UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Wear Behavior of Carbon Nanotube (CNT)/Short Natural Fiber Reinforced Epoxy Composite

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

by

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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 of Bachelor of Manufacturing Engineering (Engineering Materials) (Hons.). The member of the supervisory is as follow:

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ABSTRAK

Prestasi sifat tribologi serat semulajadi polimer komposit didapati telah berjaya di tingkatkan, tetapi, beberapa faktor perlu diambi kira sebelum komposit ini diterima pakai dengan meluas berbanding penggunaan serat sintetik. Maka, ianya dipercayai bahawa pemerbadanan *funtionalized nanomaterial* dapat membantu meningkatkan lagi prestatsi tribologi serat semulajadi polimer komposit. Fokus kajian ini bertujuan untuk menganalisa sifat kehausan karbon nanotuib (CNT) dan serat kenaf yang pendek epoksi komposit (EP/KNF/CNT) pada kadar fungsi CNT yang berbeza. Komposisi komposit telah dihasilkan dari kuantiti malar 4 wt% serat kenaf dan kadar campuran CNT yang berbeza iaitu 0.1, 0.3 dan 0.5wt%. Bagi memastikan daya lekatan antara serat dan matrik, serat kenaf telah di rawat dengan 6% natrium hidroksida dan fungsi karboksil CNT telah digunakan. Komposit yang dibentuk melalui process *vacuum casting* menunjukkan kadar liang kosong rendah dari 1%. Ujian tribologi ke atas komposit telah dijalankan pada daya normal 40 N, pada dua kelajuan yang berbeza (1 dan 2 m/s) untuk jarak sejauh 3.75 km. Umumnya, penambahan serat kenaf telah menurunkan kadar spesifik kehausan epoksi dan penambahan CNT meningkatkan lagi ketahanan kehausan komposit. Bagaimanapun, kadar spesifik kehausan pada 1 m/s lebih tinggi dari 2 m/s kerana *abrasive wear* diperhatikan telah berlaku pada halaju 1 m/s manakala *adhesive wear* berlaku pada halaju yang tinggi. Daripada semua komposit, EP/KNF/CNT0.5 komposit menunjukkan kadar ketahanan kehausan yang hebat dengan 90.2% peningkatan pada 1 m/s dan 75.4% peningkatan pada 2 m/s halaju luncur berbanding epoksi tulen. Sebaliknya, terdapat perubahan yang tidak menentu pada pekali geseran disebabkan oleh perubahan kestabilan dimensi komposit terhadap haba geseran yang terhasil menghampiri paras suhu peralihan kaca komposit.

ABSTRACT

Tribological performance of natural fiber reinforced polymer composite is found to be improved but there are some consideration that need to be adressed before natural fiber-reinforced polymer composite gain widespread acceptance as compared to synthetic fiber ones. Thus, it is perceived that incorporation of functionalized nanomaterials may help to improve the tribological behavior of the natural fiber reinforced polymer composite. This study aimed to investigate the dry sliding wear behavior of carbon nanotubes (CNT) and short kenaf fiber reinforced epoxy (EP/KNF/CNT) composite as a function of CNT loading. The composition of the composite was made up of a constant 4 wt% of kenaf fiber and varying CNT loading at 0.1, 0.3 and 0.5 wt%. To ensure better fiber-matrix interfacial adhesion, the kenaf fiber was treated with 6% sodium hydroxide and carboxyl-functionalized CNT was used. The composite fabricated via vacuum casting technique which exhibited less than 1% of void inclusion. Tribological testing of the composite was conducted at 40N load at two different sliding velocities (1 and 2 m/s) for a distance of 3.75 km. Generally, addition of kenaf fiber reduced the specific wear rates of pristine epoxy and further incorporation of CNT enhanced the wear resistance of the composite. However, it was noted that the specific wear rates at 1 m/s is higher than that of 2 m/s because abrasive wear was observed in the former one while adhesive wear was more profound in the latter. Among all, EP/KF/CNT0.5 composite showed a superior wear resistance behaviour with 90.2% improvement at 1 m/s and 75.4% improvement at 2 m/s sliding velocity as compared to the pristine epoxy. On the other hand, there was erratic change on the coefficient of friction of the composite due to the dimensional instability of the composite in regard to frictional heat generated which was closed to the glass transition temperature of the composite.

