STUDY ON THE APPLICATION OF IONIC LIQUIDS IN BIO-BASED LUBRICANT FOR A SUSTAINABLE MACHINING PROCESS

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I hereby declare that the work in this project report is my own except for quotations and summaries which have been duly acknowledged

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ABSTRACT

Many factors tend to influence the increased demand in recent years, including state-of-the-art of effective and environmentally friendly metalworking fluids (MWFs). Bio-based lubricants from vegetable oils are highly biodegradable, non-toxic, pose good lubricating properties and low production costs. They have been widely perceived as a potential to reduce or replace the high dependency on the applications of petroleum-based MWFs. However, the inconsistent chemical composition and low thermal and oxidative stabilities of the natural oils leaves significant uncertainties about the overall sustainability performance of the bio-based MWFs. In this study, with the objective of achieving machining sustainability, a novel chemically modified Jatropha-based trimethylolpropane ester (MJO) was refined by mixing it with ionic liquids (ILs) additives. Two biocompatible and oil-miscible ILs; $[P_{6,6,6,14}][(^{i}C_8)_2PO_2]$ (PIL) and $[N_{1,8,8,8}][NTf_2]$ (AIL) were mixed in the MJO at 1, 5, and 10 % weight concentrations. The newly refined mixtures are validated for their physicochemical and tribological properties as well as when being applied for minimum quantity lubrication (MQL) machining (orthogonal and oblique) of AISI 1045 steel. Results showed that, the lubrication performance of MJO+AIL10% and MJO+PIL1% outperformed the other lubricant samples used herein. With improved physicochemical and tribological performances, e.g. corrosion inhibition, friction and wear reduction, smooth surface finish and high machining efficiency, they recorded improvement in machining forces up to 12 %, cutting temperature up to 10 %, surface roughness by 7% and increased cutting tool life up to 50 % compared to the commercial synthetic ester-based MWF. A machining sustainability index evaluation was applied to the MQL machining scenario and based on results, MJO+PIL1% obtained the highest score for minimum lubricant's cost, minimal energy consumption, or the best sustainability performance (4.08/5) and seconded by MJO+AIL10% (4.06). These novel bio-based MWFs provide another alternative to the world dominating mineral oil-based lubricants for "greener" and more sustainable working environment.

