UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

MODELLING AND CHARACTERIZATION OF STONE WOOL FIBRE REINFORCED HIGH DENSITY POLYETHYLENE COMPOSITES

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MODELLING AND CHARACTERIZATION OF STONE WOOL FIBRE REINFORCED HIGH DENSITY POLYETHYLENE COMPOSITES

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled “Modelling and Characterization of Stone Wool Fibre Reinforced High Density Polyethylene Composites” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is concurrently submitted in candidature of any other degree.

Signature : …………………

Name : Leong Shu Teng

Date : 14/7/2016

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award for the award of Master of Science in Manufacturing Engineering.

Signature : ………………………………………..
Supervisor Name : Prof. Ir. Dr. Sivarao Subramonian
Date : 14/7/2016

DEDICATION

This thesis is dedicated to my beloved father, siblings and boyfriend. Thanks for always being there for me. Without their love and support this thesis would not have been made possible.

ABSTRACT

Composites are a combination of two or more constituent materials that consist of phases like reinforcement and matrix phase. Polymer matrix composites consist of long or short fibres in a polymer matrix. Most polymer composites have been created to optimize the mechanical properties and are designed to be lighter and stronger to use in variety of applications such as automotive industry, sports equipments, aircraft components and etc. This research investigates the mechanical properties of stone wool (SW) fiber-reinforced high density polyethylene (HDPE) composites at fiber loadings, 0 to 60 wt.% through two methods: experimental and finite element analysis. Nowadays, due to the increase in environmental awareness, the wide spread use of glass, carbon and aramid has greatly decreased due to greater weight, higher cost and adverse environmental impact brought by those fibres. Research into new fibres has significantly increased, making stone wool among the chosen fibres. Stone wool is a natural material that is formed from one earth's most abundant material. It becomes a mass of fine, intertwined fibres with a typical diameter of 6 to 10 micrometres after an advanced process. SW shows few good characteristics such as a good insulator, lightweight, good quality, sustainable and also environmentally friendly. It also has proven to be a safer option to be used than carbon and glass fibre. The stone wool polymer composites (SWPC) specimens were prepared using the hot compression molding process. These samples were then prepared and tested according to ASTM standards for tensile, flexural and hardness test. Scanning electron microscopy (SEM) was carried out on the fractured surface to observe the interaction between matrix and fiber in the composites. The experimental results revealed that there was an increase in fiber loading which also increases the mechanical properties of the material. Significant improvement of mechanical properties is observed and recorded for 20wt.% SWPC. The results also shows a significant decrease in tensile and flexural properties after 40wt.% SWPC. The hardness test results shows that it improves with the increase of the fibre weight percentage and the value maintained after 40wt.% SWPC. To reveal the actual phenomenon of the composites, finite element modelling and analysis has also been performed. The mechanical properties was predicted using the model developed by ANSYS. The model was then experimentally validated. The model outputs were found to have excellent agreement with the experimental results, with an accuracy of more than 90% for tensile and 85% for flexural test. The accuracy of established ANSYS model proving its robustness and expected to reduce the industrial experimental cost holistically.

