Tribological studies of multilayer and nanocomposite coatings

Thesis submitted in partial fulfillment

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In

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By

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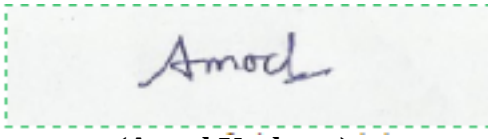

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Dedicated to my beloved grandmothers.

Abstract

The fabrication of mechanical components depends upon the applications, which call for different materials with different properties. Apart from this, the failure of lubricant properties at elevated temperatures has resulted in the proper selection of materials for various tribological applications. The cost of procurement of these materials and machining them into tools and components is also arduous. Therefore, in tribological contacts at elevated temperatures, it is imperative to select coatings as an alternative for increasing the life of these tools and machinery components.

The design and selection criteria of the coatings are based on different tribological applications. The present study was focused on the tribological responses of multilayer and nanocomposite coatings at elevated temperatures. The multilayer coatings were sputter deposited, while the nanocomposite coatings were polymer-based coatings deposited through spray pyrolysis. The incorporation of the ductile layer between the hard ceramic layers in the multilayer coating not only reduces the internal stress of the coating but also prevents the propagation of cracks from one brittle layer to another. The polymer nanocomposite coatings were prepared by reinforcing them with pristine and alkylated MoS_2 nanosheets to enhance their tribological properties.

The various machine tools and equipment made of SS 304 suffer severe damage from galling while working. Therefore, new coatings are developed to prevent surface damage to avoid galling at room and elevated temperatures. The Mo/DLC coatings were developed to prevent the galling at room and elevated temperatures (around 300˚C). All galling tests were conducted on the test rig made in accordance with ASTM G196. The DLC (diamond like carbon) has a mixture of sp^2 and sp^3 hybridized carbon. The deposition of the DLC layer through high power impulse magnetron sputtering (HiPIMS) ensured a high deposition percentage of sp^3

hybridized carbon. The soft Mo layer deposited through a pulsed DC power source helped reduce the internal stress and helped in depositing coating with higher thickness. Almost a three-fold increase in the load-bearing capacity was observed in the tribopair, having coated against uncoated samples. A cost-effective way of increasing the galling resistance of SS 304 has also been explored by coating the samples with polyurethane (PU) based nanocomposite coatings. The PU based coatings were reinforced with pristine and alkylated MoS_2 nanosheets to improve their tribological performance. A comparative study has been presented on the reciprocating and galling wear performance of the PU based nanocomposite coatings. The surface of the pristine MoS_2 nanosheets was modified with octadecane thiol (ODT) to form alkylated MoS_2 nanosheets. The PU-MoS_2-ODT coatings showed significant decrease in friction and wear, 77 and 95%, respectively. Furthermore, the galling resistance of PU-MoS_2-ODT coating was better than the plain PU and PU-MoS_2 coatings.

Various characterization techniques were employed to study the properties of the coatings and the worn scar. These include field emission scanning electron microscopy (FESEM), elemental dispersive x-ray analysis (EDAX), Raman spectroscopy, x-ray photoelectron spectroscopy (XPS), nanoindentation, Fourier transform infrared spectroscopy (FTIR), stereo-zoom optical microscopy, and nanosctratch testing.

Contents

List of Figures

List of Tables

Abbreviations/Symbols

Abbreviations	Descriptions
°C	Degree Centigrade
AC	Alternating Current
Ag	Gold
Al_2O_3	Alumina
AlCrN	Aluminium Chromium Nitride
AlN	Aluminium Nitride
Ar	Argon
ASTM	American Society of Testing and Materials
at%	atomic percentage
ATSP	Aromatic Thermosetting Polyester
Au	Silver
C	Carbon
CL	Coated Substrates With Lubrication
CN	Carbon Nitride
CNT	Carbon Nano Tubes
CoF	Coefficient of Friction
Cr	Chromium
Cr_2O_3	Chromium Oxide
CrAlN	Chromium Aluminium Nitride
CrALN	Chromium Aluminium Nitride
CrC	Chromium Carbide

CrCN	Chromium Carbon Nitride
CrN	Chromium Nitride
CVD	Chemical Vapour Deposition
CWL	Coated Substrates Without Lubrication
DC	Direct Current
DCMS	Direct Current Magnetron Sputtering
DLC	Diamond Like Carbon
d_p	Diameter Perpendicular
d_{pa}	Diameter Parallel
E	Elastic Modulus
E'	Reduced Elastic Modulus
EDAX	Elemental Disperssive X-Ray Analysis
EP	Epoxy Resin
eV	Electron Volt
Fe	Iron
FESEM	Field Emission Scanning Electron Microscopy
FTIR	Fourier Transform Infrared Radioscopy
GLC	Graphite Like Carbon
Gpa	Giga Pascal
H	Hardness
HiPIMS	High Power Impulse Magnetron Sputtering
h_{min}	Minimum Film Thickness
ICDD	International Centre for Diffraction Data
JCPDS	Joint Committee on Powder Diffraction
La	Lanthanum

MFT	Multifuctional Tribometer
MoN	Molybdenum Nitride
MoO_3	Molybdenum Trioxide
MoS_2	Molybdenum Disulphide
MoS_2-ODT	Chemically Modified Molybdenum Disulphide with Octadecanethiol
MPA	Mega Pascal
N	Nitrogen
N-DLC	Nitrogen doped Diamond Like Carbon
Ni	Nickel
O	Oxygen
ODT	Octadecanethiol
PA	Polyamide
PbO	Lead Oxide
PDCMS	Pulsed DC Magnetron Sputtering
PEEK	Polyethere Therketone
PF	Phenolic Resin
PHBA	poly-hydroxybenzonic Acid
PI	Polyimide
POM	Polyoxymethylene
PPS	Polyphenylene Sulphide
PTFE	Polytetrafluoroethylene
PU	Polyurethane
PVD	Physical Vapour Deposition
R	Radius of Ball
R'	Reduced Radius of Curvature

RF	Radio Frequency
sccm	Standard Cubic Centimeters per Minute
SEM	Scanning Electron Microscopy
Si	Silicon
Si_3N_4	Silicon Nitride
SiC	Silicon Carbide
TaC	Tantalum Carbide
Ti	Titanium
TiAlN	Titanium Aluminium Nitride
TiB_2	Titanium Boride
TiBN	Titanium Boron Nitride
TiCN	Titanium Carbon Nitride
TiCrN	Titanium Chromium Nitride
TiN	Titanium Nitride
TiO_2	Titanium Dioxide
UCL	Uncoated Substrates With Lubrication
UHMWPE	Ultra High Molecular Weight Polyethylene
V_2O_5	Vanadium Pentaoxide
VN	Vanadium Nitride
W	Tungsten
W_{lball}	Linear Wear of Ball
W_{lflat}	Linear Wear of Flat Surface
WN	Tungten Nitride
W_q	Plainmetric Wear
WS_2	Tungsten Disulphide

wt%	Weight Percentage
WV	Total Volumetric Wear
W_{Vball}	Volumetric Wear of ball
W_{Vflat}	Volumetric Wear of Flat Surface
XPS	X-Ray Photoelectron Spectroscopy
XRD	X-Ray Diffraction
ZrN	Zirconium Nitride
η_o	Dynamic Viscosity
σ^*	Composite Roughness
λ	Lambda Ratio