Nigerian Journal of Technology (NIJOTECH)
Vol. 41, No. 1, January, 2022, pp.99 –113
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v41i1.14

Performance Assessment of Vegetable Oil-Based Cutting Fluid Developed from Palm Kernel Oil using Multi-Response Optimisation Technique

J. Abutu[1, *], M. A. Oluleye[2], C. Okechukwu[3], S. I. Salawu[4], B. Dame[5], K. U. Unamba[6]

[1] *Department of Mechanical Engineering, Taraba State University, Jalingo,Taraba State, NIGERIA.*
[2] *Department of Mechanical Engineering, Ekiti State University, Ado-Ekiti, Ekiti State, NIGERIA*
[3,5] *Advanced Manufacturing Technology Development Institute, Jalingo, Taraba State, NIGERIA*
[4] *Department of Mechanical Engineering, Kogi State Polytechnic, Lokoja, Kogi State, NIGERIA*
[6] *Department of Civil Engineering, Taraba State University, Jalingo, Taraba State, NIGRIA*

Abstract

In this work, locally sourced palm kernel oil was characterised and thereafter formulated with the aid of full factorial $L_{16}2^4$ design method. The performances of the formulated and mineral cutting fluids were evaluated by examining the material removal rate, cutting temperature and surface roughness using Grey relational analysis (GRA) and Behnken's design ($L_{15}3^3$) design technique. The experimental results obtained indicate that the properties of the palm kernel oil and formulated cutting fluid falls within the preferred range for vegetable-based cutting fluids as reported in literatures. The GRA results showed an optimal turning condition of depth of cut (1.5mm), feed rate (0.3mm/rev) and cutting speed (600rev/min) for palm kernel oil-based cutting fluid while depth of cut (1.5mm), feed rate (0.2mm/rev) and cutting speed (800rev/min) is the optimal condition for mineral oil-based cutting fluid. Also, the chip formation analysis revealed continuous chips which are in conformity with ISO 3685 standards.

Keywords: Performances; vegetable based-oil; cutting fluid; palm kernel-oil.

1.0 INTRODUCTION

Cutting fluid is an intricate combination of agents, anti-corrosive, surfactants lubricants, biocides, detergents, oils and other potentially harmful ingredients [1-2]. As a result of the severe contact between workpiece and tool, the use of cutting fluids is of great importance in metal machining or forming processes [3]. They also served as a lubricant as well as coolant during machining operations, and a transporter to carry chips away from the cutting region [4]. These tasks can be conducted using several cutting fluids that are in existence [5]. Among these cutting fluids, mineral oil based fluids are the most common. Benedicto et al [6] have revealed that these oils are capable of increasing the quality and the productivity of operations during machining processes.

This accounts for the rise in the need in most machining industries. Over the last decade a lot of efforts have been made towards restricting the use of mineral based cutting fluids in the machining processes, due to the human health, costs and environmental effects related to the fluids [7-9]. Studies on occupational exposures to machining fluids such as Mineral oil-based cutting fluid (MBCF) has revealed that operators are at risk of developing diseases and allergenic disorders in machining workshops [5, 10-11]. Lawal et al [12] revealed that vegetable oils are readily biodegradable, less toxic, renewable, and environmentally friendly and can serve as highly attractive substitutes for the commonly used mineral-based oils.

Therefore, vegetable oils can be utilized as more potential candidates in industries to be used as lubricants/cutting fluids [12]. Several researches have been carried out, while some are still in progress to develop from various available vegetable oils in the globe, new organic-based cutting fluids. Consequently, the rising in need for biodegradable and renewable lubricants and cutting fluids are highly expected due to the growing regulations and environmental concerns over contamination and pollution [13-14]. Also, the method of

*Corresponding author (**Tel:** +234 (0) 9059478930)
Email addresses: abutu.joseph@tsuniversity.edu.ng (J. Abutu), modupe.oluleye@eksu.edu.ng (M. A. Oluleye), okerex2002@yahoo.com (C. Okechukwu), salawusalisu7@gmail.com (S. I. Salawu), enginebaya8@gmail.com (B. Dame), mail2kanma@gmail.com (K. U. Unamba)

