TRIBOLOGICAL PERFORMANCE OF JATROPHA OIL-BASED NANOFLUIDS FOR ORTHOGONAL CUTTING 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

The increasing awareness and concerns toward the environmental and health issues have risen the attention to shift the petroleum-based metalworking fluids (MWFs) toward the use of renewable and biodegradable energy sources for the production of MWFs. Thus, vegetable-based MWF, especially crude jatropha oil (CJO) is considered as a great potential substitution of the petroleum-based oil. However, the crucial limitation of using CJO is low thermal and oxidation stability that leads to poor lubrication behaviour. Hence, the aim of this study was to develop and evaluate the nanofluid formulations from modified jatropha oil (MJO) as the MWF. The MJOs were formulated from jatropha methyl ester with addition of trimethylolpropane (JME: TMP) at molar ratio 3.5:1 through transesterification process. Subsequently, the MJOs were mixed with hexagonal boron nitride (hBN), graphene and copper oxide (CuO) nanoparticles at various concentrations (i.e. 0.01 to 0.05 wt.%). The performance of MJOs was analysed based on the physicochemical properties, tribological behaviour and orthogonal cutting. According to the current findings, thermal-oxidation stability of MJOg3 (MJO+0.05wt.% graphene nanoparticles), MJOh3 (MJO+0.05wt.% hBN nanoparticles) and MJOc3 (MJO+0.05wt.% CuO nanoparticles) were significantly improved by achieving the highest viscosity index among the other studied samples. Contrastingly, MJOh2 (MJO+0.025wt.% hBN nanoparticles), MJOg2 (MJO+0.025wt.% graphene nanoparticles) and MJOc2 (MJO+0.025wt.% CuO nanoparticles) provided the lowest coefficient of friction, friction torque, mean wear scar diameter, surface roughness, volume wear rate and smoothest worn surfaces. For orthogonal cutting process, MJOh2, MJOg2 and MJOc2 offered the lowest cutting temperature, chip thickness and tool-chip contact length. In summary, the MJO with moderate concentration of nanoparticles (MJOh2, MJOg2, MJOc2) provided a superior tribological and machining performance which was a highly potential substitution to the synthetic ester (SE) for the green machining process.

ABSTRAK

Kesedaran dan keprihatinan terhadap masalah alam sekitar dan kesihatan yang semakin meningkat telah mendorong penggantian bendalir kerja lojam (MWFs) berasaskan petroleum ke arah penggunaan sumber tenaga yang dapat diperbaharui dan terbiodegradasi untuk pengeluaran MWFs. Justeru, MWF berasaskan minyak sayur-sayuran, terutama minyak jatropha mentah (CJO) ialah pengganti yang berpotensi besar kepada penggunaan minyak berasaskan petroleum. Namun, kelemahan utama CJO ialah kestabilan terma dan pengoksidaan yang rendah menyebabkan tingkah laku pelinciran lemah. Oleh itu, tujuan kajian ini adalah untuk membangunkan dan menilai formulasi bendalir nano daripada minyak jatropha yang diubahsuai (MJO) sebagai MWF. MJO diformulasikan dari metil ester jatropha dengan trimetilolpropana (JME:TMP) pada nisbah molar 3.5:1 melalui proses transesterifikasi. Seterusnya, MJO dicampurkan dengan zarah nano seperti heksagon boron nitrida (hBN), grafena dan tembaga oksida (CuO) pada pelbagai kepekatan (0.01 hingga 0.05wt.%). Prestasi MJO telah dianalisis berdasarkan sifat-sifat fizik kimia, kelakuan tribologi dan pemotongan ortogonal. Berdasarkan hasil kajian, MJOg3 (MJO+0.05wt.% zarah nano grafena), MJOh3 (MJO+0.05wt.% zarah nano hBN) dan MJOc3 (MJO+0.05wt.% zarah nano CuO) menunjukkan peningkatan dari segi kestabilan termal-pengoksidaan dengan mencapai indeks kelikatan tertinggi berbanding sampel-sampel lain. Sebaliknya, MJOh2 (MJO+0.025wt.% zarah nano hBN), MJOg2 (MJO+0.025wt.% zarah nano grafena) dan MJOc2 (MJO+0.025wt.% zarah nano CuO) memberikan nilai terendah dalam pekali geseran, tork geseran, purata diameter parut haus, kekasaran permukaan, kadar kehausan isipadu dan permukaan paling licin. Di dalam proses pemotongan ortogonal, MJOh2, MJOg2 dan MJOc2 mencatatkan suhu pemotongan yang terendah, ketebalan cip yang nipis dan panjang sentuhan mata alat dengan cip alat yang pendek. Kesimpulannya, MJO dengan kepekatan zarah nano secara sederhana (MJOh2, MJOg2, MJOc2) mempunyai prestasi tribologi dan pemesinan yang cemerlang dan berpotensi untuk menggantikan ester sintetik (SE) bagi proses pemesinan hijau.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Percentage, efficiency
µ	-	Speed of top rotating ball
a	-	Radius of wear scar diameter
Al_2O_3	-	Aluminium oxide
AOCS	-	American Oil Chemist's Society
ASTM	-	American Society for Testing and Material
AW	-	Anti-wear
B	-	Boron
BN	-	Boron Nitride
C	-	Carbon
C_3H_8O	-	2-propanol
CH_4O	-	Methanol
CJO	-	Crude jatropha oil
CLs	-	Coolant lubricants
CNT	-	Carbon nanotubes
Co	-	Cobalt
COF	-	Coefficient of friction
cP	-	Centipoise
Cr	-	Chromium
cSt	-	Centistoke
Cu	-	Copper
CuO	-	Copper oxide
DAQ	-	Data-acquisition
E	-	Elastic modulus
EDS	-	Energy dispersive X-ray spectrometry
EHD	-	Elastohydrodynamic