DEDICATION

To my beloved parents and family, supervisor, co-supervisor, lecturers and friends.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

C	-	Carbon
CMC	-	Ceramic Matrix Composite
CNT	-	Carbon Nanotube
COOH	-	Carboxylic Groups
CuF	-	Fluoride Copper
CuO	-	Oxide copper
CuS	-	Sulfide Copper
EP	-	Epoxy
EP/KNF	-	Epoxy/ 4wt% Kenaf
EP/KNF/CNT0.1	-	Epoxy/ 4wt% Kenaf/Carbon nanotube 0.1wt%
EP/KNF/CNT0.3	-	Epoxy/ 4wt% Kenaf/Carbon nanotube 0.3wt%
EP/KNF/CNT0.5	-	Epoxy/ 4wt% Kenaf/Carbon nanotube 0.5wt%
FTIR	-	Fourier Transform Infrared
H	-	Hydrogen
MMC	-	Metal Matrix Composite
MoS_2	-	molybdenumdisulfide
MWCNT	-	Multi-walled Carbon nanotubes
O_2	-	Oxygen
OH	-	Hydroxyl
PA6	-	Polyamide 6
PEEK	-	Polyetheretherketone
PI	-	Polyimide
PMC	-	Polymer Matrix Composite
PTFE	-	Polytetrafluoroethylene
SiC	-	Silicon Carbide
SRFP	-	Short fiber reinforced polymer
Tg	-	glass transition temperature

TiO	-	Titanium Oxide
UHMWPE	-	Ultra high molecular weight polyethylene

F_F	-	Frictional forces
F_N	-	Normal load
R_a	-	Average roughness
µ	-	Coefficient of friction
GPa	-	Gigapascal
m/s	-	Meter per second
MPa	-	Megapascal
ºC	-	Degree Celcius
p	-	Pressure
T_g	-	Gass transition temperature
v	-	Velocity
Ws	-	Specific wears rates
Wt%	-	Weight Percent
ΔV	-	Loss in volume

CHAPTER 1

INTRODUCTION

This chapter provides the background, problem statement, objective as well as scope of the study.

1.1 Background of study

“Tribology” was derived from the Greek word tribos which means rubbing. The science of tribology is comprised from three factors, which are friction, wear and lubrication of materials. In the application perspective, it deals with interface between two or more bodies in relative motion such as bearing, gears, piston-cylinder assembly and etc. Friction is the resistance to motion that occurs whenever one solid body is in contact with another solid body (Brostow *et al.*, 2010). The root of friction between two surfaces in relative motion is the key to finding answer to the ever-increasing problems of huge financial losses due to wear and friction (Chand *et al.*, 2008). The wear represents a surface damage or removal of material from one or both side of solid surface that are in contact during motion. The irregularity of the surface is the reason of wear occurs and would result in dimensional changes of the component and causes damage to the surface.

Nowadays, advanced materials such as polymer matrix composite (PMC), metal matrix composite (MMC) ceramic matrix composite (CMC) and carbon-carbon composite comprise the four main groups of tribo-materials. Among these materials, PMC have showed immerse potential because of their self lubrication properties, lightweight and resistance to wear, corrosion and organic solvent (Thomas *et al.*, 2007). The promising phenomena when polymers slide against metal counterface, is the formation of transfer film. Bahadur *et al*. (1999) mentioned that the role of transfer film in polymer-metal sliding contact has long been realized as being responsible for the gradual transition from a transient wear behaviour to steady state wear behaviour. Also, it is widely believed that transfer films provide shielding of the soft polymer surface from the hard metal asperities. As most polymers are self-lubricating materials, the transfer film of polymer can act as a lubricant so that the coefficient of friction is much lower.