its application and choice of a cutting fluid depend on significant points like influence on human health and cost environmental effects [3, 15]. As the law restrictions on environmental issues are becoming stronger, these choices of cutting fluid for machining operations are becoming very important. The application minimum quantity of fluid (MQF) is one of the options for the use of flood of cutting fluid during these operations, as it is being coined among several researchers. MQF technique involves dropping in a flow of compressed air, a mixture of cutting fluids (emulsions or neat oils), thereby, generating a *spray* which is directed towards the cutting zone to serve as coolant as well as lubricant. Prakash et al [16] and Waingaertner et al [17] studied this technique in several processes and revealed that depending on the type of cutting fluid used, the pulverization parameters and the cutting conditions, it has the potential of serving as a feasible alternative. Lawal et al [12] revealed that because of the readily biodegradable, less toxic, renewable and environmentally friendly, nature of vegetable oils, they are highly attractive substitutes for the commonly used mineral-based oils. Also, vegetable-based oil have shown that they are good substitute for use in industries as lubricants and cutting fluids [18]. Vegetable oils are renewable and viable source of eco-friendly oils consisting chiefly of triacylglycerides. Triacylglycerides are molecular structures with three long chain fatty acids having similar length with varying levels of unsaturation attached at the hydroxyl groups via ester linkages [19].

Many studies are in progress on the need to utilise various vegetable oils available around the world in developing new bio-based cutting fluids. The increase in need biodegradable cutting fluids is highly expected because of the growing regulations and heath concern over pollution and contamination. the performance of jatropha vegetable-base soluble cutting fluid was compared in the earlier work of Carlos et al [20] with other synthetic (jatropha ester), canola oils (vegetable), and the semisynthetic (mineral) in the milling of aluminum alloy (7050- T7451) for application in the production of aeronautic structures. The authors found that since the newly developed cutting fluid does not interfere with any of the elements involved in the formation of corrosion or intergranular pitting, it performed better in the machining of the aluminum alloys 7050 -T7451, which are not acceptable in the production of aeronautical parts. From the results of the level of acidity and analysis of the chlorine in the samples of oil, the authors also found that jatropha oil-based fluid performed better since it does not present any chlorine element in its composition and does not display any acidity level. Also, Ojolo et al [21] utilised tungsten carbide tool to investigate the effects of different vegetable-based oils (palm kernel oil, groundnut oil, shear butter oil and coconut oil) in the turning of aluminum alloy, copper alloy and mild steel. The experimental response investigated during this study was cutting force and the authors found that of all the four vegetable oils, groundnut oil performed better since it produced the minimum cutting force and that the four vegetable based oils are material dependent. Also, Kazeem et al [18] utilized Grey relational analysis (multi-response optimization technique) and Taguchi design technique to investigate the performance of jatropha and mineral oil-based cutting fluids in the machining of AISI 1525 steel alloy using coated carbide tool. The authors found that using the formulated jatropha oil-based cutting fluid, multi-response performance can be achieved using cutting speed (355 m/min), feed rate (0.10 mm/rev) and depth of cut (1mm) as optimal machining conditions. Also, Winter et al [22] compared the technological suitability of conventional mineral oil based with a polymer based cutting fluid in grinding process and found that when vitrified bonded aluminium oxide grinding wheel is used, even at high specific material removal rates (MRR) along with grinding oil, leads to low radial wear, constant specific cutting power and a good surface finish. In addition, Mahadi et al [23] utilised a 2^4 full factorial design technique as well as minimum quantity lubrication to investigate the performance of boric acid powder with palm kernel oil by comparing with conventional mineral oil for lubrication in AISI 431 alloy steel machining. The authors revealed that the surface integrity of the workpiece is most significantly influenced by feed rate and type of lubricant. Also, it was revealed that, boric acid powder-aided lubricant machining process recorded a percentage improvement of 7.21%, and therefore, performed better than conventional lubricant.

In addition, Lawal et al [12] studied the performances of three different cutting fluids in the turning of AISI 4340 steel using coated carbide tools, with two different vegetable oil-based developed from palm kernel and cottonseed, and a conventional type of cutting fluid (mineral). The author utilized Taguchi design technique for experimental design and revealed that type of cutting fluids (51.1%) and cutting speed (64.64%) have the most significant influence on the cutting force and surface roughness respectively. The author also found that the effects of cutting speed and depth of cut are least significant on the cutting force and surface roughness respectively. It was therefore concluded that the two vegetable oil-based cutting fluids (cottonseed and palm kernel oil based) performed better than mineral oil based.