ABSTRAK

Komposit adalah gabungan dua atau lebih bahan konstituen yang terdiri daripada fasa pengukuhan dan fasa matriks. Komposit matriks polimer terdiri daripada gentian panjang atau pendek dalam matriks polimer. Kebanyakan komposit matriks telah dibuatkan untuk mengoptimumkan sifat-sifat mekanik dan direka untuk menjadi lebih ringan dan lebih kuat untuk digunakan dalam pelbagai aplikasi seperti industri automotif, peralatan sukan, komponen pesawat dan lain-lain. Penyelidikan ini menyiasatkan sifat mekanikal tentang Polietilena berketumpatan tinggi (HDPE) yang diperkukuhkan dengan campuran batu kapas (SW) dalam komposisi 0- 60wt.% dengan menggunakan dua cara: eksperimen dan analisis unsur terhingga (FEA). Pada masa kini, disebabkan peningkatan kesedaran terhadap alam sekitar, penyebaran penggunaan serat kaca, karbon dan aramid sebagai pengisi telah dikurangkan disebabkan impak dan kesan buruk yang dibawa terhadap alam sekitar, isipadu yang berat dan kos yang tinggi. Penyelidikan untuk gentian yang baru amat diperlukan. Oleh itu, SW dipilih sebagai gentian baru yang akan dikaji. SW merupakan sebuah bahan asli yang dihasilkan daripada tanah dan ia merupakan bahan yang paling senang didapati. Ia menjadi benda yang halus dan mempunyai diameter sebanyak 6 hingga 10 mikrometer selepas mengalami pemprosesan yang lebih tinggi. SW mempunyai sifat yang amat bagus seperti penebat, ringan, kualiti tinggi, mampan dan mesra kepada alam sekitar. Ia juga telah terbukti menjadi pilihan yang lebih selamat digunakan daripada gentian karbon dan kaca. SWPC specimen telah disediakan dengan menggunakan pengacuan mampatan panas. Sampel-sampel ini kemudian disediakan dan diuji mengikuti piawaian ASTM untuk ujian tegangan, lenturan dan kekerasan. Kemikroscopan electron imbasan (SEM) telah dijalankan ke atas permukaan yang retak untuk melihat interaksi antara matriks dan gentian dalam komposit. Keputusan eksperimen menunjukkan bahawa semakin meningkat komposisi gentian, semakin meningkat sifat mekanikal komposit tersebut. Peningkatan sifat mekanikal yang ketara boleh diperhatikan dan direkodkan oleh 20wt.% komposit manakala penurunan yang ketara bagi sifat tegangan dan lenturan berlaku selepas 40wt.% komposit. Kekerasan komposit meningkat dengan penambahan komposisi gentian SW ke dalam HDPE. Untuk lebih memahami fenomena sebenar pada komposit, FEA model dan analisis telah dilaksanakan. Model yang dibangunkan oleh ANSYS telah digunakan untuk meramalkan sifat-sifat mekanikal di mana model itu kemudian disahkan dengan keputusan yang diperolehi daripada eksperimen. Keluaran model didapati mempunyai persetujuan yang amat baik dengan keputusan eksperimen, dengan ketepatan yang lebih daripada 90% bagi ujian tegangan dan 85% bagi ujian lenturan. Ketepatan model ANSYS yang ditubuhkan telah membuktikan kekukuhannya dan dijangka akan mengurangkan kos eksperimen perindustrian secara holistik.

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LIST OF ABBREVIATIONS

Al_2O_3	-	Alumina
APDL	-	ANSYS Parametric Design Language
ANSYS	-	Analysis System
ASTM	-	American Society for Testing and Materials
AWPEX	-	Apatite-Wollastonite Particulate Reinforced Polyethylene
BN	-	Boron Nitride
$CaCO_3$	-	Calcium Carbonate
CF	-	Carbon Fibre
CMC	-	Ceramic Matrix Composites
CTDIC	-	Cardinal Derivative of Toluene Diisocyanate
EL	-	Elongation
Fe	-	Ferum
FEA	-	Finite Element Analysis
FKP	-	Faculty of Manufacturing Engineering
FRC	-	Fibre Reinforced Composite
FRP	-	Fiber Reinforced Polymer
GF	-	Glass Fibre
GPa	-	Giga Pascal
HDPE	-	High Density Polyethylene