For polymers that posses high specific wear rates in the unreinforced condition, incorporation of almost any type of reinforcing fibers would result in significant reduction in wear and improve mechanical properties (Chand *et al.,* 2008). The commonly used synthetic fibers such as glass, carbon, graphite and aramid are available as short, long fiber or fabric for reinforcement in thermoset as well as thermoplastic. Among the numerous fibers used for PMC, Kim *et al.* (2011) reported that glass fiber-reinforced PMC shows good tribological properties due to the superb bond strength with the matrix, but it may cause damage the counter surface by abrasion. The presence of continuous fiber reinforcement in plastic shows higher wear resistance than that of short fiber reinforced polymer. The fact is that higher length-to-fiber ratio results in more contact load transfer from matrix to fiber (Stachowiak, 2006; Chand *et al.,* 2008). However, short fiber reinforced polymer are more favoured because of the potential for easy, cost effective and rapid moldability (Bahadur *et al*., 1990)

On the other hand, effect of particulate reinforcement or fillers such as oxide copper (CuO), sulfide copper (CuS), fluoride copper (CuF), silicon carbide (SiC), titanium oxide (TiO) are also well-known to enhance mechanical and tribological properties of polymer composite (Chang *et al.,* 2010). The improvement of wear resistance due to either enhancement of modulus and hardness of materials or improved bonding between transfer film and metallic counterpart. Apart from that, when inoganic particles are used to combination with functional fillers such as polytetrafluoroethylene (PTFE), short-glass ,aramid and carbon fiber polymer with high wear resistance can be obtained (Stachowiak, 2006; Chand *et al.,* 2008).

Recently it was found that the contact surface was reduced with the presence of nanoparticles, in such a way that stress concentration on the individual fiber was minimized with dispersed nano-filler in contact region which consequently protected the polymer matrix in the interfacial region from the thermal mechanical failure (Stachowiak, 2006).

The major drawback of using synthetic fiber in tribo materials is about the environmental issue. The production of synthetic composite requires huge energy consumption and the environmental quality has suffered because of the pollution generated during the production and recycling of these synthetic fibers (Kalia *et al.*, 2009). At present, the interest in using natural fibers (such as flax, hemp, jute, sisal, kenaf, flax and coir) as reinforcement for polymeric composite has increased due to their lightweight, renewability, low density, high specific strength, non abrasivity, combustibility, non toxicity, low cost and biodegrability (Aji *et al.*, 2009). However, challenges in utilizing natural fiber as reinforcement is the lack of interfacial adhesion between the matrix and fibers due to the hydrophilicity of natural fiber (Yousif *et al.*, 2012)

Therefore, Chand *et al.* (2008) have conducted a study on the effect of chemical treatment (silane) of sisal fiber on the tribological behavior of the sisal/polyester composite and concluded that treated sisal fiber/polyester composite have greater specific wear rates that untreated sisal fiber/polyester composite. The poor bonding between untreated fiber and matrix resulted in ease of fiber pull out and fiber debonding during dry sliding with metallic counterface. As review by Chin *et al.* (2009) they found that the kenaf fiber has a strong interfacial adhesion with polymers and thus it is superior than other natural fibers such as oil palm, sugarcane and jute. Besides, it is said that the presence of kenaf fiber have improved wear performance of epoxy about 85% but varies with the sliding direction on the fiber orientation. Thus, natural fiber serves as an important potential as tribomaterials.

1.2 Problem Statement

Recently many natural fibers have been studied in a view to ensure their optimum utilization in developing tribo-compsite. Kenaf fiber is the most promising natural fiber used as reinforcement in polymer matrix due to it good mechanical properties along with having economic and ecological advantages. Many research has been carried out to study what extend they satisfy the required specification for good natural fiber based-reinforced polymer composite for tribological application. The challenges of incorporating natural fiber into a polymer matrix is the lack of good interfacial adhesion between the two components which would affect the wear behavior of natural fiber composite. Other than that, the thermal stability of natural fiber composite imposes limitation in application at high temperature which causes degradation of the fiber organic structure. These limitations are highly concerned because materials subjected to wear would expose to the material removal process and accumulation of frictional heat at the counterface. Thus, incorporation of nanoparticulates such carbon nanotube (CNT) may serve to improve the interfacial properties and thermal stability of natural fiber composite as well as the wear behaviour. Furthermore, technique to fabricate this composite via vacuum casting has not been explored and it is a new venture to fabricate near-net shaped composite component. This technique may also serve an improvement of the mechanical and physical properties of end products.