Kamal et al [24] also used L_{27} Taguchi design technique to investigate the Metal Removal Rate (MRR) in turning of C-34000 workpiece using Computer Numerical Control (CNC). The authors identified the optimum condition of experimental factors for instantaneous optimisation of MRR (8.91mm^3/min). Confirmation experiments were conducted to verify these optimal results and the authors concluded that cutting speed and feed rate has the highest impact on the MRR.

Also, different types of cutting fluids (emulsion, a neat cutting oil-immiscible with water and coconut oil) were utilised by Xavior and Adithan [25] to investigate their influence on surface finish and tool wear during turning of AISI 304 stainless steel with carbide tool. It was revealed that coconut oil based cutting fluid outperformed the conventional mineral oils. Papiya et al [26] studied the performances of three environmental friendly vegetable based cutting fluid (neem oil, soya oil and groundnut oil) and one conventional mineral oil based during machining of mild steel workpiece in wet as well as dry conditions and revealed that workpiece machined with vegetable oil based cutting fluids (VBCFs) produced fine surface morphology as compared with conventional cutting fluid.

This work therefore utilised multi-response optimisation technique (Grey relational analysis) and Behnken's experimental design technique in the formulation emulsion cutting fluids using palm kernel oil. The formulated cutting fluid was characterised and its effects on material removal rate, cutting temperature and surface finish during turning of AISI 1030 steel with coated carbide insert were investigated and compared with conventional mineral oil based cutting fluid.

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.1 Formulation of cutting fluid

The formulation of the cutting fluid was carried using palm kernel oil (*Elaeis guineensis*), collected from a local palm kernel oil extraction factory situated at Orokam, Benue State-Nigeria and mineral soluble oil (MobilMet 424). Other additives used include emulsifier (0.5M sodium stearoyl lactylate in 5litres of water), banana plant juice (anti-corrosion agent), anti-oxidant and biocide.

2.1.2 Turning processes

Turning operation was conducted on a conventional 4-jaw lathe (MITCHELL of Keighley, 3.73kW rated power and cutting speed: 30-1000rpm) domiciled at a commercial workshop in Kaduna -Nigeria, AISI 1030 steel workpiece (1.6m length and 70mm diameter) and a tungsten carbide tool insert (Model: CNMG 1204082H- DCLNR 2020 K/Z, insert thickness of 4.7624 mm and size: 12).

2.2 Methods

2.2.1 Characterization of Oil

As adopted by Agu et al [28] and Kazeem et al [18], the physicochemical and lubricant properties of the palm kernel oil were analyzed using the testing procedure outlined by ASTM D445-19a (viscosity value) ASTM D93 (Flash point) ASTM D7946-19 (pH value), and ASTM D7397-21 (cloud point). The peroxide value was calculated using Equation 1 [27].

$$Peroxide\ Value = \frac{S\ x\ N\ x\ 1000}{Weight of\ \ sample(g)} \quad (1)$$

N is the normality of Sodium thiosulphate ($Na_2S_2O_3$)
S is the Test-Blank (mL $Na_2S_2O_3$)

2.2.2 Formulation of Emulsion Cutting Fluid

Formulation of the cutting fluid was carried out at the Department of Mechanical Engineering Laboratory, Taraba State University, Jalingo-Nigeria. As suggested by Lawal et al [12] and Agu et al [28] simpler less formula with additives was adopted in order to facilitate disposal and easy treatment of cutting fluid after use. The formulation of the palm kernel oil-in-water emulsion cutting fluids involved the application of experimental design (DOE) technique under the conditions stipulated by $L_{16}2^4$ full-factorial design. Table 1 shows the Factor levels for variables employed in the factorial design. Experimental runs obtained using Table 1 were formulated by mixing oil in distilled water along with other additives using a mechanical stirrer operating at a speed of 800 rpm for 12 minutes at room temperature (25°C). The total volume contained in each formulation was 100 ml.

Table 1: Factor levels for variables employed in the factorial design.

Factors	Symbol	Minimum Level (-1) %	Maximum level (+1) %
Anticorrosive agent	AC	1.5	3.5
Emulsifier	E	7.0	11
Antioxidant	AO	0.4	0.8
Biocide	B	0.4	0.8

2.2.3 Characterization of formulated cutting fluids

The formulated palm kernel oil-based cutting fluid (PBCF) was characterized by determining its stability, viscosity, and corrosion level and pH value. The stability of the cutting fluid formulations was assessed visually at constant temperature (25ºC) for 24 hours, as to phase separation, in 100ml measuring cylinders (with 1mL subdivisions) in the following oil concentrations. Also, a calibration constant of 0.1 was used to measure the viscosity of the formulated fluid concentrates at room temperature and elevated temperature of 25°C and 80°C respectively. The corrosion level was determined using the testing procedure adopted by Agu et al [28] while a digital pH meter was utilised in obtaining the pH value.

