Faculty of Mechanical Engineering

WEAR FAILURE ANALYSIS OF EMPTY FRUIT BUNCH AND KENAF FIBRES COMPOSITES

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DECLARATION

I declare that this thesis entitled "Wear Failure Analysis of Empty Fruit Bunch and Kenaf Fibres 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.

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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 Mechanical Engineering.

Signature :……………...

Supervisor Name :……………………….....................................

Date :……………………….......................................

DEDICATION

To my beloved family

ABSTRACT

Several investigations have been explored the influence of test conditions, contact geometry and environment on the frictional and wear behaviour of polymers and composites. However, there is a lack of understanding about the tribological behaviour of thermoset composites based on natural fibres. Furthermore, the wastes of empty fruit bunches are abundantly available and have reached a level that severely threats the environment. Therefore, it is a great need to find useful applications of those waste materials. Kenaf also grown commercially and it is certainly one of the important plants cultivated for natural fibres globally. It has great potential to use as automotive and construction materials. The aim of this study is to compare the tribological characteristics of Empty Fruit Bunch Fibre/Epoxy (EFBF/E) composites to those of Kenaf Fibre/Epoxy (KF/E) composites. The matrix material used for the present investigation is epoxy resin as the most commonly used polymer matrix with reinforcing fibres for advanced composites applications and provide good performance at room and elevated temperatures. A pin sample with a diameter of 10mm was made using the hot compaction technique. The tribological test was carried out using a pin-on-disc tribometer in dry sliding conditions by applying various temperatures from 23 ^{o}C to 150 ^{o}C and it was further tested against JIS-SKD 11 (AISI D2) steel disc. Different fibre loadings were prepared in a range of 30 %-70 % weight percentage for both composites. The results revealed that increasing the temperature leads to increased wear and decreased friction coefficient for both composites. The surface morphology of worn surfaces was also presented to analyse the wear mechanism using Scanning Electron Microscopy (SEM). A wear mapping approach was undertaken to present a clear comparison of wear transition and wear mechanism for both composites. This resulted in increased fibre composition for the EFB leading to severe wear, while the fibre composition of the KF showed better wear performance. Conclusively, EFBF/E can be considered as a tribo-material with great potential, such as in bearing applications and for KF/E composite can expands as the potential of friction materials. However, wear improvement is required further study. The predominant wear mechanisms for the EFBF/E composite and KF/E composite are related to adhesive and abrasive wear.

ABSTRAK

Terdapat beberapa siasatan telah mengkaji pengaruh keadaan ujian, geometri sentuhan dan persekitaran terhadap kadar geseran dan kadar kehausan polimer dan komposit. Walaubagaimanapun, terdapat kekurangan pemahaman mengenai tingkah laku tribologi komposit termoset berasaskan serat semula jadi. Tambahan pula, sisa tandan buah kosong adalah begitu banyak dan telah mencapai tahap yang boleh mengancam alam sekitar. Oleh itu, ia adalah satu keperluan yang besar untuk mencari aplikasi yang berguna daripada bahan-bahan buangan. Kenaf juga ditanam secara komersial dan ia sudah pasti salah satu tumbuhan yang penting untuk gentian asli di peringkat global. Ia mempunyai potensi yang besar untuk digunakan sebagai bahan automotif dan pembinaan. Tujuan kajian ini adalah untuk membandingkan ciri-ciri tribologi terhadap serat buah tandan kosong / epoksi komposit (EFBF/E) dengan serat kenaf / epoksi (KF/E) komposit. Sampel pin dengan diameter 10 mm dibuat menggunakan teknik pemadatan yang panas. Ujian tribologi telah dijalankan dengan menggunakan tribometer pin-pada-cakera dalam keadaan gelongsor kering dengan menggunakan pelbagai suhu dari 23 ℃ hingga 150 ℃ dan telah diuji terhadap cakera keluli "JIS-SKD 11(AISI D2)". Komposisi serat yang berbeza telah disediakan dalam lingkungan 30 % -70 % peratusan berat untuk kedua-dua komposit. Keputusan menunjukkan bahawa peningkatan suhu menyebabkan kadar kehausan meningkat dan penurunan pekali geseran untuk kedua-dua komposit. Mikrostruktur permukaan kehausan juga turut dipersembahkan untuk kajian mekanisma kehausan dengan menggunakan mikroskop elektron pengimbas (SEM). Pendekatan peta kadar kehausan telah dijalankan untuk perbandingan yang jelas terhadap peralihan kehausan dan mekanisma kehausan untuk kedua-dua komposit. Keputusannya adalah peningkatan komposisi gentian EFB membawa kepada kehausan yang teruk manakala peningkatan komposisi serat daripada KF menunjukkan prestasi kehausan yang lebih baik. Kesimpulannya, EFBF/E boleh dianggap sebagai bahan tribologi yang mempunyai potensi yang tinggi untuk aplikasi galas dan untuk KF/E komposit boleh berkembang sebagai bahan-bahan geseran yang berpotensi. Walau bagaimanapun, penambahbaikan dalam kadar kehausan memerlukan kajian lanjut. Mekanisma haus utama bagi EFBF/E komposit dan KF/E komposit berkaitan dengan haus lekatan dan haus lelas.

