Faculty of Manufacturing Engineering

MECHANICAL AND TRIBOLOGICAL PROPERTIES OF RECYCLED CARBON FIBER REINFORCED POLYPROPYLENE COMPOSITES

Anisah binti Abdul Latiff

Master of Science in Manufacturing Engineering

2017

MECHANICAL AND TRIBOLOGICAL PROPERTIES OF RECYCLED CARBON FIBER REINFORCED POLYPROPYLENE COMPOSITES

ANISAH BINTI ABDUL LATIFF

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

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this thesis entitled ―Mechanical and Tribological Properties of Recycled Carbon Fiber Reinforced Polypropylene 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 not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Anisah Bt Abdul Latiff
Date	:	....

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 of Master of Science in Manufacturing Engineering.

Signature : ....

Supervisor's Name : Prof Madya Dr.Noraiham Bt Mohamad

Date : ....

DEDICATION

To my beloved mother and

to all my family members and friends

ABSTRACT

Recently, the use of carbon fiber waste is accepted as a wise approach to benefit the performance of the carbon fiber and considered as green effort for disposal management. This research is an effort to study the potential of recycled carbon fibers as reinforcement in polypropylene (PP) matrix especially for tribology application. The effects of fibers condition, fiber loading as well as chemical modifications on physical, mechanical and tribological properties of PP reinforced with recycled carbon fibers were studied. The composites were prepared via melt compounding using a Haake internal mixer at 180 °C and rotor speed of 50 rpm for 10 minutes. This research is divided into three different studies; 1) effect of recycled carbon fibers condition (with or without uncured resins) on the physical and tensile properties at different carbon fiber (CF) loading of 0, 3, 5, 10, 13, 15 wt%, 2) effect of chemical modification using 3 and 5 wt% maleic anhydride (MA) on the tensile properties and 3) wear characteristics of recycled carbon fiber reinforced polypropylene composites at CF loading of 0, 0.5, 1.0, 3.0, 5.0, 7.0, 10.0, 13.0, 15.0, 20.0 wt%. In Study 1, the uncured resins on carbon fibers had proven to improve the interaction between reinforcement and matrix which manifested by increment in physical and mechanical properties with the optimum at 3 wt% fiber loading. In Study 2, the recycled carbon fibers were first pulverized into finer fibers before undergone oxidation in nitric acid and treatment with maleic anhydride. The treatment was observed to improve the physical and mechanical properties of the composites at low MA content of 3 wt% and proven to increase interaction at limited loading of fibers for only up to 1 wt%. The properties were supported by morphological analysis on the fracture surfaces observed by using Scanning Electron Microscopy and chemical analysis using Fourier Transform Infrared Spectroscopy. In Study 3, the composites with low carbon fiber loading of up to 3 wt% imposed higher resistance to dry sliding friction. In contrast, the increment of fiber loading at 5 wt% to 20 wt%, decreased the wear rate of the composites due to the formation of patchfilm and transfer film which accelerated with the MA treatment. The wear mechanism of the composites was for different fiber loading was proposed from morphological observation. As the conclusions, the composites showed promising self-lubricating properties with significant physical and mechanical properties.