2.2.4 Turning processes

a. Experimental design

Design of experiment (DOE) was carried out in accordance with Box Behnken Design (BBD)-$L_{15}(3)^3$ method using Minitab 17 statistical software. This type of Response surface methodology (RSM) design technique was selected in preference to Central composite Design (CCD) since it does not include additional runs (axial points) which tends to increase the complicity and cost of the entire process. The cutting variables selected along with their respective levels are shown in Table 2 while the experimental design layout is shown in Table 3.

Table 2: Factor levels of cutting parameters

Factor	Unit	Level	
		Low	High
Depth of cut (dc)	mm	0.5	1.5
Feed rate (Fr)	mm/rev	0.1	0.30
Cutting speed (Cv)	rev/min	400	800

b. Turning operation

Turning operations were performed on the AISI 1030 steel workpiece using a conventional 4-jaw lathe (MITCHELL of Keighley, 3.73kW rated power and cutting speed: 30-400rpm) domiciled at a commercial workshop in Kaduna-Nigeria and a tungsten carbide tool insert (Model: CNMG 1204082H- DCLNR 2020 K/Z, insert thickness of 4.7624 mm and size: 12). The workpiece samples were reduced to 280mm length so as to achieve a diameter to length of 1:4 which eliminates flexing and ensures rigidity during the turning operation [12, 28] while the diameter of 70mm was maintained. The turning operation represented in Figure 1 involved mounting the test sample on the lathe between the live centre and chuck so as to ensure better clamp force in the turning process. This was followed by machining off thin layer of outer surface of each specimen before the commencement of the process and thereafter, turning at different depth of cuts, feed rates and velocities as stipulated in Table 3.

Table 3: BBD-RSM $L_{15}(3)^3$ Experimental Design Layout

Run	Orthogonal array			Cutting parameters		
	dc (mm)	Fr (mm/rev)	Cv (rev/min)	dc (mm)	Fr (mm/rev)	Cv (rev/min)
1	0	-1	-1	1.0	0.1	400
2	0	-1	1	1.0	0.1	800
3	0	1	-1	1.0	0.3	400
4	0	1	1	1.0	0.3	800
5	-1	0	-1	0.5	0.2	400
6	-1	0	1	0.5	0.2	800
7	1	0	-1	1.5	0.2	400
8	1	0	1	1.5	0.2	800
9	-1	-1	0	0.5	0.1	600
10	-1	1	0	0.5	0.3	600
11	1	-1	0	1.5	0.1	600
12	1	1	0	1.5	0.3	600

13	0	0	0	1.0	0.2	600
14	0	0	0	1.0	0.2	600
15	0	0	0	1.0	0.2	600

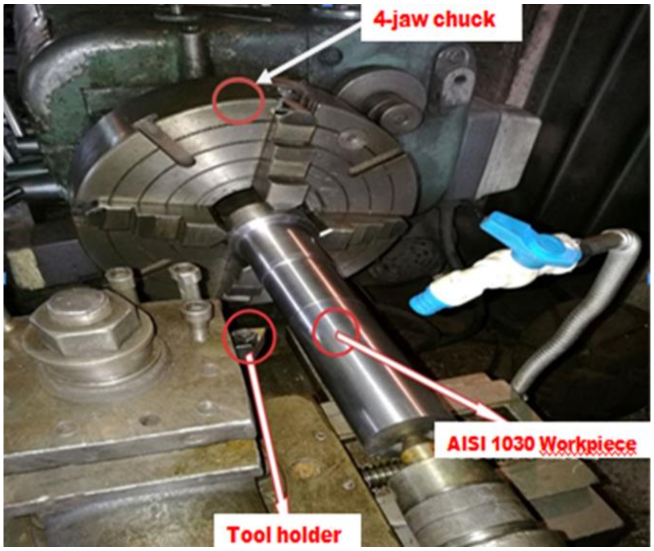


Figure 1: Experimental set up for turning operation

2.3 Experimental responses

The surface integrity of machined part of workpieces was measured with surface roughness tester (Model: SRT–6200, ±10% accuracy, Merit-mi Instruments Co., Ltd). Three readings were taken along the axis of each machined workpiece and the average value was calculated and recorded. Also, the cutting temperature of each experimental process was obtained with an Infra-red thermometer (PeakTech: 4960-IR thermometer, -50 to +1200ºC). This measurement was carried out by holding the device 50mm away from the chip-tool interface and thereafter pointing the probe of the thermometer at the interface during machining. Three measurements were also taken for each experimental run and the mean value was calculated and recorded. In addition, the Material removal rate (MRR) was calculated using Equation 2 [29].

