UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TRIBOLOGICAL PROPERTIES OF CARBON FIBER PREPREG WASTE REINFORCED THERMOPLASTIC COMPOSITES PREPARED VIA MELT MIXING

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineerings (Engineering Materials) (Hons.)

By

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DECLARATION

I hereby, declared this report entitled "Tribological Properties of Carbon Fiber Prepreg Waste Reinforced Thermoplastic Composites Prepared via Melt Mixing" is the results of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree in Bachelor of Manufacturing Engineering (Engineering Materials) (Hons). The member of the supervisory committee is as follow:

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ABSTRAK

Serat karbon polimer bertetulang (CFRP) komposit telah digunakan secara meluas kerana prestasinya yang bagus dan ringan. Dengan penggunaannya yang berterusan dan meluas dalam aplikasi teknologi tinggi telah menyebabkan pengumpulan sisa yang terhasil daripada lebihan pembuatan dan juga prapreg yang telah tamat tempoh. Kedua-dua faktor eknonomi dan persekitaran telah memacu pembangunan kaedah penebusgunaan sisa CFRP yang terjana semakin bertambah. Oleh itu, laporan kerja ini membentangkan kajian untuk mengitar semula serat karbon plastik bertetulang CFRP, dan kajian ini memfokuskan kepada ciri-ciri tribological komposit berdasarkan sisa-sisa buangan .Kajian ini cuba untuk mencari alternatif bagi bahan sisa ini supaya dapat dimanfaatkan dalam industri sebagai sisa yang bermanafaat. Seterusnya, kajian akan dijalankan dengan menggunakan sifat-sifat tribologi sebagai alat untuk mengukur prestasi CFRP komposit kitar semula sama ada boleh menghasilkan keluaran yang terbaik atau tidak. Perbandingan CFRP kitar semula dan serat karbon baru (CF) dalam ujian tribological akan menentukan prestasi bahan-bahan buangan sebagai sisa bermanfaat atau tidak. Pemilihan matrik sebagai gabungan interaksi yang baik antara tetulang komposit telah mempengaruhi hasil kajian ini. Oleh itu, hipotesis yang boleh dibuat adalah kombinasi bagi kitar semula CFRP ke dalam matrik polipropilena telah meningkatkan sifat-sifat tribologi bagi komposit.

ABSTRACT

Carbon fibre reinforced polymer (CFRP) composites were been extensively used because of their excellent performance and lightweight. With continuous and widespread use of these composites in high-technology application cause its waste constantly accumulated and generated from manufacturing scrap and end-of-life prepregs. Both environmental and economic factors have driven the development of reclamation routes for the increasing amount of generated CFRP waste. Thus, this report presents the research for recycling carbon fibre reinforced plastics (CFRP), focusing on the tribological properties of the composite based on the waste materials This study tries to find some alternative for waste materials to take place in the industry as beneficial waste. Thus, the experiment was conducted by using the tribological properties as tool to measure the performance of the recycle CFRP composite whether can be come out with the best output or not. The comparison of the recycle CFRP and fresh carbon fiber (CF) in tribological testing was determine the performance of waste materials as a beneficial waste or not. The selection matrix as a good interaction between the reinforcements influences the results of the experiment. Thus, it was hypothesised that the incorporation of CFRP waste into polypropylene matrix will improve the tribological properties of the composites.

DEDICATION

I dedicate this work to my beloved parents for all their love & attention which has made it possible for me to make it up to this point and as well as to my helpful supervisor, Dr. Noraiham binti Mohamad, who bestowed me with the courage, the commitment and the awareness to follow the best possible route, by her unmatchable style and by best possible guideline. Last but not least, to my best and kindly mentor Ms. Juliana binti Yaakub, who are the best mentors in the world which never give up guiding me for this research. I would also like to thank all of my colleagues for their assistance, patients and friendship over the past four years.

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Thank you very much.