ABSTRAK

Sejak kebelakangan ini, penggunaan sisa gentian karbon diterima sebagai satu pendekatan bijak dalam memanfaatkan prestasi serat karbon dan dianggap sebagai satu usaha hijau dalam pengurusan pelupusan. Kajian ini merupakan satu usaha untuk mengkaji potensi gentian karbon dikitar semula sebagai bahan pengukuh dalam matriks polipropilena (PP) terutamanya bagi kegunaan tribologi. Kesan keadaan gentian, pembebanan gentian serta pengubahsuaian kimia pada sifat-sifat fizikal, mekanikal dan tribologi komposit PP diperkukuh gentian karbon kitar semula telah dikaji. Komposit telah disediakan melalui kaedah penyebatian leburan menggunakan pengadun dalaman Haake pada suhu 180 ºC dan kelajuan rotor 50 rpm selama 10 minit. Penyelidikan ini dibahagikan kepada tiga kajian yang berbeza; 1) kesan keadaan gentian karbon dikitar semula (dengan atau tanpa resin belum matang) kepada sifat-sifat fizikal dan tegangan pada pembebanan gentian karbon (CF) yang berbeza pada 0, 3, 5, 10, 13, 15 wt%, 2) kesan pengubahsuaian kimia menggunakan 3 dan 5 wt% maleik anhidrida (MA) pada sifat-sifat tegangan dan 3) ciri-ciri haus komposit PP diperkukuh gentian karbon dikitar semula pada pembebanan bahan pengukuh sebanyak 0, 0.5, 1.0, 3.0, 5.0, 7.0, 10.0, 13.0, 15.0, 20.0 wt%. Dalam Kajian 1, resin belum matang pada gentian karbon terbukti meningkatkan interaksi antara bahan pengukuh dan matriks yang ditunjukkan oleh kenaikan dalam sifat-sifat fizikal dan mekanikal dengan nilai optimum pada pembebanan gentian sebanyak 3%. Dalam Kajian 2, gentian karbon kitar semula dilumatkan kepada serat halus sebelum menjalani pengoksidaan dalam asid nitrik dan dirawat dengan maleik anhidrida. Rawatan ini diperhati meningkatkan sifat-sifat fizikal dan mekanikal komposit pada kandungan MA rendah sebanyak 3% berat dan terbukti dapat meningkatkan interaksi pada pembebanan gentian terhad hanya sehingga 1% berat. Sifat ini disokong oleh analisis morfologi pada permukaan patah yang diperhatikan dengan menggunakan Kemikroskopan Elektron Imbasan dan analisa kimia dengan menggunakan Spektroskopi Inframerah Penjelmaan Fourier. Dalam Kajian 3, komposit pada pembebanan gentian karbon rendah sehingga 3% berat mengenakan rintangan yang lebih tinggi terhadap geseran gelongsoran kering. Sebaliknya, kenaikan pembebanan gentian pada 5 % kepada 20% berat, menurunkan kadar haus komposit kerana pembentukan filem-tampal dan filem-pindahan yang dipercepat dengan rawatan MA. Mekanisme haus bagi komposit untuk pembebanan gentian berlainan dicadangkan daripada pemerhatian morfologi. Sebagai kesimpulan, komposit menunjukkan sifat pelinciran kendiri dengan sifat-sifat fizikal dan mekanikal yang bererti.

ACKNOWLEDGEMENTS

Bismillahirrahmanirrahim,

In the name of Allah, the Most Merciful and the Most Gracious. Alhamdulillah, all praises to the Almighty Allah S.W.T for His blessing which have given me patience and undying strength throughout this research until its successful completion. I also pay my gratitude to the Almighty for enabling me to complete this research report within due course of time.

I express my gratitude to my supervisor Prof Madya Dr. Noraiham Binti Mohamad for her constant guidance, insightful comments and encouragement during my period of study. I wish to express my deep sense of gratitude to my co-supervisor, Dr. Mohd Edeerozey bin Abd Manaf, Mr Hairul Effendy bin Maulod and not to forget Prof Qumrul Ahsan, Mr Iqbal bin Shueb and Dr Jeeffeerie bin Abdul Razak for their valuable tips and pertinent pieces of advice. I would also like to extend my deepest appreciation to all the staff in Faculty of Manufacturing Engineering UTeM and Malaysian Nuclear Agency for their co-operation and help.

To all my beloved friends, thank you so much for your support and encouragement. Last but not least, I would like to express my indebtedness and heartfelt thank you to my beloved mother, husband and family members for their blessings, love, dream and sacrifice throughout my life. I acknowledge the sincerity of my family who consistently encouraged me to carry on my study until today. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. To everyone who has directly or indirectly contributed to this project, only Almighty Allah S.W.T can repay your kindness and may Allah S.W.T bless you all. Amin.

Finally, I would like to thank UTeM for sponsoring my research work under grant RAGS/2013/FKP/TK04/02//B00029 which made my research possible and fulfilled my desire to pursue this Master of Science.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CFRP	-	Carbon fiber reinforced polymers
DSC	-	Differential scanning calometry
SEM	-	Scanning electron microscopy
MMC	-	Metal-matrix composites
PMC	-	Polymer matrix composites
GFRP	-	Glass fiber-reinforced polymer
PAN	-	Polyacrylonitrile
AFRA	-	Aircraft Fleet Recycling Association
PP	-	Polypropylene
rPP	-	Recycled Polypropylene
TEPA	-	Polyaminetetraethylenepentamine
PTFE	-	Polytetrafluroethylene
PEI	-	Polyetherimide
SCF	-	Short carbon fiber
COF	-	Friction coefficient
PA6/PPS-CF	-	Polymide6/ polyphenylene sulphide-Carbon Carbon Fiber
WCF	-	Whiskered carbon fibers
ASTM	-	American standard testing method
PEI	-	Polyetherimide
PET	-	Polyethylene terephthalate
PA	-	Polyamide
PPS	-	Polyphenylene sulfide
PEEK	-	Polyether ether ketone
MAPP	-	Maleic anhydride grafted polypropylene
MINT	-	Nuclear Agency Malaysia
LGM	-	Lembaga Getah Malaysia
HNO_3	-	Nitric acid
c-CFP	-	Comminutes of carbon fiber prepreg
c-CF	-	Comminutes of carbon fiber
rCFP	-	Recycled carbon fiber prepreg
rCF	-	Recycled carbon fiber
t-CF	-	Treated carbon fiber
unt-CF	-	Untreated carbon fiber

