strides made by scientific discovery and the drive to push the limits of material properties, composite materials have been the focus of many studies and have seen much advancement in recent years. Scientists have carefully designed composites with far superior properties compared to conventional materials in order to fulfil specific requirements for various applications. Basically, composites are defined as materials that consist of two or more chemically and physically different phases (typically the reinforcing phase and the matrix phase) separated by a distinct interface (Jose and Joseph, 2012). The different systems are combined to achieve a system with improved structural or functional properties.

Polymer composites have become an integral part of today's material due to its advantages such as low weight, corrosion resistance and faster assembly. From construction to the aerospace industry, polymer composites have proven its significance due to the many advantages it offers (Shaw et al., 2010). Polymeric materials reinforced with synthetic fibres such as glass and carbon provide the advantage of higher stiffness and strength to weight ratio as compared to conventional construction materials such as wood, steel and concrete. Despite the advantages, the widespread usage of synthetic fibre as reinforcement in polymeric materials has its disadvantages such as high cost, adverse environmental impacts and its abrasive nature.

Therefore, over the past few decades, there has been a rapid growth in the utilisation of natural fibres as green reinforcement or filler in composites (Alizadeh et al., 2016; Pickering et al., 2015; Idicula et al., 2009). This is driven by the advantages they offer such as high specific strength and moduli, and a non-abrasive nature during processing (Lee et al., 2010; Ku et al., 2011; Mantia et al., 2011; Hamma et al., 2014). Natural fibres have been proven to be a greener, cheaper and viable replacement for conventional glass fibres (Assarar et al., 2016). In addition, the usage of high loading of natural fibres would significantly lower the usage of petroleum-based plastic. Since the price of petroleum-based plastics has risen sharply over the past decade, adding natural fibre to plastics provides an avenue for cost reduction to the plastic industry as well as increased value for the agro-based component. All these advantages may not be possible with conventional fibres.

In light of the current interest and advancements in natural fibre composites, its commercialization in the automotive industry has been progressive and positive. The shift to parts of higher suitability in the automotive industry was not only an initiative towards cost efficiency and a greener environment but was also required for the fulfilment of European regulations. In 2000, The European Commission issued the European Guideline 2000/53/EG which required that 85 % of the weight of a vehicle to be recyclable (Koronis et al., 2013). Car manufacturers like Mercedes-Benz, Audi, Toyota, Ford, Mitsubshi and BMW have all utilised natural fibre composites in automotive interior parts such as door trim panels, and floor mats (Suddell and Evans, 2005; Mohanty et al., 2005; Stewart, 2010). Apart from that, natural fibre composites are also used in exterior components of cars. Flax/polyester composites have been used to make the engine and transmission enclosures for sound insulation in Mercedes-Benz's Travego while the spare tire well covers of the Mercedes-Benz A-class was made up of abaca/PP composites (Koronis et al., 2013).

Despite the availability of various types of natural fibre nowadays, kenaf fibre, KF, (*Hibiscus cannabinus*) is a particularly attractive option due to its fast growth over a wide range of climatic conditions (Cho et al., 2009) and its consequent low cost. Recently, the promotion of KF as the next commodity plant in Malaysia has become a national agenda. The Malaysian government has shown great commitment in supporting the KF industry which will provide a new source of economic growth for the country. In 2010, the National Kenaf and Tobacco Board received more than RM 30 million to develop KF industry in various states including Kelantan, Terengganu and Pahang. The allocation includes more than RM 2 million for research and development of KF and its product (Utusan Malaysia, 2011).

In this research, nonwoven KF was incorporated into the epoxy matrix in order to produce a 'green' composite with the intention of obtaining materials which potentially possess improved properties that are suitable for interior or exterior automotive parts. Thus, this dissertation focuses on the effects of nonwoven KF loading on the physical and mechanical properties of the nonwoven kenaf fibre/epoxy (NKFE) composites produced by resin transfer moulding (RTM). Furthermore, the prediction of tensile properties through micromechanical models and the determination of composites efficiency factors through micromechanics analysis are also presented.

1.2 Problem Statement

There are several issues that are highlighted in this research. First of all, this study aimed to promote the shifting of synthetic fibre to natural fibre, particularly kenaf fibre as reinforcement in composites. To achieve this, nonwoven kenaf fibre was used as reinforcement in composite as opposed to synthetic fibres which have environmental disadvantages. Kenaf fibre offers both economic and ecological advantages, hence making it a good candidates for reinforcement in composites (Alexopoulou et al., 2013). Also, nonwoven kenaf fibre possesses advantages such as lightweight, environment-friendly and attractive cost/performance ratio making its composites suitable for interior automotive applications (Vasile and van Langenhove, 2004; Thilagavathi et al., 2010; Sayeed et al., 2013; Diener and Siehler, 1999).

Secondly, there have been limited studies on the mechanical properties of resin transfer moulded nonwoven kenaf fibre/epoxy composites. Mechanical properties are one of the most essential and crucial properties as nearly all fabrication processes and most service conditions are exposed to some type of mechanical loading. A research by Fiore et al. (2014), only reported the effect of alkaline treatment on the tensile properties of epoxy composites reinforced with randomly oriented kenaf mats. The effect of fibre loading on the mechanical properties of the composites was not covered. It is worthwhile to note that the nonwoven KF used in the study by Fiore et al. (2014) was produced by simple fibre dispersion followed by wetting and hot pressing.

Thirdly, there has been limited work on the prediction of tensile properties of nonwoven natural fibre composites. Prediction of mechanical properties by using micromechanical models is vital in order to avoid costly and time-consuming experiments. However, most models were created to predict the tensile properties of synthetic fibres such as glass fibre and carbon fibre (Harper et al., 2005; Thomason et al., 1996). Therefore, there is a need to identify a good micromechanical model to represent the behaviour of NKFE composites. It is also worthy to note that the intrinsic properties of fibres are key factors in producing an accurate prediction of the composite's properties.

Many studies have failed to predict the stiffness of randomly-oriented natural fibre composites accurately due to assumption of fibre isotropy (Epaarachchi et al., 2009; Islam and Begum, 2011; Facca et al., 2006). Most research did not take into account the fibre transverse modulus in their prediction leading to inaccurate prediction. Furthermore, the elastic anisotropy of most natural fibres has been left undetermined. The transverse fibre modulus (E_{f2}) and the longitudinal Young's modulus (E_{f1}) need to be quantified in order to produce better predictions using micromechanical models. While it is easy to measure the E_{f1} directly, characterising the E_{f2} has proven to be challenging. Consequently, there is a great necessity to find a simple and proper method to quantify the elastic anisotropy of natural fibre accurately.

Resin transfer moulding (RTM) is a suitable processing method for reinforcing thermosets with nonwoven natural fibres. However, research directed on the fabrication of nonwoven KF composites by using the RTM is still lacking. RTM processing method retains the shape of the needle-punched nonwoven natural fibres, as well as produces a composite with better mechanical properties compared to other processing methods such as compression moulding and the hand lay-up method (Idicula et al., 2009; Davallo et al., 2010; Sreekumar et al., 2009).

Lastly, there is a need to better understand and quantify the micromechanical parameters which control the structure-properties relationship of NKFE composites.