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LIST OF ABBREVIATIONS

BCC	-	Body-Centered Cubic
c-CF	-	Comminite Carbon Fibers
c-CFP	-	Communite Recycle Carbon Fiber Prepregs
CFRP	-	Carbon Fiber Reinforced Polymers
CH	-	Closed Packed Hexagonal
CMC	-	Ceramic-Matrix Composite
CNT	-	Carbon Nanotubes
DSC	-	Differential Scanning Calometry
EoL	-	End-of-Life
FCC	-	Face-Centered Cubic
FRP	-	Fiber Reinforced Polymers or Plastics
GFRP	-	Glass Fiber-Reinforced Polymer
MMC	-	Metal-Matrix Composites
PBCs	-	Polymer Based Composites
PC	-	Polycarbonate
PEEK	-	Polyether Ether Ketone
PEI	-	Polyethyleneimine
PMC	-	Polymer-Matrix Composite
PP	-	Polypropylene
PPS	-	PolyPhenylene Sulfide
r-CF	-	Recycled Carbon Fiber
r-CFP	-	Recycled Carbon Fiber Prepreg
SEM	-	Scanning Electron Microscopy
T_g	-	Glass Transition Temperature
TPCL	-	(ThermoPlastic Consolidated Laminate)
TPUD	-	(ThermoPlastic UniDirectional)
PP/r-CF	-	Recycled Carbon Fiber Reinforced Polypropylene
VGCF	-	Vapour Grown Carbon Fibre

PP/r-CFP	-	Recycled Carbon Fiber Prepreg Reinforced Polypropylene

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the usage of composite in the manufacturing field has become the mainstream in engineering materials.The superior properties and universal characteristics in improving the materials performance for specific application has lead to the reasons why composite is selected as favourite choice in high application technology. One of the famous composite used in the high technology application in these days is carbon fiber reinforced polymers (CFRP).This high performance composite materials has superior properties that gives them an edge over traditional materials which include longer life cycles due to high fatigue strength, increased corrosion resistance, improved fire resistance, easier design because of functional integration, possibility of complex shapes and lightweight.

Besides that, due to CFRP benefits in term of weight saving and performance work have caused increasing usage of composites in space and military systems, as well as in commercial aircraft development, is expected to be continuing far into the foreseeable future (Allred, 1999).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 (2009), the global production of carbon fiber was 27,000 tones in 2009 and is predicted to rise exponentially in the next 10 years. Most of the carbon fiber waste 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.

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). Increase of environmental awareness and new environmental protection laws made it unacceptable to dispose all composites on landfill sites (Buggy and Farragher, 1995). 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. By developing this method, it will significantly reduce for carbon fiber disposal at save, low cost and thereby producing a positive impact both environmentally and economically.

In recent years, polymeric matrices reinforced with glass and carbon fibers were being increasingly 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 (Bahadur *et al.*, 1990; Zhang *et al.*, 1998; 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 (Pal *et al.*, 2012). A great attention was given especially to the fibrous fillers because of the easy processing and the significant improvement in mechanical and tribological properties (Suresha *et al.*, 2000). Carbon fiber reinforcement, which dominates in the high performance applications due to its outstanding mechanical properties combined with low weight, have 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 recycledd carbon fiber on the polymeric matrix can be published. So, it is original and interesting to study the tribological and mechanical properties of the thermoplastic based composites reinforced with recycledd carbon fiber.

1.2 Problem Statement

The dumping of carbon fiber reinforced polymers (CFRP) waste in the landfill will reduce the space of waste disposal and produce raises concerns on waste disposal and consumption of non-renewable resources. The costing to disposal the waste material is also expensive and also unprofitable comparing to their usage. In addition, it also cause some negative effect 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 composites 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).

It cannot be denied that the recycled product is sucessfully produced by advanced technology today. However, the performance and properties of materials of these recycledd product has become the vital issue; whether their performance can be achieved as good as the first product or not. Therefore, this vital issue has stimulate the interest among the researchers to investigate the performance of the carbon fiber waste materials in term of their mechanical properties and tribological properties.

Based on the paper work by Pimenta *et al.*, (2010), it is proved that the characteristic of recycled CFRP was affected after the recycling process, 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. Then, another properties such as tribological properties and thermal properties of the recycled CFRP also will be affected too.

Today, many advanced technical applications of polymeric materials involve wear and friction often at elevated operation temperatures. In order to further exploit the economical advantages of polypropylene (PP) and to tailor the performance of components to these ever increasing demands regarding the overall tribological performance, a fundamental assessment not only of the intrinsic materials properties but also of the complete tribo-system in required. On the other hand, material properties such as degree of crystallinity, glass transition temperature (T_g), 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 will be expected to impart enhancement on the 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 polypropylene filling by recycled carbon fibers. Therefore, studies about the effect of recycled carbon fibers reinforcement on the mechanical and tribological properties of polypropylene would be an interesting work, and it is expected to offer some useful reference for developing and producing high quality polymer-based composites.