LIST OF SYMBOLS

μ	-	Coefficient of Friction
CO_2	-	Carbon Dioxide
N	-	Newton
Fr	-	Friction force
Fn	-	Normal force
K	-	specific wear rate
L	-	Sliding Distance
Δm	-	Mass loss of the samples
ρ	-	Density
Tg	-	Glass transition temperature
T	-	Thickness
LO	-	Length overall
L	-	Length of narrow section
G	-	Gage Length
D	-	Distance between grips
Wc	-	With of narrow section
R	-	Radius of fillet
ΔV	-	Volume difference

LIST OF UNITS

ºC	-	Celsius
rpm	-	Revolution per minutes
min	-	Minutes
h	-	Hours
%	-	Percentage
Mg	-	Miligram
m	-	Meter
m/s	-	Meter per Second
GPa	-	GigaPascal
MPa	-	MegaPascal
kJ/m^2	-	kiloJoul per Meter Second
g	-	Gram
g/cm^3	-	Gram per Meter Cube
kg/L	-	Kilogram per Liter
g/l	-	Gram per Liter
µm	-	Micrometer
psi	-	Pound per Square inch
mm/min	-	Milimeter per minutes
mm^3	-	Milimeter per Cube
s	-	Second

LIST OF PUBLICATIONS

1. Latiff, A.A., Mohamad, N., Jeefferie, A.R., Nasir, M.H.M., Rahmah, S.S., Mahamood, M.A., Abdullah, M.I.H.C. and Ab Maulod, H.E., 2016. Correlation of Wear Characteristics with Hardness of Recycled Carbon Fiber Prepreg Reinforced Polypropylene Composites. *Journal of Materials Research*, 31(13), pp.1908-1913.
2. Latiff, A.A., Mohamad, N., Jeefferie, A.R., Nasir, M.H.M., Rahmah, S.S., Mahamood, M.A., Abdullah, M.I.H.C. and Ab Maulod, H.E., 2015. “Tribological Behaviour of Recycled Aerocomposite Carbon Fibre Reinforced Polypropylene Composites”. *Malaysian International Tribology Conference 2015 (MITC)*, Penang, Malaysia, 16-17 November 2015.
3. Mohamad, N., Abd Latiff, A., Drahman, M.A., Shamsuri, S.R., Abdil Razak, J., Othman, I.S., Karjanto, J., Abdollah, M.F. and Ab Maulod, H.E., 2015. Tensile Behavior of Polypropylene Reinforced with Comminutes Extracted from Out-of-Condition Aerospace Grade Carbon Fiber Prepreg Waste. *In Applied Mechanics and Materials*, 761, pp. 526-530.
4. Mazliah, M., Noraiham Mohamad,N., Latiff, A.A., Ab Maulod, H,E., Jeefferie A.R., Manaf, M.E.A., 2015. Energy Absorption and Morphological Characteristics of Opened-Cell Green Rubber Foam at Different Recycled Carbon Fiber Loading.*Malaysian Journal of Microscopy*.

5 Mohamad, N., Latiff, A.A., Maulod, H.E.A., Azam, M.A. and Manaf, M.E.A., 2014. A Sustainable Polymer Composite from Recycled Polypropylene Filled with Shrimp Shell Waste. *Polymer-Plastics Technology and Engineering*,53(2), pp.167-172.

6 Mohamad, N., Abd Latiff, A., Drahman, M.A., Shamsuri, S.R., Abdil Razak, J., Othman, I.S., Karjanto, J., Abdollah, M.F. and Ab Maulod, H.E., 2014. Tensile Behavior of Polypropylene Reinforced with Comminutes Extracted from Out-of-Condition Aerospace Grade Carbon Fiber Prepreg Waste. *International Conference on Design and Concurrent Engineering 2014 (iDECON)*, Malacca, Malaysia, 22-23 September 2014.

.

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays the usage of composite in the manufacturing field has become the engineering materials application. Its superior properties and universal materials performance for specific application selected to be a favourite choice in high application technology. Composites used in high technology application these days are CFRP. This high performance composite has a superior properties that gives them an edge over traditional materials for longer life cycles applications due to high fatigue strength, increased corrosion resistance, improved fire resistance, easier design for functional integration, possibility of complex shapes and lightweight (Latiff et.al., 2016).

CFRP causes increasing usage of composites in space and military systems, as well as in commercial aircraft development and is expected to continue far into the foreseeable future (Giulvezan and Carberry, 2003). Carbon fiber composite materials are increasingly being adopted by the aerospace, automotive and wind turbine markets as engineers strive to reduce weight and increase stiffness. According to Marsh (2008), the global production of carbon fiber was 27,000 tonnes in 2009 and is predicted to rise exponentially in the next 10 years. Most of the carbon fiber wastes are in the form of off-cuts from the manufacturing process, out of life rolls of prepreg and end-of-life components, has already reached significant levels and will increase in line with future production (Latiff et.al., 2016).