$$MRR=\frac{\pi}{4}x(D_1^{\,2}-D_2^{\,2})\,x\,f\,x\,N \qquad (2)$$

where, N is the cutting speed, rpm, f is the Feed rate in mm/rev, D_2 is the final diameter in mm and D_1 is the Initial diameter in mm.

3.0 RESULTS AND DISCUSSIONS

3.1 Characterization of extracted oil

The results of the physiochemical and lubricity related properties of palm kernel oil are presented in Table 4. As shown in Table 4, it can be observed that the condition of palm kernel oil at room temperature is in liquid form. This state of the oil makes it easy to be used as lubricant and as base oil for cutting fluid formulation. Viscosity is commonly perceived as resistance to pouring or thickness and represents the measure of the resistance of the oil to deformation under shear stress [30]. The viscosity of 113.6 cst indicates that the oil possesses a good resistance to deformation under shear stress. Also, it is also clear from the result that palm kernel oil have good flash point (237ºC) as it compare well with conventional oils such as SAE 30 and SAE 40 which has a flash point of 243 and 260ºC respectively [30]. In addition, the pH of palm kernel oil is alkaline (10.46) which indicates good tendency of not corroding metals during turning processes while the peroxide value of the oil was 7.5 mg/g oil which revealed a high peroxide value and this suggest a high levels of antioxidant and is an indication of good levels of oxidative rancidity of the oils. The palm kernel oil exhibited a relatively high cloud point at 29ºC; which indicates that the oil can stay a longer time before congealing.

Table 4: Physiochemical and lubricity related properties of palm kernel oil

S/N	Parameter	Value
1	Viscosity at 40 ºC	113.6 cst
2	Flash point	237 ºC
3	pH value	10.46
4	Peroxide Value	7.5 mg/g oil
5	Cloud point	27ºC
6	Colour	Clear light yellow
7	Appearance at 25ºC	Liquid

3.2 Characterization of cutting fluids

The properties of the formulated oil-in-water emulsion and the mineral oil-based cutting fluids are shown in Table 5. The data obtained for the pH values of each formulated cutting fluid were analyzed using Minitab statistical software and the optimal combination of additive and percentage oil content were used to formulate the oil based emulsion cutting fluid. The optimum additive parameters for 30% palm kernel oil content include emulsifier (8.29 vol.%), anticorrosion (2.75 vol.%), biocide (0.97 vol.%) and Anti-oxidant (0.92vol.%). Also, based on the results presented in Table 5, it can be observed that the palm kernel oil-based cutting fluid compared well with conventional based cutting fluid (pH of 10.1 -alkaline). A viscosity value of 2.54 (Cst) was recorded, thereby making it safe-to use and effective as cutting fluid in machining process.

3.3 Experimental Results and S/N Ratios

The results of MRR obtained during the turning operation conducted using palm kernel oil-based cutting fluid (PBCF) and mineral oil-based cutting fluid (MBCF) are shown in Table 6 while the summary of the experimental findings along with their corresponding signal-to noise (S/N) ratio values of responses for PBCF and MBCF are shown in Table 7 and Table 8 respectively. The S/N ratios of surface finish and cutting temperature were calculated using smaller- the better quality characteristics (Equation 3) while that of MRR was using larger- the better quality characteristics (Equation 4).

$$\text{S/N value} = -10\log\frac{1}{n}\left(\sum_{i-1}^{n} y_i^2\right) \quad (3)$$

$$\text{S/N value} = -10\log\frac{1}{n}\left(\sum_{i-1}^{n}\frac{1}{y_i^2}\right) \quad (4)$$

where, n and y represent the number of experimental samples and responses of given factor level combination respectively.