The tribological properties is seen as the critical issue in this study, due to the carbon fiber is one of the essential materials in the production of polymer composite for high technology application especially for the abrasive materials for cutting tools and shaft bearing. Out of condition carbon fiber prepreg waste are common in any composite manufacturing industry. The polypropylene is thermoplastic polymer which is excellent in their mechanical properties, rugged and resistant to lots of chemicals. Thus, the combination of both materials will be expected to produce results that could enhance the tribological properties of the composite.

1.3 Objectives

1. To prepare recycled carbon fiber prepreg reinforced polypropyelene (PP/CFRP) composite via melt mixing

2. To compare the tribological properties between recycled carbon fiber prepreg reinforced polypropylene and recycled carbon fiber reinforced polypropylene

3. To study the correlation of tribological properties on morphological properties recycled carbon fiber prepreg reinforced polypropylene

1.4 Scopes

This research is focusing on a composite made of recycled carbon fiber prepreg in polypropylene matrix via melt mixing. The tribological properties of recycled carbon fiber prepreg reinforced polypropylene composite (PP/r-CFP) will be compared with recycled carbon fiber reinforced polypropylene composite (PP/r-CF). The tribological properties of recycled carbon fiber reinforced polypropylene will be characterized by a tribological testing (pin on disk). The findings will be further supported by analysis such as differential scanning calometry (DSC) and scanning electron microscopy (SEM).

1.5 Chapter Overview

This research is divided into five chapters that describe the analytical and experimental research performed. The First Chapter is an introduction to the study that brief about objectives, problem statement, significant of study and the thesis overview. Chapter Two presents the published literature reviews that are relevant to the theories on advanced composites and previous investigations on the issues and current reclamation of carbon fiber efforts. The important element that is included in this chapter is about the materials and process involved and also related experimental testing. Chapter Three, provides details explanations on the methodology used for overall research work, raw materials, characterization of the materials, samples preparation and procedure property analysis and testing. In Chapter 4 were discusses the observations, results, analysis and evaluation done throughout the study and recommendation or suggestion for future works and improvement for this research were discussed in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Tribology

If we talk about tribology it will deal with relative motion of surfaces, the friction of surfaces, the wear resistance of materials, and also the abrasion resistance of the materials. This is the common words that the people classify the definition of tribology. However, in more pedantic definition of tribology, it is describes as a science and technology of surfaces that are in contact and relative motion, as well as supporting activities that should reduce costs resulting from friction and wear (Brostow *et al.*, 2010). Indeed, it is well-known that an improvement of the mechanical properties can be effectively achieved by including “small” inorganic particles in the polymer matrices (Dasari *et al.*, 2009).

Previously, the traditional tribology originally can be applied for the metals and ceramics only. It not suitable to apply the tribological testing to polymer based composites (PBCs) because they have some difficulties in their properties. First, PBCs are viscoelastic and their properties are depending on time and this is very contrast compare to metals and ceramics properties. Second, external liquid lubricants, which work well for other classes of materials, are easily absorbed by PBMs. It will show swelling in the result. Actually in traditional experimental methods of wear determination is only based on the amount of debris formed are not well usable for PBCs since often there is no debris - while there is significant material displacement (top ridge formation, densification) (Brostow *et al.*, 2010).
However in (2006) the developing tribology of PBCs also taking into account some other aspects such as viscoelasticity, materials brittleness and besides connections of brittleness to recovery in sliding wear determination, relation of friction and scratch

resistance to surface tension, and the effects of magnetic fields on polymer tribology (Brostow *et al.*, 2010).