In the last decade, the waste of CFRP composite materials were regarded as non-recyclable and most of the CFRP waste is landfill (Pickering, 2006). Since 1995, the increase of environmental awareness and new environmental protection laws made it unacceptable to dispose all composites on landfill sites (Anandjiwala and Blouw 2007). The land filling of CFRP has many environmental and cost related concerns. A need for reclamation of carbon fiber prepregs has arisen and technologies have been developed to recover the carbon fiber from the composite waste (Juliana, 2012).

Glass and carbon fiber reinforced polymers are increasingly being used for numerous mechanical and tribological purposes, such as seals, gears, bearings and cams to replace metallic materials owning to their attractive combination of lightweight, economic fabrication, good chemical resistance and low friction coefficient (Zhou et.al., 2013 and Burris et. al., 2007). The feature that makes polymer composites so promising in industrial applications is the possibility of tailoring their properties with functional fillers (Basavarajappa et. al., 2009). Attention was given especially to the fibrous fillers because of the easy processing and the significant improvements in physical, mechanical and tribological properties (Suresha et. al., 2006). Carbon fiber reinforcement has been widely investigated by many researchers in order to attempt to understand the modifications in the tribological behavior of the polymer matrix. However, most of the present studies were focused on the terms of wear resistance of glass fiber-reinforced polymer composites, very few reports dealing with recycled carbon fiber on the polymeric matrix can be published (Khun et. al., 2014 and Li and Xia, 2009) .

1.2 Problem Statement

Carbon fibers and their composites represent new engineering materials possibilities. It is used to improve the material properties such as mechanical, physical and thermal properties, and growing in popularity due to its high strength & stiffness, and low density. One challenge with using this new material is what to do with it when the structure made is ready to be decommissioned. Generally, the options are to throw it away, incinerate it, or recycle it. Recycling makes sense from an economic and environmental perspective; however the carbon fiber composite recycling industry is only just beginning. Traditional methods have concentrated largely on disposal in landfill sites. Other approaches need to be developed for recycling and reuse because of decreasing landfill space and rising landfill costs.

The dumping of carbon fiber reinforced polymers (CFRP) waste in the landfill will reduce the space of waste disposal and raises concerns on waste disposal and consumption of non-renewable resources. The costing to disposal of waste material is also expensive and unprofitable comparing to their usage. In addition, it also causes negative effects to the environment like air pollution and hazardous condition in landfill. Thus, some alternatives to overcome this crucial issue by recycling or reusing again the CFRP by oxidation and thermal decomposition like pyrolysis process and fluidised bed should be taken. In whatever way, the recycling composite is inherently difficult because of their complex composition (fibers, matrix and fillers) and also the crosslinked nature of thermoset resins which cannot be remoulded (Pimenta et.al., 2010).

Recycled carbon fiber product has been successfully produced by advanced technology today such as injection molding, extrusion, melt compounding and laser lay up process (Callister, 2007). However, the performance and properties of materials of this recycled product has become the vital issue; whether their performance can be achieved as good as the virgin product. Therefore, this vital issue has stimulated the interest among the researchers to investigate the performance of the carbon fiber waste materials in terms of their properties.

Based on the work by Pimenta et al. (2010), it was proven that the recycling process affected the characteristic of recycled CFRP. It was found that fiber bundles — held together by minimal amounts of residual matrix not completely pyrolysed and also seen as a recycling defect such as incomplete removal of matrix and the fibers during remanufacturing led to a considerable degradation of tensile strength at the composite level. Other properties such as tribological properties and thermal properties of the recycled CFRP also were also affected.

Advanced technical applications of polymeric materials involve wear and friction often operating at high wear and friction condition such as break pad in automative manufacturing seal and gasket. In order to further exploit the economic advantages of polymeric materials and to tailor the performance of components to these ever increasing demands regarding the overall tribological, performance, and a fundamental assessment not only of the intrinsic materials properties but also of the complete tribo-system it requires. On the other hand, material properties such as degree of crystallinity, glass transition temperature (Tg), hardness and surface energy are factors that have been shown to influence the wear and friction behaviour of composites under various experimental conditions. The incorporation of carbon fibers into thermoplastic is expected to impart enhancement on the physical, mechanical and tribological properties of the composites. As to the method of improving the performance of thermoplastic properties by filler, very limited references have studied its reinforcement effect on the mechanical and tribological properties of thermoplastic materials filling by recycled carbon fibers (Li and Xia, 2009). The combination of both materials will be expected to produce results that could enhance the physical, mechanical and tribological properties of the composite.