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LIST OF ABBREVIATIONS AND SYMBOLS

KF	Kenaf Fibre
EFBF	Empty Fruit Bunch Fibre
SEM	Scanning Electron Microscope
PMCs	Polymer Matrix Composites
MMCs	Metal Matrix Composites
CMCs	Ceramic Matrix Composites
NFCs	Natural Fibre Composites
MPOB	Malaysian Palm Oil Board
BOD	Block-On-Disc
POD	Pin On Disc
T-KF	Treated Kenaf Fibre
UT-KF	Un-treated Kenaf Fibre
OPRP	Oil Palm Fibre Reinforced Polyester
T-OPRP	Treated Oil Palm Fibre Reinforced Polyester
UT-OPRP	Un-Treated Oil Palm Fibre Reinforced Polyester
KFRE	Kenaf Fibre Reinforced Epoxy
KPEC	Kenaf Polyester Composite
KEC	Kenaf Epoxy Composite
NE	Neat Epoxy
NP	Neat Polyester
G-E	Glass-Epoxy
OPWF	Oil Palm Wood Flour
OPF	Oil Palm Fronds
OPT	Oil Palm Trunks
PALF	Pineapple Fibre
BMBFRE	Bamboo Fibres Reinforced Epoxy
SCRP	Sugarcane Fibre/Polyester
CFRP	Coir Fibres Reinforced Polyester

T-BFRP	Treated-Betelnut Fibres Reinforced Polyester
UT-BFRP	Untreated-Betelnut Fibres Reinforced Polyester
SP (T-SP)	Treated- Sisal Fibres/Polyester Composite
SP (UT-SP)	Untreated- Sisal Fibres/Polyester Composite
CGRP	Chopped Strand Mat Fibreglass Reinforced Polyester
GRP	Glass Fibre/Polyester
PVC	Polyvinyl Chloride
NaOH	Sodium Hydroxide
HCL	Hydro Chloric Acid
VARTM	Vacuum Assisted Resin Transfer Molding
RTM	Resin Transfer Molding
SMC	Sheet Molding Compound
PE	Polyethylene
PET	Poly (Ethylene Terephthalate)
PHA	Poly (Hydroxyalkanoate)
PLA	Poly (Lactic Acid)
PP	Polypropylene
PU	Polyurethane
PEEK	Polyether Ether Ketone
PHB	Polyhydroxybutyrate
Ws	Specific Wear Rate
COF	Coefficient Of Friction
N-O	Normal Orientation
P-O	Parallel Orientation
AP-O	Anti-Parallel Orientation
R-O	Random- Orientation
TGA	Thermogravimetric analysis
Vf	Volume fraction
wt.%	weight percentage of fibre composition
De	Debonding
Dl	Delamination
Db	Debris
Fr	Fracture

Cr	Micro-Crack
Fg	Fine Grooves
Tf	Torn Fibre
Bf	Broken fibre
Df	Plastic deformation

