PERFORMANCE EVALUATION OF BIODEGRADABLE METALWORKING FLUIDS FOR MACHINING PROCESS

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ABSTRACT

The widely use of metalworking fluids (MWFs) petroleum-based in the industry have a negative impact to the environment and human. Thus, various initiatives have been undertaken to develop bio-based MWFs especially from crude jatropha oil (CJO). However, the main drawback of CJO is that it has low thermal-oxidative stability. Therefore, the objective of this study is to develop a new formulation of CJO-based MWFs. The newly developed modified jatropha oils (MJOs) were formulated using transesterification process at various molar ratios of jatropha methyl ester to trimethylolpropane (JME:TMP) denoted by MJO1 (3.1:1), MJO3 (3.3:1) and MJO5 (3.5:1). Later, the MJOs were blended with hexagonal boron nitride (hBN) particles at various concentrations (0.05 to 0.5wt.%). MJOs with and without hBN particles were analysed based on the physicochemical properties, tribology behaviour test, orthogonal cutting and turning proses. From the results, MJO5 showed an improvement at thermal (high viscosity index) and oxidative stability (lubricant storage). MJO5c (MJO5+0.5wt.% of hBN particles) showed the optimum physicochemical properties. In the contrary, MJO5a (MJO5+0.05wt.% of hBN particles) exhibited excellent tribological behaviour as reduction of friction and wear, with high tapping torque efficiency. In the orthogonal cutting process, MJO5a recorded the lowest machining force and temperature, thus contributed to the formation of thinner chips, small tool-chip contact length and reduction of the specific energy. MJO5a produced an excellent result in the machinability test by reducing the cutting force, cutting temperature and surface roughness stimulated longer tool life and less tool wear. In conclusion, the MJO5a has a potential impact on the lubricant market as a sustainable MWFs for the machining processes.

ABSTRAK

Penggunaan bendalir kerja logam (MWFs) berasaskan petroleum secara meluas di industri telah memberikan kesan negatif kepada alam sekitar dan manusia. Justeru, pelbagai inisiatif telah dilakukan untuk membangunkan MWFs berasas bio terutamanya daripada minyak jatropha mentah (CJO). Namun begitu, kelemahan utama CJO ialah mempunyai kestabilan terma-oksidatif yang rendah. Oleh itu, objektif kajian ini adalah untuk membangunkan formulasi baharu MWFs berasaskan CJO. Minyak yang baru dibangunkan, minyak jatropha yang dibuahsuai (MJOs) telah diformulasi mengunakan proses transesterifikasi pada pelbagai nisbah molar metil ester jatropha kepada trimetilolpropana (JME:TMP) yang diwakili oleh MJO1 (3.1:1), MJO3 (3.3:1) dan MJO5 (3.5:1). Kemudian, MJOs telah dicampur dengan zarah heksagonal boron nitrida (hBN) pada pelbagai kepekatan (0.05 to 0.5wt.%). MJOs dengan dan tanpa zarah hBN telah dianalisis pada sifat-sifat fizikokimia, ujian kelakuan tribologi, pemotongan ortogonal dan proses pelarikan. Daripada hasil kajian, MJO5 menunjukkan peningkatan terhadap kestabilan termal (index kelikatan yang tinggi) dan oksidatif (penyimpanan pelincir). MJO5c (MJO5+0.5wt.% zarah hBN) menunjukkan sifat-sifat fizikokimia yang optimum. Sebaliknya, MJO5a (MJO5+0.05wt.% zarah hBN) mempamerkan tingkah laku tribologi yang sangat baik dengan pengurangan terhadap geseran dan kehausan, serta kecekapan penguliran tork yang tinggi. Di dalam proses pemotongan ortogonal, MJO5a mencatatkan daya dan suhu pemotongan yang rendah, seterusnya menyumbang kepada pembentukan tatal yang nipis, panjang sentuhan mata alat-tatal yang kecil dan pengurangan tenaga spesifik. MJO5a menghasilkan keputusan yang cemerlang dalam ujian kebolehmesinan dengan mengurangkan daya pemotongan, suhu pemotongan dan kekasaran permukaan merangsang jangka hayat mata alat yang lebih panjang dengan kurang kehausan. Kesimpulannya, MJO5a mempunyai potensi di pasaran minyak pelincir sebagai MWFs yang mampan untuk proses pemesinan.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Percent, efficiency
µ	-	Micro
μ	-	Coefficient of friction
µm	-	Micrometer
a	-	Radius of wear scar diameter
ADDC	-	Antimony dialkyldithiocarbamate
Al	-	Aluminium
Al_2O_3	-	Aluminium oxide
AOCS	-	American Oil Chemist's Society
ASTM	-	American Society for Testing and Material
AW	-	Anti-wear
B	-	Boron
BHA	-	Butylated hydroxyl anisole
BHT	-	Butylated hydroxyl toluene
BSTFA	-	N,O-Bis(trimethylsilyl)tri-fluoroacetamide
BUE	-	Built-up-edge
C	-	Carbon
C_3H_8O	-	2-propanol
CAN	-	Canola oil
CC	-	Coconut oil
CH_4O	-	Methanol
CJO	-	Crude jatropha oil
cm	-	Centimeter
CNT	-	Carbon nanotube
Co	-	Cobalt
COF	-	Coefficient of friction

