Faculty of Manufacturing Engineering

DRY SLIDING WEAR AND FRICTION BEHAVIOR OF SILICON CARBIDE AND MULTI WALL CARBON NANOTUBES REINFORCED MAGNESIUM MATRIX HYBRID COMPOSITES

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2015

DECLARATION

I declare that this thesis entitled "Dry Sliding Wear and Friction Behavior of Silicon Carbide and Multi-Walled Carbon Nanotubes Reinforced Magnesium Matrix Hybrid 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 Manufacturing Engineering.

Signature : .....

Name : .....

Date : .....

DEDICATION

I Humbly Dedicate to

My Beloved Father and Mother,
Tee Cheng Sum and
Khoo Swee Lan

&

All My Friends;
Who Have Bring Me

The Gairty, Encourage, Delight and Happiness in My life!

ABSTRACT

In order to optimize the functionality of magnesium, a modest attempt has been made to develop magnesium hybrid composites incorporating of synthesis micro and nano size fillers. Commercially pure magnesium (Mg) reinforced with (i) 10 wt.% micro-sized silicon carbide (SiC) particles (ii) combination of 10 wt.% micro-sized silicon carbide (SiC) particles and 1 wt.% multi-walled carbon nanotubes (MWCNTs), respectively, were synthesized via powder metallurgy route followed by hot extrusion. After the specimen preparation, microstructural characterization studies were conducted to determine the distribution of reinforcement, grain morphology, and presence of porosity by using Optical Microscope, Scanning Electron Microscope and Field Emission Scanning Electron Microscopy. Density and porosity measurements were carried out accordance with Archimedes' principle. Micro-Vickers Test was also carried out to investigate the hardness of material. The dry sliding tests were performed using a pin-on-disc tester against a grey cast iron counterbody under two applied normal loads (5, 10, 20, 40 N) with four sliding speeds (0.5, 1.5, 3.5, 4.5 m/s) corresponding to a constant sliding distance of 5000 m to identify the wear rate and coefficient of friction of magnesium composite. The morphology of the worn pin surfaces and collected wear debris were examined using Scanning Electron Microscope. Throughout this work, reasonably uniform distribution of SiC particulates and MWCNTs in magnesium matrix were observed. Low porosity (below 2.0 %) was obtained which indicated the suitability of the processing parameters. The Vickers hardness of all the hierarchical magnesium composite configurations are significantly higher than the pure magnesium. Wear rate for both unreinforced magnesium and its composite increased with increasing load but the incorporation of micro and nano size fillers reduced the wear rate of magnesium particularly at loads of 5, 10, 20 N. The sliding speed increment induced higher wear on magnesium composites. However, at the highest load of 40 N, a crossover in wear rate was observed with the increased in sliding speeds, i.e., at sliding speed of 1.5 m/s the wear rate of the composite higher than unreinforced magnesium, but the incorporation of SiC and MWCNTs shifts to minimize the wear rate at sliding speeds of 3.5 and 4.5 m/s respectively. There is a small reduction in the coefficient of friction for Mg/SiC/MWCNTs composite as compared to Mg/SiC particularly at low loads of 5, 10, 20 N as the sliding speed increased but the change of coefficient of friction among different materials become insignificant at high load of 40 N. Five wear mechanisms mostly operated in combination namely abrasion, adhesion, oxidation, delamination and plastic deformation have been observed in various sliding conditions. Such modify hybrid approach may bring significant implications on application particularly in automotive and aviation sectors. These would become as another material option to further improve the fuel efficiency as well as service life of components.