LIST OF PUBLICATIONS

JOURNAL PAPER

1. **F.F. Shuhimi**, M.F.B. Abdollah, M.A. Kalam, H.H. Masjuki, A. Mustafa, H. Amiruddin, *Tribological characteristics comparison for oil palm fibre/epoxy and kenaf fibre/epoxy composites under dry sliding conditions*, Tribology International, 101 (2016), pp. 247-254. DOI: http://dx.doi.org/10.1016/j.triboint.2016.04.020 (ISI Q1).
2. **F.F. Shuhimi**, M.F.B. Abdollah, M.A. Kalam, H.H. Masjuki, A. Mustafa, S.E. Mat Kamal, H. Amiruddin, *Effect of operating parameters and chemical treatment on the tribological performance of natural fibre composites: A review*, Particulate Science and Technology (2016), In Press. DOI: http://dx.doi.org/10.1080/02726351.2015.1119226 (ISI Q3).

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1. **F.F. Shuhimi**, M.F.B. Abdollah, M.A. Kalam, H.H. Masjuki, A. Mustafa, H. Amiruddin, *Surface Durability Of Oil Palm Fibre/ Epoxy Composite At Various Temperature,* Proceedings of Mechanical Engineering Research Day 2016, Melaka, 31 March 2016, pp.108-109.
2. **F.F. Shuhimi**, M.F.B. Abdollah, M.A. Kalam, H.H. Masjuki, A. Mustafa, H. Amiruddin, *Surface Durability Of Kenaf Fibre/Epoxy Composite With Different Fibre Compositions At Various Temperatures*, Ist My Tribos Colloquium 2016(MTC 2016), 26th January 2016, School Of Mechanical Engineering, Engineering Campus Universiti Sains Malaysia.
3. **F.F. Shuhimi**, M.F.B. Abdollah, M.A. Kalam, H.H. Masjuki, A. Mustafa, S.E. Mat Kamal, H. Amiruddin (2014). *Effect of Applied Load, Sliding Speed and Fibre Orientation on the Wear Performance Of Natural Fibre Composites: A Review*, 2nd Advanced Materials Conference, 25th-26th November 2014, Langkawi Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Background

Owing to their potential as reinforcements in polymers, natural fibre polymer composites have had numerous applications in nearly every field of engineering e.g. automobiles, furniture, packing and construction (Shalwan and Yousif, 2013). Therefore, these composites can greatly impact socio-economic development (Chand and Mohammed, 2008). There are many types of natural fibres such as Kenaf (Nishino et al., 2003; Akil et al., 2011; Chin and Yousif, 2009), flax (Goutianos et al., 2006; Bos, 2004) oil palm (Yousif and El-Tayeb, 2007a; Kalam et al., 2005; Hassan et al., 2010), hemp (Pickering et al., 2007), sisal (Idicula et al., 2005), jute (Yallew et al., 2014), bamboo (Rassiah and Ahmad, 2013) and banana (Sakthive and Ramesh, 2013) fibre. The development of high-performance engineering products from natural resources is increasing due to the superior advantages of these resources over traditional glass fibres.

The current research focuses on Empty Fruit Bunch Fibre (EFBF) from oil palm and Kenaf Fibre (KF) as natural reinforcements EFBF has indicated great potential as a reinforcing material. This is of significant relevance to Malaysia as a large quantity of the biomass is generated by oil palm industries (Mohanty et al., 2005; Bakar et al., 2005; Hassan et al., 2010). Besides to utilize the waste materials for a better benefit, EFBF also have great physical and mechanical properties of the material as well that could replace synthetic fibres (Koguleshun et al., 2015). The incorporation of empty fruit bunch (EFB) into polymers to obtain cost reduction and reinforcement has been reported by various workers (Yusoff et al., 2009).

KF has a long history of cultivation in some areas of the world such as Bangladesh, Australia, Thailand, parts of Africa and Malaysia (Aji et al., 2009). It is not only produced for its use in composites but also as a viable source of raw materials for applications such as food and bio-fuel processing. All these factors make kenaf a commodity of interest, especially in developing countries (Faruk et al., 2012; Shalwan and Yousif, 2013). As part of the environmental sustainability efforts, natural fibres have been used to reinforce materials for over a thousand years (Nosonovsky and Bhushan, 2012). Moreover, the remaining empty fruit bunches are very numerous and it is a great need to find useful application of those waste materials as well as Kenaf that also grown commercially and it is certainly one of the most important plants cultivated for natural fibres globally. It has great potential to use as automotive and construction materials.

