EFFECT OF WS_2 AND TiO_2 NANOPARTICLES ON THE TRIBOLOGICAL CHARACTERISTICS OF ta-C COATING

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DECLARATION

I hereby declare that the material in this thesis is my own except for the equations, summaries, and references, which have been duly acknowledged.

28 March 2017

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ABSTRACT

Tetrahedral amorphous carbon (ta-C) coating is one of the Diamond-like Carbon (DLC) coating which display some excellent properties of a diamond, such as high hardness properties, high wear resistivity and chemically inertness. It is widely used in engineering applications. The interaction of the lubricant additive could affect the tribological performance of the ta-C coating layer with its intrinsic factor. This project was carried out to investigate the effect of tungsten disulphide (WS_2) and titanium dioxide (TiO_2) nanopowder separately in Poly-alpha-olefin (PAO4) oil on the friction and wear behavior of the ta-C coating films. PAO4 base oil blended with different weight ratio of a WS_2 and TiO_2 was used (0 wt%, 0.1 wt%, 0.5 wt%, and 1.0 wt% TiO_2 blended with PAO4, and 0 wt%, 3.0 wt%, 4.0 wt%, and 5.0 wt% WS_2 blended with PAO4). The ta-C coating was deposited on the bearing steel using the Filtered Cathodic Vacuum Arc (FCVA) method. The hardness and young modulus value of this coated films were measured to be 64.53 GPa and 418.23 GPa, respectively. A ball-on-disc tester was used to investigate the friction and wear behavior of ta-C films. Under boundary lubrication condition, the presence of the WS_2 and TiO_2 additives in the base oil reduced the wear of the ta-C films. The specific wear rate obtained under PAO4 lubrication was the highest at 0.2816 X 10^{-6} mm^3/mN. This lubrication condition had the lowest lambda ratio of 0.551 indicating of boundary lubrication resulting in severe interaction of the asperities and a significant shear properties of the lubricant film onto the ta-C surface. In contrast, sliding under PAO4 containing 3.0 wt% of WS_2 with lambda ratio of 0.851 resulted in micro-elastrohydrodynamic lubrication condition and a lower specific wear rate of 0.1494 X 10^{-6} mm^3/mN. Among all the PAO4 blended with TiO_2 lubricant, the lubricant containing 1.0 wt% of TiO_2 with the highest lambda ratio value of 0.989 gave the lowest wear rate of 0.1314 X 10^{-6} mm^3/mN. The TiO_2 and WS_2 had different effects on the friction coefficient and the specific wear rate. Increasing the weight percentage of WS_2 led to a reduction in the COF but an increasing specific wear rate. However, for PAO4 blended with TiO_2 lubricants, higher content of TiO_2 resulted in higher COF but lower specific wear rate. The Raman result showed that the presence of the additives had significant effect on the graphitization of the ta-C structure. Higher amount of additives caused more sp^3 bond structure to break into

sp^2 bonds which had adverse effect on its wear resistance. On the other hand, the additives could form a protective layer capable of reducing the wear of the ta-C film. Overall effect was these was a reduction in wear.

ABSTRAK

KESAN WS_2 DAN TiO_2 NANOPARTIKEL TERHADAP CIRI-CIRI TRIBOLOGI SALUTAN ta-C

Tetrahedral amorphous carbon, ta-C adalah salah satu jenis salutan untuk Diamond-like carbon (DLC). Salutan ta-C ini menpunyai sifat-sifat yang baik seperti berlian, contohnya, salutan ini mempunyai kekuatan menghalang haus yang tinggi dan tidak berkesan sama bahan kimia. Oleh sebab itu, salutan ini banyak digunakan dalam aplikasi kejuruteraan. Kebelakangan ini, kesan untuk salutan ta-C bersama perlinciran telah menarik perhatian kebanyakan penyelidik. Oleh sebab, penambahan bahan seperti sebuk yang bersiaz nano meter dapat mengesankan kebeberapa perubahan dalam sifat -sifat tribologi untuk salautan ta-C. Dengan pertimbangan untuk menemui pengubahan sifat-sifat tribologi untuk salutan ini, penambahan sebuk seperti titanium dioxide (TiO_2) dan tungsten disulphide (WS_2) telah pun dibuat. Dalam projek ini, TiO_2 telah disediakan dalam 4 jenis peratusan berat badan, adalah seperti, 0 wt%, 0.1 wt%, 0.5 wt%, dan 1.0 wt%. Bagi sebuk berjenis WS_2, juga disedia bagi 4 jenis peratusan berat badan, adalah seperti, 0 wt%, 3.0 wt%, 4.0 wt%, dan 5.0 wt%. Salutan-salutan ta-C telah disediakan dengan kaedah Filtered Cathodic Vacuum Arc, FCVA. Nilai-nilai kekerasan dan elastic modulas untuk salutan ta-C adalah 64.53 GPa dan 418.23 GPa. Ujian tribo telah dilakukan dengan pengunaan ball-on-disc dalam projek ini. Kehadiran bahan tambahan dapat mengurankan kadar haus untuk salutan ta-C, sebagai buktinya, untuk kes hanya minyak sintetik, PAO4, kadar hausnya didapati pada 0.2816 X 10^{-6} mm^3/mN. Manakala untuk peratusan berat badan bagi TiO_2 dan WS_2 yang mencapai kelajuan haus yang terendah adalah, 1.0 wt% dan 3.0 wt%. Dengan kadar haus 0.1314 X 10^{-6} mm^3/mN bagi 1.0 wt% TiO_2, dan 0.1494 X 10^{-6} mm^3/mN bagi 3.0 wt% WS_2. Dalam kajian ini, hasil untuk pekali geseran dan kadar haus tertentu menunjukkan hasil yang berbeza. Ini disebabkan oleh kekuatan permukaan filem ta-C di mana bahan tambahan ditambah pelincir boleh berkelakuan seperti lapisan perlindungan semasa ujian dengan ball-on-disc. Kerana pekali geseran yang diukur adalah interaksi antara lapisan perlindungan dan (bola