ABSTRAK

Bagi mengoptimumkan fungsi magnesium, satu percubaan telah dibuat untuk menghasilkan komposit hybrid magnesium yang bertetulang saiz mikro dan nano. Magnesium tulen (Mg) diperkukuhkan dengan (i) 10 wt.% silikon karbida (SiC) bersaiz mikro (ii) 10 wt.% silikon karbida (SiC) bersaiz mikro dan 1 wt.% tiub nano karbon berdinding ganda (MWCNTs), masing-masing, telah disintesis melalui kaedah metalurgi serbuk diikuti oleh penyemperitan panas. Selepas penyediaan spesimen, kajian pencirian mikrostruktur telah dijalankan untuk menentukan pengagihan tetulang, morfologi ira, dan kehadiran keliangan dengan menggunakan Mikroskop Optik, Pengimbasan Elektron Mikroskop dan Bidang Pelepasan Mengimbas Mikroskopi Elektron. Ketumpatan dan keliangan pengukuran telah dijalankan mengikut prinsip Archimedes. Ujian micro-Vickers juga telah dijalankan untuk mengkaji kekerasan bahan. Ujian haus pada keadaan kering telah dilakukan dengan menggunakan penguji pin terhadap besi tuang kelabu di bawah empat kenaan beban normal (5, 10, 20, 40 N) dengan empat kelajuan gelongsor (0.5, 1.5, 3.5, 4.5 m/s) dengan jarak yang tetap, 5000 m untuk mengenal pasti kadar haus dan pekali geseran komposit magnesium. Morfologi permukaan pin yang telah haus dan serpihan haus yang dipungut telah diperiksa menggunakan Pengimbasan Elektron Mikroskop. Dari kajian ini, taburan yang seragam zarahan SiC dan MWCNTs di dalam matriks magnesium telah diperhatikan. Keliangan yang rendah (di bawah 2.0 %) yang telah diperolehi menunjukkan kesesuaian parameter pemprosesan. Kekerasan Vickers bagi hierarki konfigurasi komposit magnesium adalah jauh lebih tinggi daripada magnesium yang tulen. Kadar haus untuk kedua-dua magnesium tanpa tetulang dan komposit meningkat dengan peningkatan beban tetapi penambahan pengisi bersaiz mikro dan nano mengurangkan kadar haus magnesium terutamanya pada 5, 10, 20 N. Peningkatan kelajuan gelongsor menyebabkan kadar haus yang lebih tinggi pada komposit magnesium. Walau bagaimanapun, pada beban tertinggi 40 N, peralihan dalam kadar haus diperhatikan dengan peningkatan dalam kelajuan gelongsor; iaitu pada kelajuan 1.5 m/s kadar haus daripada komposit lebih tinggi daripada magnesium tanpa tetulang tergelincir, tetapi penambahan SiC dan MWCNTs mengurangkan kadar haus pada kelajuan gelongsor 3.5 dan 4.5 m/s masing-masing. Terdapat pengurangan kecil dalam pekali geseran Mg/SiC/MWCNTs komposit berbanding Mg/SiC terutamanya pada beban rendah 5, 10, 20 N dimana kelajuan gelongsor meningkat tetapi perubahan pekali geseran di antara bahan-bahan yang berbeza menjadi tidak ketara pada beban tertinggi 40 N. Lima mekanisma haus yang kebanyakannya beroperasi secara gabungan iaitu lelasan, rekatan, pengoksidaan, delaminasi dan ubah bentuk plastik telah diperhatikan dalam pelbagai keadaan gelongsor. Pengubahsuaian komposit hybrid magnesium ini boleh membawa implikasi yang besar ke atas aplikasi terutamanya dalam sektor automotif dan penerbangan. Ia akan menjadi salah satu pilihan bahan untuk meningkatkan lagi kecekapan bahan api dan juga hayat perkhidmatan komponen.

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ASTM	American society for testing materials
Al	Aluminium
Al_2O_3	Alumina
AlN	Aluminum nitride
AE42	Magnesium alloy with about 4 wt.% Al and 2 wt.% about mischmetal
AM60B	Magnesium alloy with about 6 wt.% Al and less than 1 wt.% Mn
AZ91D	Magnesium alloy with about 9 wt.% Al and about 1 wt.% Zn
B_4C	Boron carbide
BCC	Body centered cubic
BN	Boron nitride
BPR	Ball to powder ratio
C	Carbon
CFMMCs	Continuous fiber reinforced metal matrix composites
CMCs	Ceramic matrix composites
CNT	Carbon nanotube
CO_2	Carbon dioxide
CTE	Coefficient of thermal expansion
Cu	Copper

DMD	Disintegrated melt deposition
EDX	Energy dispersive X-ray spectrometer
FCC	Face centered cubic
FEG	Field Emission Gun
FESEM	Field emission scanning electron microscopy
Grp	Graphite
HCP	Hexagonal close packed
Hv	Vickers hardness number
Mg	Magnesium
Mg/SiC	Magnesium reinforced with silicon carbide
Mg/SiC/MWCNTs	Magnesium reinforced with silicon carbide and multi-wall carbon nanotubes
Mg_2Si	Magnesium silicide
MgO	Magnesium oxide
MM	Mechanical milling
MMCs	Metal matrix composites
Mn	Manganese
MSDS	Material safety data sheet
Ni	Nickel
OM	Optical microscopy
PCA	Process control agent
PM	Powder metallurgy
PMCs	Polymer matrix composites
PRMMCs	Particulate reinforced metal matrix composites

PSA	Particle size analyzer
QE22	Magnesium alloy with 2.5% Ag, 2% RE and 0.7% Zr
RE	Rare earth metals
SEI	Secondary electron imaging
SEM	Scanning electron microscopy
SiC	Silicon carbide
SiO_2	Silica
Ti	Titanium
TiB_2	Titanium diboride
TiC	Titanium carbide
W	Tungsten
XRD	X-ray diffraction
Y_2O_3	Yttrium(III) oxide
Zn	Zinc
Zr	Zirconium