Table 5: Characteristics of palm kernel oil-based cutting fluids

S/N	Property	Palm kernel oil	Mineral based oil
1	Corrosion Level	Corrosion Resistant	Corrosion Resistant
2	Viscosity at 30% (Cst)	2.54	1.2
3	pH Value at 30% Oil Content	10.32	10.1
4	Stability	Stable	Stable
5	Colour	Whitish	Milky

Table 6: Results of material removal rate for PBCF and MBCF

Run	Cutting parameters			PBCF		MBCF		MRR mm^3/min	
	dc (mm)	Fr (mm/ rev)	Cv (rev/ min)	D1 (mm)	D2 (mm)	D1 (mm)	D2 (mm)	PBCF	MBCF
1	1.0	0.1	400	70.00	69.00	66.50	65.50	4367.4	4147.44
2	1.0	0.1	800	69.00	68.00	65.17	64.17	8609.1	8127.73
3	1.0	0.3	400	67.50	66.50	63.84	62.84	12631	11940.9
4	1.0	0.3	800	65.80	64.80	62.51	61.51	24621	23380.3
5	0.5	0.2	400	64.40	63.90	61.18	60.68	4031.2	3828.84
6	0.5	0.2	800	61.60	61.10	58.52	58.02	7710.5	7323.37
7	1.5	0.2	400	58.80	57.30	55.86	54.36	10944	10389.3
8	1.5	0.2	800	56.00	54.50	53.20	51.70	20832	19775.8
9	0.5	0.1	600	70.00	69.50	66.50	65.00	3287.3	9296.39
10	0.5	0.3	600	67.70	67.20	64.34	63.84	9536.8	9061.69
11	1.5	0.1	600	65.80	64.30	62.51	61.01	9197.4	8732.25
12	1.5	0.3	600	63.70	62.20	60.52	59.02	26702	25352.6
13	1.0	0.2	600	61.60	60.60	58.52	57.52	11519	10937.9
14	1.0	0.2	600	60.66	59.66	57.62	56.62	11341	10768.3
15	1.0	0.2	600	56.70	55.70	53.87	52.87	10595	10061.3

Table 7: Experimental Process Parameters, Results and S/N Ratios (PBCF)

Run	Surface finish (Ra)		Cutting Temperature (T)		Material removal rate (MRR)	
	Ra (µm)	S/N (dB)	T(^{0}C)	S/N (dB)	MRR (mm^3/min)	S/N (dB)
1	0.98	0.175	44.92	-33.050	4367.38	72.8044
2	1.15	-1.214	56.38	-35.022	8609.08	78.6991
3	1.56	-3.865	44.15	-32.898	12630.84	82.0286
4	1.58	-3.954	55.93	-34.953	24620.71	87.8260
5	1.31	-2.345	43.15	-32.699	4031.19	72.1087

Run	Surface finish (Ra)		Cutting Temperature (T)		Material removal rate (MRR)	
	Ra (µm)	S/N (dB)	T(°C)	S/N (dB)	MRR (mm^3/min)	S/N (dB)
6	1.35	-2.607	52.15	-34.346	7710.47	77.7416
7	1.63	-4.244	43.03	-32.676	10943.57	80.7832
8	2.83	-9.036	54.60	-34.744	20831.46	86.3744
9	2.29	-7.197	56.16	-34.988	3287.32	70.3368
10	2.84	-9.066	46.26	-33.304	9536.76	79.5880
11	3.63	-11.198	48.26	-33.672	9197.42	79.2733
12	2.41	-7.643	50.60	-34.082	26701.5	88.5307
13	3.55	-11.012	51.71	-34.271	11518.57	81.2280
14	3.44	-10.744	51.93	-34.308	11341.36	81.0933
15	3.67	-11.293	52.15	-34.346	10594.82	80.5019

Table 8: Experimental Process Parameters, Results and S/N Ratios (MBCF)