The purpose of the research in tribology is to minimize and remove losses that occur due to friction and wear at all levels, where rubbing, grinding, polishing, and cleaning of surfaces take place. The tribological parameters include surface roughness, mechanisms of adhesion, friction and wear, and physical and chemical interactions of lubricants (if present). Wear represents a surface damage or removal of material from one or both sides of solid surfaces that are in contact during motion (Brostow *et al.*, 2010). However, in most cases, wear is caused by surface interactions on the surface irregularities. The phenomenon of wear occurs when two solid surfaces in contact are sliding relatively to each other. It is sometimes common to call erosion of the surface of interest “wear” and erosion of the counter surface “abrasion” or “galling.” Wear processes have been classified into four categories of principles: abrasion, adhesion, surface fatigue and tribochemical wear. Figure 2.1 showed the description of tribology interacting with other sciences and technology.

Whereas, the friction is a force of resistance to the relative motion of two contacting surfaces, so that a low coefficient of friction is required for a bearing material (Jiao, Wang and Kutsovsky, 2008). There are two coefficients of friction. In a stationary specimen, the static coefficient of friction applies: The static coefficient of friction is the force required to create motion divided by the force pressing mating surfaces together. With a specimen in motion, the dynamic coefficient of friction applies: The dynamic coefficient of friction is the force required to sustain motion at a specified surface velocity divided by the force pressing mating surfaces together. The lower the coefficient of friction, the easier the two surfaces to slide over each other. The coefficient of friction varies with applied load, velocity and temperature.

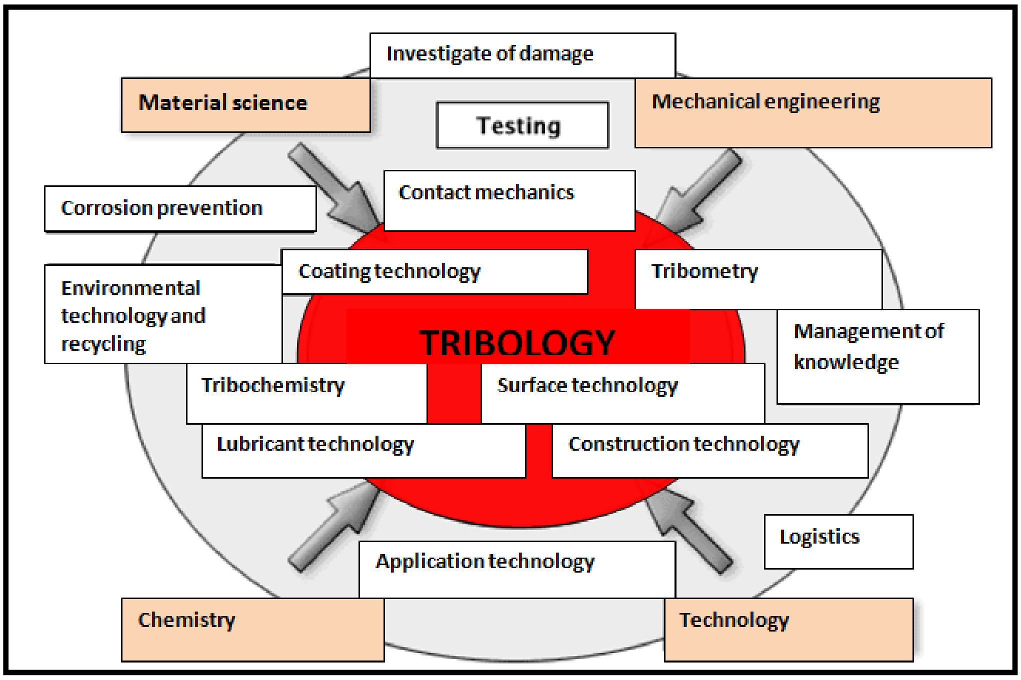

Figure 2.1: The description of tribology interacting with other sciences and technology (source :< http://www.emeraldinsight.com/journals.htm?articleid=874631&show=html>29/11/13)

2.2 Tribological Properties of Materials

Tribological properties are very wide range of research because it depends on the type materials and the behaviour of the materials. Actually there is no fixed and standard formula to evaluate all the tribological properties in term of all materials. This is because the different types of materials have differences in their microstructure and materials characterizations. As we know, the tribological properties are something that are related to the abrasion resistance, friction and wear resistance of materials (Gualtier, 2004). However, in the nowadays industry, there are lots of materials used are suitable to their application including all ceramic, metal., polymer, and composite material without any concern on their tribological properties.

According to Brostow *et al.*, (2010) it is known that the ceramic materials are very brittle, and that even shallow scratching may be accompanied by deformation that