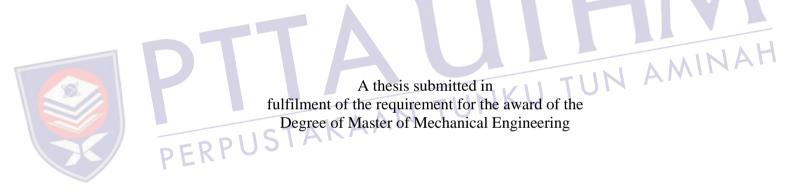
## TRIBOLOGICAL PERFORMANCE OF JATROPHA OIL-BASED NANOFLUIDS FOR ORTHOGONAL CUTTING PROCESS

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JANUARY 2021

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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#### ACKNOWLEDGEMENT

Alhamdulillah (الْحَصْدُ لِلَّهُ), first and foremost, In the Name of Allah, the Most Beneficent, the Most Merciful. All the praises and thanks be to Allah, for giving me opportunity, strength, and dedication to complete my Master thesis through all difficulties and challenges that I faced during this journey.

I would like to express special appreciation to my supervisor, Ts. Dr. Norfazillah bin Talib and co-supervisor Dr. Amiril Sahab bin Abdul Sani for the valuable guidance, support and encouragement from the starting to the final stage of my master study. Moreover, I am really grateful because they are willing to spend their time to give advises and recommendation to improve my research.



Furthermore, I would like to thanks to the academic and laboratory staff for all guidance and support which have made my research work smoot. Many to thanks my fellow colleagues and friends for their help, suggestions and sharing knowledge.

Special thanks to my most beloved family especially to my father, Jamaluddin bin Ahmad and my mother, Siti Azizah binti Abd Ghani for their endless support and always there during my struggle and pain situation throughout my studies.

#### 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 MJOg2 nanoparticles), (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 sayursayuran, 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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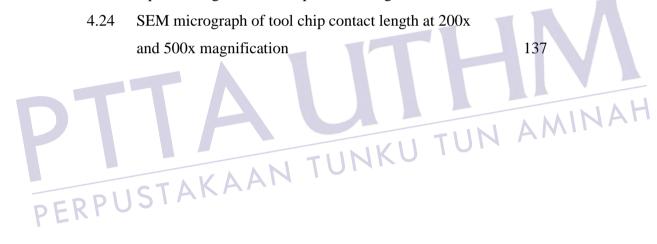


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# LIST OF SYMBOLS AND ABBREVIATIONS

%	-	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
В	-	Boron
BN	-	Boron Nitride
С	-	Carbon
$C_3H_8O$	-	Carbon 2-propanol Methanol
$CH_4O$	-	Methanol
CJO	-	Crude jatropha oil
CLS R	-	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 <sub>2</sub> O <sub>3</sub>	-	Iron oxide
FESEM	-	Field emission scanning microscope
FFA	-	Free fatty acid
fr	-	Feed rate
GO	-	Graphene oxide
GPLs	-	Graphene nanoplatelets
Н	-	Hydrogen
$H_{min}$	-	Dimensionless minimum film thickness
$h_{min}$	-	Minimum film thickness
$H_2SO_4$	-	Sulphuric acid
H <sub>3</sub> PO <sub>4</sub>	-	Ortho-phosphoric acid
hBN	-	Hexagonal boron nitride
HOSBO	-	High oleic soybean oil
HOV	-	High oleic soybean oil Vegetable oil of rapeseed High strength low allow
HSLA	-	Vegetable oil of rapeseed High strength low alloy
ILs	-	Ionic liquids
JOME	<b>P</b> _	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
MIOc1	_	Modified intropha oil with $0.01$ wt % of CuO nanoparticles

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MJOc1 - Modified jatropha oil with 0.01wt.% of CuO nanoparticles

- Modified jatropha oil with 0.025wt.% of CuO nanoparticles MJOc2 -
- 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
	Ν	-	nitride, normality (strength of alkali)
	Ν	-	Nitrogen
	Ν	-	Sliding velocity
	$\eta_{\rm o}$	-	Dynamic viscosity of oil sample
	NaOCH <sub>3</sub>	-	Sodium methoxide
	NaOH	-	Sodium hydroxide
	NGPs	F	Graphene nano platelets Neopenthylglycol Oxygen
	NPG	-	Neopenthylglycol
	0	-	Oxygen
	Ø	5	Shear angle
	ØERI	_	Diameter
	Р	-	Phosphorous
	PAGs	-	Polyalkylene Glycol Synthetic
	PAOs	-	Polyalphaolefins
	PE	-	Pentaerythritol
	PIB	-	Polyisobutylene
	PIOs	-	Poly(internal olefins)
	РКО	-	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
	Т	-	Friction torque
	t	-	Sliding time, thickness of cutting tool
	tc	-	Deformed chip thickness
	Ti	-	Titanium Titanium dioxide Triethylolpropage
	TiO <sub>2</sub>	-	Titanium dioxide
	TEP	-	Titanium dioxide Triethylolpropane
	ТМВ	5	Trimethylolbutane
	TMER	-	Trimethylolethane
	TMP	-	Trimethylolpropane
	TSDZ	-	Tertiary shear deformation zone
	h	-	Undeformed chip thickness
	υ	-	Poisson ratio
	v	-	Kinematic viscosity
	Vc	-	Cutting speed
	VI	-	Viscosity index
	VO	-	Vegetable oil
	vol.	-	Volume
	vol.%	-	Percentage based on volume of oil
	W	-	Applied load
	W	-	Width of cut

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- 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
- $\alpha$  Rake angle
- *α* Pressure-viscosity coefficient
- $\beta$  Clearance or relief angle



PTTAKAAN TUNKU TUN AMINAH PERPUSTAKAAN TUNKU TUN AMINAH

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PERPUSTAKAAN TUNKU TUN AMINAH





### **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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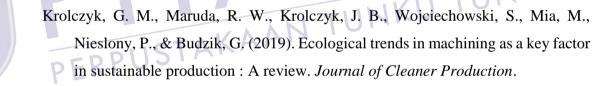
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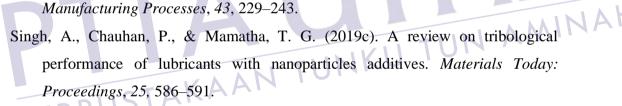
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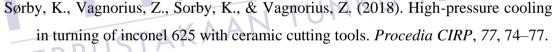
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