HDPE-r	-	Recycled High Density Polyethylene
LDPE	-	Low Density Polyethylene
MMC	-	Metal Matrix Composites
MPa	-	Mega Pascal
NaOH	-	Sodium Hydroxide
PE	-	Polyethylene
PEMA	-	Polyethylene Grafted with Maleic Anhydride
PMC	-	Polymer Matrix Composites
rpm	-	Revolutions per minute
SEM	-	Scanning Electron Microscope
SFFT	-	Single Fibre Fragmentation Test
SRPE	-	Sand Reinforced Polyethylene
SS	-	Sago Starch
SWPC	-	Stone Wool Polymer Composites
SWRHDPEC	-	Stone Wool Reinforced High Density Polyethylene Composites
TCP/HDPE	-	Tri-Calcium Phosphate-High Density Polyethylene
UTS	-	Ultimate Tensile Strength

LIST OF PUBLICATIONS

1. Sivaraos, Leong, S. T., Yusof, Y. and Tan, C. F., 2015. An Experimental and Numerical Investigation of Tensile Properties of Stone Wool Fiber Reinforced Polymer Composites. *Advanced Materials Letters*, 6(10), pp. 888-894. (SCOPUS Indexed)

2. Sivarao, Aidy Ali and Leong, S. T., 2014. Enhanced Tensile Properties of Stone Wool Fiber-Reinforced High Density Polyethylene Composites. *Materialpruefung/Materials Testing,* 56(2), pp. 150-154. (SCOPUS Indexed)

CHAPTER 1

INTRODUCTION

1.1 Background

Composites are a material made from two or more constituent materials with different chemical and physical properties. When constituent materials are combined, a composite material, which has characteristics different from the individual components, is produced. Examples of typical engineering composite materials are polymer matrix composites (PMC), metal matrix composites (MMC) and ceramic matrix composites (CMC). The polymer matrix in a polymer matrix composite consists mainly of thermoset or thermoplastic resin.

According to Rassiah et al. (2011), polymer is a long chain of repeated atoms and produced by joining molecules, which are known as monomers. In other words, polymer is a high molecular weight compound consisting of many repeated small segments. The block results of a polymer are usually a result of the factual characteristics of a chemical reaction with the usage of the smallest building block. All of these blocks result in a polymer. Polymers can be made using two different methods, known as condensation and poly-addition. The main bonds that are being formed between the molecules are covalent bonds, which are very strong. These bonds are caused by the forces of Van der Waal (Callister and Rethwisch, 2007). They are able to produce branched or linear polymers. The molecules also have a tendency to form secondary bonds, which actually hold a magnitude of lower power compared to the covalent bonds.

Most composites have been created to optimize the mechanical properties and are designed to be stronger and lighter to apply through environments of high temperature and to resist corrosion. This is because reinforced fibres are the principal load-carrying constituents while matrix is the load transfer medium between them (Kaw, 2006). Thermoplastic composites which is reinforced with different types of fibres such as long, short and mat of natural and synthetic fibres like coconut, oil palm, hemp, glass, carbon , and etc. are used in a variety of applications such as in the automotive industry, sports equipments, aircraft structural components, ballistic, tires , and etc. They are used because of their improved properties such as stiffness, toughness, ambient and high temperature strength, creep resistance, and corrosion resistance (Chandra et al., 1999). Many researchers have investigated the mechanical properties of thermoplastic composites and discovered that there is improvement in its mechanical properties.

High density of polyethylene (HDPE) is a polymer that has a low degree of branching in a long chain of repeated atoms, thus having strong intermolecular force (Rassiah et al., 2011). Mineral fibres such as carbon fibre (CF) and glass fibres (GF) are widely used as reinforcement of polymer composites. Enhanced mechanical properties of mineral fibre reinforced HDPE composites have been observed and reported in many investigations. Huang et al. (2013) studied the effect of individual and combined GF on morphology and mechanical performance of HDPE composites. Mechanical properties of composites with combined GF fibres varied with GF ratio at a given total fibre loading level. The use of larger portion of GF in the mix can lead to better composites performance. Lopresto et al. (2011) investigated the mechanical characterisation of basalt fibre reinforced plastic. The results obtained showing a high performance of the basalt reinforced composites in terms of young modulus, compressive and bending strength.