bearing) badan kaunter. Dengan lapisan perlindungan ini, tribofilms kurang ditarik dari permukaan salutan ta-C. Secara kesimpulannya, penambahan sebuk-sebuk yang bersaiz nano dapat menambah-baikan sifat sifat tribologi untuk salutan ta-C.

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LIST OF ABBREVIATIONS

a-C:H	-	amorphous hydrogenated carbon
AE	-	Acoustic Emission
AFM	-	Atomic Force Microscope
ANSI	-	American National Standard Institute
CAP	-	Circumferencial Antenna Plasma
CVD	-	Chemical Vapour Deposition
COF	-	Coefficient of Friction
DG	-	Defected Graphite
DLC	-	Diamond-Like Carbon
DNA	-	Deoxyribonucleic Acid
DOMS	-	Deep Oscillation Magnetron Sputtering
ECR	-	Electron Cyclotron Resonance
EDX	-	Characteristic X-Ray
FCVA	-	Filter Cathodic Vacuum Arc
FIB-CVD	-	Focused Ion-Beam Chemical Vapor Deposition
HCD	-	Hollow Cathode Discharge
HiPIMS	-	High Power Impulse Magnetron Sputtering
IBAD	-	Ion Beam Assisted Deposition
LPCVD	-	Low Pressure Chemical Vapor Deposition
MW SWP	-	Microwave Surface-Wave Plasma
NMR	-	Nuclear Magnetic Resonance
PAO4	-	Poly-alpha-olefins Group IV
PACVD	-	Plasma Assisted Chemical Vapour Deposition
PC	-	Personal Computer
PCVD	-	Plasma Chemical Vapor Deposition
PECVD	-	Plasma Enhance Chemical Vapour Deposition
PIID	-	Plasma Immersion Ion Deposition
PLD	-	Pulsed Laser Deposition

PVD	-	Physical Vapor Deposition
PW 6	-	Pigment White 6
RCN	-	Random Covalently Network
RF	-	Radio-Frequency
RMS	-	Root Mean Square
SEM	-	Scanning Electron Microscope
ta-C	-	tetrahedral amorphous Carbon
TiO_2	-	Titanium Dioxide
UV	-	Ultra-Violet
WS_2	-	Tungsten Disulphide
XRD	-	X-Ray Power Diffraction

LIST OF SYMBOLS

η_D	-	Refractive index
η	-	lubricant viscosity
ω	-	Rotational speed of the motor
p_0	-	Maximum Hertzian contact pressure
R	-	Reduce radius of curvature
R_1, R_2	-	Radii of two bodies
E	-	Reduce modulus, contact modulus
E_1, E_2	-	Elastic modulus of two bodies
$F_N,$	-	Normal load
F_s	-	Frictional force
v_1, v_2	-	Poisson's ratio of two bodies
a	-	Radius of contact circle
P	-	Normal load applied
k	-	Specific wear rate
r_s	-	Sliding radius
h_{min}	-	Minimum films thickness
η_0	-	Dynamic viscosity of lubricant
α	-	Viscosity pressure coefficient
U_m	-	Mean velocity of two moving surfaces
k_1	-	Ellipticity parameter
Λ	-	Lamda ratio
μ_s	-	Dimensionless Friction coefficient
R_a	-	Centre line average roughness
R_q	-	Root mean square roughnes
R_{q1}, R_{q2}	-	Root mean square roughness of two solid surfaces
W_{powder}	-	Weight of additives powder
W_{PAO4}	-	Weight of Poly-alpha-olefin oil

LIST OF APPENDIX