EJO - Esterified jatropha oil
EP - Extreme pressure
FAME - Fatty acid methyl ester
Fe - Iron
Fe_2O_3 - Iron oxide
FESEM - Field emission scanning microscope
FFA - Free fatty acid
fr - Feed rate
GO - Graphene oxide
GPLs - Graphene nanoplatelets
H - Hydrogen
H_{min} - Dimensionless minimum film thickness
h_{min} - Minimum film thickness
H_2SO_4 - Sulphuric acid
H_3PO_4 - Ortho-phosphoric acid
hBN - Hexagonal boron nitride
HOSBO - High oleic soybean oil
HOV - Vegetable oil of rapeseed
HSLA - High strength low alloy
ILs - Ionic liquids
JOME - Jatropha oil methyl esters
JME - Jatropha methyl ester
k - Volume wear rate
k - Elipticity ratio
KOH - Potassium hydroxide
L - Evaluation length
Lc - Total contact length
λc - Cut-off length
MJOc1 - Modified jatropha oil with 0.01wt.% of CuO nanoparticles
MJOc2 - Modified jatropha oil with 0.025wt.% of CuO nanoparticles
MJOc3 - Modified jatropha oil with 0.05wt.% of CuO nanoparticles
MJOg1 - Modified jatropha oil with 0.01wt.% of graphene nanoparticles
MJOg2 - Modified jatropha oil with 0.025wt.% of graphene nanoparticles

MJOg3	-	Modified jatropha oil with 0.05wt.% of graphene nanoparticles
MJOh1	-	Modified jatropha oil with 0.01wt.% of hBN nanoparticles
MJOh2	-	Modified jatropha oil with 0.025wt.% of hBN nanoparticles
MJOh3	-	Modified jatropha oil with 0.05wt.% of hBN nanoparticles
MJOs	-	Modified jatropha oil
Mn	-	Manganese
MoS_2	-	Molybdenum disulphide
MQL	-	Minimum quantity lubrication
MWF	-	Metalworking fluid
MWSD	-	Mean wear scar diameter
N	-	nitride, normality (strength of alkali)
N	-	Nitrogen
N	-	Sliding velocity
$ŋ_o$	-	Dynamic viscosity of oil sample
$NaOCH_3$	-	Sodium methoxide
NaOH	-	Sodium hydroxide
NGPs	-	Graphene nano platelets
NPG	-	Neopenthylglycol
O	-	Oxygen
Ø	-	Shear angle
Ø	-	Diameter
P	-	Phosphorous
PAGs	-	Polyalkylene Glycol Synthetic
PAOs	-	Polyalphaolefins
PE	-	Pentaerythritol
PIB	-	Polyisobutylene
PIOs	-	Poly(internal olefins)
PKO	-	Palm kernel oil
POME	-	Palm oil methyl ester
PSDZ	-	Primary shear deformation zone
r	-	Distance from the centre of the contact surface, r =3.67mm
R	-	Radius of the ball, resultant force
ρ	-	Density