Generally, natural fibres consist of cellulose, hemi-cellulose, lignin, pectin, waxes and water soluble substances (Xess, 2012). The properties of natural fibres are greatly influenced by their chemical compositions. It is evident that the tensile strength of glass fibre is significantly higher than that of natural fibres although the modulus follows the same order, as summarised by John and Anandjiwala (2008). However, natural fibres have advantages in higher specific modulus and therefore have better specific properties preferred for weight sensitive applications (Xess, 2012).

Natural fibres were introduced with the intention of yielding lighter composites and lower costs compared to the existing fibre glass reinforced polymer composites. The low density of natural fibres is very beneficial to the automotive industry (Zini and Scandola, 2011). Natural fibres have a lower density (1.2–1.6 g/cm3) than that of glass fibre (2.4 g/cm3), which ensures the production of lighter composites (Huda et al., 2006).

The development of natural fibre reinforced composites for use as green friction products in automotive applications is important to minimise the environmental implications caused by asbestos-based products (Nosonovsky and Bhushan, 2012). Nowadays, industrial engineering faces problems of friction and wear which can lead to the replacement of components and assemblies in engineering (Unal et al., 2004). The shortage is mainly related to the lifetime of the machinery (Holmberg et al., 2012).

Several researchers, such as Kato (2000), and Chowdhury and Helali (2006), have observed that frictional force and wear rate depend on the roughness of the rubbing surfaces, relative motion, type of material, temperature, normal force, stick slip, relative humidity, lubrication and vibration. The parameters that dictate the tribological performance of polymer and its composites also include polymer molecular structure, processing and treatment, properties, viscoelastic behaviour, surface texture, etc. There have been a number of investigations exploring the influence of test conditions, contact geometry and environment on the frictional and wear behaviour of polymers and composites.

Tribological properties have been an area of interest for many scholars and researchers. Frictional and wear performance have been the points of focus for many researchers like Bajpai et al. (2013) and Yousif (2013) with respect to a composite‟s application in brakes, clutches, bearing, bolts and nuts. On the other hand, Shalwan and Yousif (2013) have clarified that friction is the value of energy which dissipates at the material‟s contact surface. In literature, there is an evident lack of understanding about the tribological behaviour of thermoset composites based on natural fibres. This lack has significantly motivated the current study.

1.2 Problem Statement

The use of natural fibre composites in various applications has opened up new avenues for academics as well as industries to manufacture a sustainable module for future applications. Natural fibre reinforced composites are emerging very rapidly as the potential substitute to metal or ceramic-based materials in automotive, aerospace, marine, sporting and electronic industries (Pickering et al., 2015). Natural fibre composites exhibit good specific properties, but have a high variability. Such shortcomings can be overcome with the development of advanced processing techniques for the natural fibres and their composites (Chan and Stachowiak, 2005).

The tribological performance of natural fibre/polymer composites is an important element of mechanical part designs. However, tribological and mechanical properties have different goals in their performance. Mechanical properties are classified on their strength, ductility, hardness, impact resistance and fracture toughness whereas tribological properties refer to the surface properties of the material that can reduce wear. The two sets of properties in conjunction can extend the working life of materials and help save large sums of money leading to conservation of material, energy and the environment.

There are several factors related to natural fibre composites which influence the performance of the composites such as moisture absorption, volume fraction, orientation, and physical, i.e. mechanical or tribological properties. Natural fibres can improve the mechanical and tribological properties of polymers and lead to improvements in the surface characteristics (Basumatary, 2013). Basically, most of the industrial and manufacturing parts are exposed to tribological loadings such as adhesive, abrasive, etc. in their services (Yousif et al., 2010). Some studies have highlighted that the tribological behaviour of composite polymers is strongly dependent on many processing parameters