cP - Centipoise
CPO - Crude palm oil
Cr - Chromium
cSt - Centistoke
CTAB - Cetyltrimethylammonium bromide
Cu - Copper
CVD - Chemical vapour deposition
d - Depth of cut
DAQ - Data-acquisition
DBDS - Dibenzyldisulfide
DBP - Dibutyl 3.5-di-t-butyl-hydroxy
DE - Diester
DNA - Deoxyribonucleic acid
DTC - Dithiocarbamates
DTP - Zincdithiophosphates
E - Elastic modulus
EDS - X-ray spectrometer
EHD - Elastohydrodynamic
EJME - Epoxidized jatropha methyl ester
EJO - Esterified jatropha oil
EJRO - Epoxidized jatropha raw oil
emf - Electro motive force
EP - Extreme pressure
EPME - Epoxidized pongam methyl ester
EPRO - Epoxidized pongam raw oil
F - Friction force
FAME - Fatty acid methyl ester
F_c - Cutting force
Fe - Iron
FESEM - Field emission scanning microscope
FFA - Free fatty acid
F_n - Normal force to friction
f_r - Feed rate
F_s - Shear force

F_t - Thrust force
g - Gram
GC - Gas chromatography
G-ratio - Grinding ratio
H - Hydrogen
h - Hour
H_2SO_4 - Sulfuric acid
H_3PO_4 - Ortho-phosphoric acid
hBN - Hexagonal boron nitride
HOSBO - High oleic soybean oil
J - Joule
JME - Jatropha methyl ester
k - Volume wear rate
KOH - Potassium hydroxide
l - Litre
L - Evaluation length
L_c - Total contact length
λ_c - Cut-off length
LCA - Life cycle analysis
LN - Liquid nitrogen
L_s - Sliding length
m - Meter
Mbar - Megabar
ME - Monoester
mg - Milligram
min - Minute
MJO1 - Modified jatropha oil (3.1:1)
MJO1a - Modified jatropha oil (3.1:1) with 0.05wt.% of hBN particles
MJO1b - Modified jatropha oil (3.1:1) with 0.1wt.% of hBN particles
MJO1c - Modified jatropha oil (3.1:1) with 0.5wt.% of hBN particles
MJO3 - Modified jatropha oil (3.3:1)
MJO3a - Modified jatropha oil (3.3:1) with 0.05wt.% of hBN particles
MJO3b - Modified jatropha oil (3.3:1) with 0.1wt.% of hBN particles
MJO3c - Modified jatropha oil (3.3:1) with 0.5wt.% of hBN particles

MJO5 - Modified jatropha oil (3.5:1)
MJO5a - Modified jatropha oil (3.5:1) with 0.05wt.% of hBN particles
MJO5b - Modified jatropha oil (3.5:1) with 0.1wt.% of hBN particles
MJO5c - Modified jatropha oil (3.5:1) with 0.5wt.% of hBN particles
MJOs - Modified jatropha oil
Ml - Millilitre
mm - Millimeter
Mn - Manganese
MoS_2 - Molybdenum disulphide
MPa - Megapascal
MQL - Minimum quantity lubrication
MQLPO - MQL palm oil
MQLSE - MQL synthetic ester
MWF - Metalworking fluid
MWSD - Mean wear scar diameter
N - Newton, nitride, normality (strength of alkali)
N - Normal force to friction
$NaOCH_3$ - Sodium methoxide
NaOH - Sodium hydroxide
nm - Nanometer
NPG - Neopenthylglycol
npi - Nanoparticle inclusions
O - Oxygen
Ø - Shear angle
Ø - Diameter
º - Degree of angle
ºC - Degree celsius
OL - Ordinary lubricant
P - Phosphorous
PAO - Polyalphaolefins
PCR - Poly-merase chain reaction
PE - Pentaerythritol
PG - Propyl gallate
POME - Palm oil methyl ester

PVD - Physically vapour deposited

r - Distance from the centre of the contact surface, r =3.67mm

R - Radius of the ball, resultant force

ρ - Density

r_a - Chip thickness ratio

R_a - Surface roughness value

RBD - Refined, bleached and deodorised

rev - Revolution

rpm - Revolution per minute

RR - Roundup Ready

r_{tip} - Maximum stylus tip radius

s - Second

S - Sulphur

SBO - Soybean oil

$SCCO_2$ - Supercritical carbon dioxide

SE - Synthetic ester

SEM - Scanning electron machine

Si - Silicon

SS - Sesame oil

T - Friction torque

t - Sliding time, thickness of cutting tool

TAN - Total acid number

TBHQ - Mon-tert-butyl-hydroquinone

t_c - Deformed chip thickness

TE - Triester

Ti - Titanium

TiO_2 - Titanium dioxide

TMP - Trimethylolpropane

TMPE - Synthetic lubricant

TMPTO - Trimethylolpropanetrioleate

t_o - Undeformed chip thickness

υ - Poisson ratio

U - Specific energy

UFA - Unsaturated fatty acids

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