ra	-	Chip thickness ratio
Ra	-	Surface roughness value
rev	-	Revolution
RME	-	Rapeseed methyl ester oil
rpm	-	Revolution per minute
RSO	-	Rapeseed oil
R_x	-	Effective radii in x direction
S	-	Sulphur
SE	-	Synthetic ester
SEM	-	Scanning electron machine
Si	-	Silicon
SSDZ	-	Secondary shear deformation zone
SVO	-	Straight vegetable oil
T	-	Friction torque
t	-	Sliding time, thickness of cutting tool
tc	-	Deformed chip thickness
Ti	-	Titanium
TiO_2	-	Titanium dioxide
TEP	-	Triethylolpropane
TMB	-	Trimethylolbutane
TME	-	Trimethylolethane
TMP	-	Trimethylolpropane
TSDZ	-	Tertiary shear deformation zone
h	-	Undeformed chip thickness
υ	-	Poisson ratio
v	-	Kinematic viscosity
V_c	-	Cutting speed
VI	-	Viscosity index
VO	-	Vegetable oil
vol.	-	Volume
vol.%	-	Percentage based on volume of oil
W	-	Applied load
w	-	Width of cut

W1	-	Weight pycnometer with sample
WC	-	Tungsten carbide
Wo	-	Weight of dried pycnometer
WSD	-	Wear scar diameter
wt	-	Weight
wt.%	-	Percentage based on weight of oil
ZDDP	-	Zinc dialkyldithiophosphates
ZnO	-	Zinc oxide
α	-	Rake angle
α	-	Pressure-viscosity coefficient
β	-	Clearance or relief angle

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Vegetable oils provide desirable characteristics including high biodegradability and low toxicity towards the environment and human since it is derived from edible material and renewable sources. However, the vegetable oils are not widely used as a base stock of lubricant due to the undesirable properties i.e. low thermal and oxidation stability (Karmakar *et al*., 2017; Singh *et al*., 2017a; Talib *et al*., 2017a). According to Panchal *et al*. (2017), the vegetable oils can undergo chemical modification in order to develop a perfect biodegradable lubricant which has possibility to withstand their performance in a wide operating conditions.

Metalworking fluids (MWF) is widely used for metal removal purpose in shaping, dimensioning and surface finishing of the workpiece in the machining process. Joseph *et al*. (2018) stated that a better machining performance during the machining operation in terms of tool wear, cutting torque and thrust force were achieved by consuming the vegetable-based oil in comparison with the commercial oil. The vegetable oil with a presence of nanoparticles as nanofluid are far more effective in machining as compared to a pure oil by reducing the friction and cutting temperature at the contact surfaces (Yuan *et al*., 2018). A recent investigation by Singh *et al*. (2018) reported that the tribological properties of the vegetable-based nanofluids provided a smoother wear scar surface. The result showed that the worn surfaces might be reduced after sliding by using the lubricant with an optimum concentration of the nanoparticles.

Sustainability has emerged in global thinking perspectives which lead to a decisive change in the manufacturing industry by reconsidering the numerous approaches in the manufacturing process over the past decades. The major dimensions in achieving sustainable manufacturing are vitally related to economic, social, and environmental aspects. According to Hassan *et al*. (2015), the aim of implementing the sustainable manufacturing is to reduce adverse impacts of various activities on the environment and operation in the manufacturing industries. A strong relationship between the natural environment and manufacturing operations can positively improve industrial profits. The increase of the health and environmental consciousness have driven the effort of the technology improvement on lubrication by finding and exploring the other potential replacement candidates to substitute the currently used mineral-based lubricants. In general, mineral-based lubricants those are derived from petroleum are non-biodegradable and heavily toxic. In addition, the diminishing supplies of the natural resources have resulted in the rising of petroleum-based oil prices. Attributable to these issues, thus vegetable oil has received a considerable attention among the researchers as it offers promising opportunities as a lubricant in machining application (Attia *et al*., 2016; Mannekote *et al*., 2018; Rahim *et al*., 2016).

In this present study, the nanofluid formulation from modified jatropha oils (MJOs) was chosen as a sustainable MWFs for machining process. The tribological behaviour and machining performance of MJOs were evaluated to investigate the potential ability of the developed MWF.

1.2 Problem statement

Lubricants are primarily served as a friction reduction, protects against wear between interacting surfaces and acts as a heat removal agent in most of the industrial applications, especially in the machining process. The conventional lubricants were commercially produced using mineral oil as a base fluid which was attained from the crude petroleum oil. The usage of mineral-based lubricant has highlighted a major concern which is resulted by the negative impact on the health and environment due to its poor biodegradability, heavily toxic and nearly impossible to be disposed (Zulhanafi & Syahrullail, 2019). Moreover, the mineral-based lubricant is hazardous to the workers which can cause dermatitis, respiratory ill health and cancer when they were continuously exposed to the machining lubricant in a very long period of time (Mahadi *et al*., 2017). The growing consciousness on the sustainable prospect has

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