1.3 Objective

The objectives of this study are as follows:

1. To fabricate Carbon Nanotube (CNT)/ short kenaf fiber reinforced epoxy composite with different CNT loading via vacuum casting technique
2. To analyze a characteristic of composites in terms of physical, thermal, chemical and morphological properties.
3. To study wear behavior of CNT/ short kenaf fiber reinforced epoxy composite in term of specific wear rates and coefficient of friction via pin-on-disc wear test.

1.4 Scope

The scope of this study is mainly focusing on the wear behaviour of polymer composite of epoxy reinforced with kenaf fiber as micro filler and carbon nanotube as nano filler. The loading of short kenaf fiber is remained constant at 4 wt% while the loading for CNT varied at 0.1, 0.3 and 0.5 wt%. dispersion of CNT process is performed by ultrasonication while the vacuum casting technique is used to produce void-free composite samples. The study include characterization of molecular interaction among the constituents in the CNT and kenaf fiber, determination of physical properties, thermal behaviour of the composite, as well as tribological properties under dry sliding test of the composite. The wear test was carried out with the application of two different sliding velocities (i.e. 1 and 2 m/s), at a constant load of 40 N and constant sliding distance of 3.75 km**.** The topological characteristic of the composite after dry sliding wear test is also studied to examine the wear mechanism.

CHAPTER 2
LITERATURE REVIEW

A review on previous research work in various area which relevant to this research is presented in this chapter.

2.1 Tribology

"Tribology" is defined as the science and technology of interacting surface in relative motion, having its origin in the Greek words *tribos* meaning rubbing. Its is a study of the friction, wear and lubrication of materials. Tribology is the science and technology of interacting surface in relative motion or more simply expressed the study of friction, wear and lubrication (Cziochos, 1986). In the application perspective, it deals with interface between two or more bodies in relative motion. In any machine there are lots of component parts that operate by rubbing together such as bearings, gears, cams and tappets, piston cylinder assembly, bushing and etc.

Friction is the resistance to motion that occurs whenever one solid body is contact with another solid body (Stachowiak *et al.*, 2010). In human life, friction must be exists in order to make thing work such as during walking, holding an object, contact between tires and road need some friction to move and etc. Sometimes, it is desirable to have high friction as in the case of brakes or low friction to save energy. Respecting to the moving parts in such machine or engine, almost no friction is required because interaction between two interface cause friction and wear of material involves. Undesirable of wear mechanism need to be avoided thus, people use a lubricant to prevent such high friction which causes wear.

Suh (1986) as cited by Chand *et al.*, (2008), wear is defined as the progressive loss material from the operating surface of body as result of relative motion at the surface. The wear would result the dimensional change and irregularities on the contact surface either both side or one side. The dimensional would affect the efficiency of the operating component. While some types of material removal are beneficial (cutting, grinding and polishing), wear of single component (e.g. a bearing in the main rotor of a helicopter) can lead to catastrophic failure (Tuszynski, 1995).

2.1.1 Classification of Wear

Material can be removed from a solid surface by melting or sublimation, by chemical dissolution, or physical separation of atoms from the surface Ludema, (1992). In the wear process, the amount of material removed is quite small which makes its difficult to detect wear by casual inspection. However, the changed in shape, like obsolescence and surface damage in some parts, becomes very obvious. Refers to Tuszynski (1995) and Chand *et al.* (2008), the common forms of wear are defined as follows:

i. *Abrasive wear*: Abrasive wear occur when a hard, solid particle or asperity comes in contact with a softer surface. The softer surface experience both material loss and deformation of the remaining portion.

ii. *Adhesion wear*: Adhesive wear occurs when surface in contact bond together through local welding of asperities or cohesive bonding. If the bonded junction are stronger than one of the solid, wear arise from a shearing process within the solid

iii. *Fatigue wear*: Fatigue wear is a result of periodic stress variation between wearing surfaces. Even though the forces may be less than that required to permanently deform the material, local fatigue produces cracks that eventually lead to removal of relatively large pieces of material in the form of pitting, spalling or flaking

iv. *Chemical or corrosive wear*: This type of wear is found when chemical reaction occurs along with mechanical wear. This form of wear may lead to a