ABSTRAK

Dewasa ini penggunaan bendalir kerja logam (MWFs) yang terkini, canggih dan mesra alam adalah semakin meningkat disebabkan pelbagai faktor. Bendalir kerja logam berasaskan minyak tumbuhan adalah terbiodegradasi, tidak toksik, bersifat pelincir yang baik dan tidak menelan kos pembuatan tinggi. Ianya telah diterima secara meluas sebagai suatu potensi untuk mengurangkan atau menggantikan kebergantungan tinggi terhadap penggunaan MWFs berasaskan petroleum. Namun, minyak berasaskan tumbuhan mempunyai sifat komposisi kimia yang tidak konsisten dan kestabilan terma-oksidatif yang rendah menyebabkan prestasi keseluruhan mereka terencat untuk mencapai kelestarian dalam proses pemesinan. Dalam kajian ini, dengan objektif mencapai kelestarian dalam proses pemesinan, ester trimetilolpropana berasas minyak jarak dan diubahsuai secara kimia (MJO) telah disempurnakan dengan bahan tambah cecair ionik (ILs). Kedua-dua ILs; $[P_{6,6,6,14}][(^{i}C_8)_2PO_2]$ (PIL) dan $[N_{1,8,8,8}][NTf_2]$ (AIL), adalah bio-serasi dan larut minyak. Sampel campuran dengan ILs pada kepekatan berbeza 1, 5, dan 10 % berat daripada MJO telah ditentusahkan melalui sifat fizikokimia, tribologi serta pelinciran kuantiti minimum (MQL) ketika proses pelarikan (ortogonal dan oblik) logam AISI 1045. MJO+AIL10% dan MJO+PIL1% menunjukkan keputusan yang meyakinkan untuk mengatasi prestasi pelincir-pelincir lain yang diuji. Keduanya menunjukkan sifat-sifat fizikokimia dan ujian kelakuan tribologi yang cemerlang seperti perencatan kakisan, pengurangan geseran dan kehausan, penghasilan kualiti kekasaran permukaan yang tinggi serta mencatatkan pengurangan dalam daya pemesinan sehingga 12%, suhu pemotongan sehingga 10%, kekasaran permukaan sebanyak 7% dan peningkatan jangka hayat mata alat sehingga 50% berbanding dengan ester sintetik komersil. Penilaian indeks kelestarian semasa proses pemesinan MQL menunjukkan MJO+PIL1% (4.08) mengatasi MJO+AIL10% (4.06) dalam memperoleh skor tertinggi untuk kos pelincir dan penggunaan tenaga minimum atau prestasi kelestarian terbaik. Suatu sumber alternatif yang lebih mampan telah berjaya dihasilkan untuk membentuk persekitaran kerja yang lebih lestari.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Percent, efficiency
a	-	Radius of wear scar diameter
AES	-	Auger Electron Spectrometer
AFM		Atomic force microscopy
AIL	-	methyltrioctylammonium bis(trifluoromethylsulfonyl)imide; $[N_{1,8,8,8}][NTf_2]$
AISI	-	American Iron and Steel Institute
Al		Aluminium
AOCS	-	American Oil Chemists' Society
ASTM	-	American Society for Testing and Materials
AW	-	Antiwear additive
BF_4	-	Tetrafluoroborate
BL	-	Boundary lubrication
BUE	-	Built up edge
C	-	Carbon, carbide
C_3H_8O	-	Isopropyl alcohol
CEC	-	Coordinating European Council
CH_4O	-	Methanol
CJO	-	Crude jatropha oil
CNC		Computer numerical control
COF	-	Coefficient of friction
CrN	-	Chromium nitride
d	-	Depth of cut
DAQ	-	Data acquisition system
DIN	-	Deutsches Institut für Normung (German national oganization for standardization)

e.g.	-	exempli gratia (for example)
EDM	-	Electrical discharge machining
EDS / EDX	-	Electron dispersion X-ray spectroscopy
EHL	-	Elastohydrodynamic lubrication
EN	-	European Norms/Standards
EP	-	Extreme pressure additive
et al.	-	et alia (and others)
f	-	Feed
F	-	Frictional force tangential to the rake face
F_a	-	Active force
FAME	-	Fatty acid methyl ester
F_c	-	Cutting force
F_D	-	Drive force
Fe	-	Iron, Ferum
Fe_2O_3		Iron (III) oxide
FeO		Iron (II) oxide
F_f	-	Feed force
FFA	-	Free fatty acid
FM	-	Friction modifier additive
F_p	-	Passive force
FP		Flash point
F_s	-	Shear force tangential to the shear plane
FTIR	-	Fourier Transform Infrared
GPa	-	Gigapascal
h	-	Height of the spherical cap worn
H_2SO_4	-	Sulphuric acid
H_3BO_3	-	Boric acid
H_3PO_4	-	Orthophosphoric acid
HD	-	Hydrodynamic lubrication
HF	-	Hydrogen fluoride
HRC	-	Hardness scale Rockwell C
i	-	Inclination angle

IL	-	Ionic liquid
IR	-	Infrared
ISO	-	International Organization for Standardization
$I_{sub\text{-}index}$		Individual aspect of the sustainability index
KB	-	Crater width
KM	-	Crater centre distance
KOH	-	Potassium hydroxide
k_r	-	Tool's lead angle
KT	-	Crater depth
kW	-	Kilowatt
L	-	Tool life in mm (Axial cutting length), evaluation length
L_c	-	Total tool-chip contact length
L_n	-	Evaluation length of surface roughness
L_S	-	Length of shear plane
L_{sl}	-	Sliding length at the tool-chip contact
L_{st}	-	Sticking length at the tool-chip contact
m	-	Meter
MCD	-	Merchant's Circle Diagram
mg	-	Milligram
M_i	-	Medium measurement of a metric
min	-	Minute
MJO	-	Modified jatropha oil, jatropha-based TMP ester
MJO1	-	Modified jatropha oil (3.1:1)
MJO3	-	Modified jatropha oil (3.3:1)
MJO5	-	Modified jatropha oil (3.5:1)
ml	-	Milliliter
mm	-	Millimeter
M_{max}	-	Maximum measurement of a metric
M_{min}	-	Minimum measurement of a metric
MPa	-	Megapascal
mPa	-	Millipascal
MQL	-	Minimum quantity lubrication
MRR	-	Material removal rate

