

**EFFECT OF WS<sub>2</sub> AND TiO<sub>2</sub> NANOPARTICLES  
ON THE TRIBOLOGICAL CHARACTERISTICS  
OF ta-C COATING**

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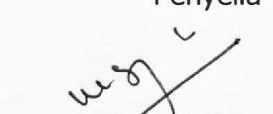
  
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I hereby declare that the material in this thesis is my own except for the equations, summaries, and references, which have been duly acknowledged.

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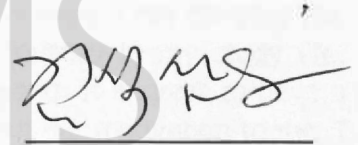
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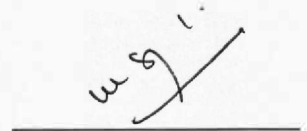


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## ABSTRACT

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  $0.2816 \times 10^{-6} \text{ mm}^3/\text{mN}$ . 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  $0.1494 \times 10^{-6} \text{ mm}^3/\text{mN}$ . 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  $0.1314 \times 10^{-6} \text{ mm}^3/\text{mN}$ . 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<sup>2</sup> 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.



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# 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 mempunyai 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 salutan 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 disediakan 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 modulus untuk salutan ta-C adalah 64.53 GPa dan 418.23 GPa. Ujian tribo telah dilakukan dengan penggunaan ball-on-disc dalam projek ini. Kehadiran bahan tambahan dapat mengurangkan kadar haus untuk salutan ta-C, sebagai buktinya, untuk kes hanya minyak sintetik, PAO4, kadar hausnya didapati pada  $0.2816 \times 10^{-6} \text{ mm}^3/\text{mN}$ . 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  $0.1314 \times 10^{-6} \text{ mm}^3/\text{mN}$  bagi 1.0 wt%  $TiO_2$ , dan  $0.1494 \times 10^{-6} \text{ mm}^3/\text{mN}$  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-baikkan sifat sifat tribologi untuk salutan ta-C.*



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## LIST OF ABBREVIATIONS

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

<b>PVD</b>	-	Physical Vapor Deposition
<b>PW 6</b>	-	Pigment White 6
<b>RCN</b>	-	Random Covalently Network
<b>RF</b>	-	Radio-Frequency
<b>RMS</b>	-	Root Mean Square
<b>SEM</b>	-	Scanning Electron Microscope
<b>ta-C</b>	-	tetrahedral amorphous Carbon
<b>TiO<sub>2</sub></b>	-	Titanium Dioxide
<b>UV</b>	-	Ultra-Violet
<b>WS<sub>2</sub></b>	-	Tungsten Disulphide
<b>XRD</b>	-	X-Ray Power Diffraction



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## LIST OF SYMBOLS

$\eta_D$	-	Refractive index
$\eta$	-	lubricant viscosity
$\omega$	-	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
$\nu_1, \nu_2$	-	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
$\eta_0$	-	Dynamic viscosity of lubricant
$\alpha$	-	Viscosity pressure coefficient
$U_m$	-	Mean velocity of two moving surfaces
$k_1$	-	Ellipticity parameter
$\Lambda$	-	Lamda ratio
$\mu_s$	-	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

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