Run	Surface finish (Ra)		Cutting Temperature (T)		Material removal rate (MRR)	
	Ra (µm)	S/N (dB)	T(°C)	S/N (dB)	MRR (mm^3/min)	S/N (dB)
1	2.92	-9.321	49.96	-33.972	4147.44	72.3556
2	3.18	-10.058	62.69	-35.944	8127.73	78.1994
3	3.22	-10.160	49.09	-33.820	11940.86	81.5407
4	2.91	-9.289	62.20	-35.876	23380.25	87.3770
5	3.77	-11.538	47.98	-33.621	3828.84	71.6613
6	4.13	-12.310	57.99	-35.268	7323.37	77.2942
7	3.49	-10.846	47.85	-33.598	10389.34	80.3318
8	5.30	-14.488	60.71	-35.666	19775.75	85.9227
9	2.69	-8.610	62.45	-35.910	9296.39	79.3663
10	3.56	-11.030	51.44	-34.226	9061.69	79.1442
11	3.58	-11.069	53.67	-34.594	8732.25	78.8225
12	2.41	-7.643	56.26	-35.004	25352.64	88.0805
13	4.57	-13.189	57.50	-35.193	10937.93	80.7787
14	4.47	-13.016	57.75	-35.231	10768.26	80.6429
15	4.61	-13.274	57.99	-35.268	10061.31	80.0531

Based on the experimental results shown in Table 7, it can be found that the surface finish, cutting temperature and material removal rate (MRR) of the machining operation carried out using the newly formulated PBCF falls within 0.98-3.67 µm, 43.03-56.38ºC and 4031.19-26701.5mm^3/min respectively. These results indicate that the performance of the PBCF compared favourably with that of MBCF whose surface finish, cutting temperature and MRR lies within 2.41-4.61µm, 47.85-62.45ºC and 3828.84-25352.64 mm^3/min respectively as presented in Table 8. These findings are in agreement with the earlier work of Lawal et al [12] who reported surface finish of 0.48- 3.62 µm and revealed that the cutting fluid formulated using palm kernel oil can favourably serve as a replacement for MBCF.

3.4 *Analysis of Variance*

ANOVA was utilized in investigating the percentage contributions of individual machining parameters. This analysis was carried out using 95% confidence level and 5% significance level. The ANOVA result presented in Table 9 revealed that cutting speed (74.95%) and feed rate (73.29%) has the most significant effects on the surface finish of the AISI 1030 when using PBCF and MBCF respectively as cutting fluid. This result is in agreement with the earlier work of Lawal et al [12] who also utilised PBCF and reported that surface finish is most influenced by cutting speed (64.46%) and least influenced by depth of cut (0.3079%). In addition, Table 10 showed that the cutting temperature for both PBCF (81.56%) and MBCF (82.53%) are most influenced by cutting speed, followed by depth of cut and feed rate while ANOVA results presented in Table 11 revealed that feed rate has the most significant impact on material removal rate of both PBCF (43.75%) and MBCF (41.56%). This is also followed by depth of cut and feed rate. The percentage error recorded during this analysis were less than 5% indicating that the experiment was performed with minima influence of experimental noise [18]. DOF, SS, MS, F, P, dc, Fr and Cv were used as notations for degree of freedom, sum of square, mean square, f-value, percentage contribution, depth of cut, feed rate and cutting speed respectively in this section.

3.5 Multi-response optimisation

3.5.1 Grey relational analysis

As reported in the earlier work of Chin [31], Abutu et al [32] and Yiyo et al [33] Grey relational analysis (GRA) is a multi-response optimisation technique which involves using Equation 5 (smaller-the-better attributes) and Equation 6 (larger-the-better attributes) to calculate the grey relational generation (GRG) of responses using the signal to-noise (S/N) ratios values presented in Table 7 and 8.

This is preceded by the calculation of grey relational coefficient (GRC) using Equation 7. The final phase of GRA is the calculation of grey relational grade (GR-Grade) using Equation 8. The results for the GRA of PBCF and MBCF are presented in Table 12 and 13 respectively.

Table 9: ANOVA for surface finish

Factor	PBCF					MBCF				
	DOF	SS	MS	F	P(%)	DOF	SS	MS	F	P (%)
dc	2.00	1.42	0.71	9.73	10.47	2.00	0.87	0.44	14.17	9.31
Fr	2.00	1.39	0.70	9.55	10.28	2.00	6.88	3.44	111.62	73.29
Cv	2.00	10.16	5.08	69.68	74.95	2.00	1.39	0.69	22.51	14.78
Error	8.00	0.58	0.07		4.30	8.00	0.25	0.03		2.63
Total	14.00	13.55	0.97		100.00	14.00	9.39	0.67		100.00