MS-Index	-	Machining sustainability index
MWF	-	Metalworking fluid
N	-	Newton, Nitrogen, nitride, normality (strength of alkali)
N	-	Frictional force normal to the rake face
$NaOCH_3$	-	Sodium methoxide
NaOH	-	Sodium hydroxide
NIOSH	-	National Institute of Occupational Safety and Health
NPG	-	neopenthyglycol
O	-	Oxygen, oxide
º	-	Degree of angle
ºC	-	Degree Celsius
P	-	Phosphorous, phosphide
PAO	-	Polyalphaolefin
PC		Personal computer
$P_{consumption}$	-	Cutting power
$P_{cutting}$	-	Total power consumed during cutting
PE	-	Pentaerythritol
PEP	-	Passive extreme-pressure-additive
PF_6	-	Hexafluorophosphate
pH	-	potential of hydrogen
P_{idle}	-	Idle power consumed by spindle rotation
PIL	-	trihexyltetradecylphosphonium bis(2,4,4-trimethylpentyl)phosphinate; $[P_{6,6,6,14}][_i(C_8)_2PO_2]$
ProcSI	-	Metrics-based Process Sustainability Index
ProdSI	-	Metrics-based Product Sustainability Index
PSI	-	Product Sustainability Index
R	-	Resultant force of *F* and *N*, ball bearing radius
r	-	Radial distance from the centre of the contact surface
r_e	-	Tool edge radius
rpm	-	Rotation per minute
RTIL	-	Room temperature ionic liquid
S	-	Sulphur, sulphide
S	-	Individual metric score

s	-	second
$scCO_2$	-	Supercritical carbon dioxide
SCF	-	Supercritical fluid
SE	-	Synthetic ester
SEM	-	Scanning electron microscopy
SiO_2	-	Silicium oxide
$SV\gamma$	-	Displacement of cutting edge in face direction
t	-	Sliding time
T	-	Frictional torque
TAN	-	Total acid number
T_c	-	Tool life in minute (Cutting time)
t_c	-	Chip thickness
TE	-	Triester
TEM	-	Transmission electron microscopy
TiCN	-	Titanium carbonitride
TiN	-	Titanium nitride
TMP	-	Trimethylolpropane, 2-ethyl-2(hydroxymethyl)-1,3-propanediol
t_o	-	Uncut chip thickness
U	-	Specific cutting energy
VB_B	-	average flank wear land width
VB_{Bmax}	-	maximum flank wear land width
VB_C	-	width of flank wear at tool corner
VB_N	-	width of notch wear
v_c	-	Cutting speed
v_{ch}	-	Chip velocity
v_e	-	Resultant cutting speed
v_f	-	Feed rate
VI	-	Viscosity Index
viz.	-	videlicet (namely / as follows)
w	-	Width of cut
W	-	Test load
WC	-	Tungsten carbide

WSD	-	Wear scar diameter
wt. %	-	Percentage based on weight of oil
W_V	-	Volumetric material removal
XPS	-	X-Ray photoelectron spectroscopy
XRD		X-ray diffraction
XRF	-	X-ray fluorescence
$Z(x)$	-	Roughness profile height
ZDDP	-	Zinc dialkyl dithiophosphate
ZrN	-	Zirconium nitride
α	-	tool rake angle
β	-	tool wedge angle
γ	-	tool clearance angle
η	-	Dynamic viscosity
λ_c	-	Cut-off length
μ	-	Coefficient of friction
μm	-	Micrometre
v	-	Kinematic viscosity
ρ	-	Density
σ_c	-	Shear stress
τ	-	friction angle
τ_c	-	Normal/friction stress
ϕ	-	Shear plane angle

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