Table 10: ANOVA for cutting temperature

Factor	PBCF					MBCF				
	DOF	SS	MS	F	P (%)	DOF	SS	MS	F	P (%)
dc	2.00	24.60	12.30	8.60	7.60	2.00	34.38	17.19	59.28	8.59
Fr	2.00	23.63	11.82	8.26	7.30	2.00	33.19	16.60	57.22	8.29
Cv	2.00	263.98	131.99	92.30	81.56	2.00	330.3	165.1	569.4	82.53
Error	8.00	11.44	1.43		3.53	8.00	2.32	0.29		0.58
Total	14.0	323.65	23.12		100.0	14.0	400.2	28.58		100.0

Table 11: ANOVA for Material Removal Rate (MRR)

	PBCF					MBCF				
Factor	DOF	SS ($x10^6$)	MS ($x10^6$)	F	P (%)	DOF	SS ($x10^6$)	MS ($x10^6$)	F	P (%)
dc	2	242.97	121.5	33.97	34.81	2	176.4	88.201	27.02	31.16
Fr	2	305.38	152.7	42.70	43.75	2	235.3	117.63	36.03	41.56
Cv	2	120.99	60.50	16.92	17.34	2	128.3	64.124	19.64	22.66
Error	8	28.61	3.576		4.10	8	26.12	3.2649		4.61
Total	14	697.95	49.85		100	14	566.0	40.431		100

The resulting effects of cutting parameters (cutting speed, feed rate and depth of cut) for PBCF and MBCF obtained using the GR-grade values in Table 12 and 13 are shown in Table 14. The values highlighted in italics represent the optimal level of cutting parameters while the main effect plots for PBCF and MBCF obtained using values presented in Table 14 are shown in Figure 2 and 3 respectively.

$$\text{Smaller-the better, } (a_{ij}) = \frac{\bar{l}_{ij} - l_{ij}}{\bar{l}_j - l_j} \quad (5)$$

$$\text{Larger-the-better attributes} = \frac{l_{ij} - \underline{l}_i}{\bar{l}_i - \underline{l}_j} \quad (6)$$

(i = 1, 2,….w and j = 1, 2, …. x)

where, $l_i = (l_{i1}, l_{i2}, \ldots, l_{ij}, \ldots, l_{ix})$, l_{ij} represent the performance value of alternative i attribute j and $\overline{l_j} = \max\{l_{ij}, i = 1, 2, \ldots, w\}$ and $\underline{l_j} = \min\{l_{ij}, i = 1, 2, \ldots, x\}$.

$$\text{GRC}, \alpha(a_{0j}, a_{ij}) = \frac{\Omega_{\min} + \kappa\Omega_{\max}}{\Omega_{ij} + \kappa\Omega_{\max}} \quad (7)$$

$j = 1, 2, \ldots, w$ and $i = 1, 2, \ldots, x$, $\Omega = a_{0j} - a_{ij}$, $\Omega_{\min} = \min(\Omega_{ij}, i = 1, 2, \ldots, w; j = 1, 2, \ldots, x)$, $\Omega_{nax} = \max(\Omega_{ij}, i = 1, 2, \ldots, w; j = 1, 2, \ldots, x)$ and κ is the distinguishing coefficient, $\kappa \in [0, 1]$. The aim of distinguishing coefficient is to reduce or increase the range of the grey relational coefficient and the widely accepted value is 0.5 [33].

$$\text{Grade} = \frac{\Delta GRC}{Number\,of\ \exp erimental\ responses} \quad (8)$$

Table 12: GRG, GRC and GR-grades for PBCF

	GRG			GRC			GR-grade
Sn	**Ra**	**Tc**	**MRR**	**Ra**	**Tc**	**MRR**	
X_o	1.000	1.000	1.000				
1	0.000	0.159	0.136	0.333	0.373	0.366	0.358
2	0.121	1.000	0.460	0.363	1.000	0.481	0.614
3	0.352	0.095	0.643	0.436	0.356	0.583	0.458
4	0.362	0.970	0.961	0.439	0.944	0.928	0.770
5	0.220	0.010	0.097	0.391	0.336	0.356	0.361
6	0.243	0.711	0.407	0.398	0.634	0.457	0.496
7	0.385	0.000	0.574	0.449	0.333	0.540	0.441
8	0.803	0.881	0.881	0.718	0.808	0.808	0.778
9	0.643	0.986	0.000	0.583	0.972	0.333	0.630
10	0.806	0.268	0.508	0.720	0.406	0.504	0.543
11	0.992	0.424	0.491	0.984	0.465	0.496	0.648
12	0.681	0.600	1.000	0.611	0.555	1.000	0.722
13	0.975	0.680	0.599	0.952	0.610	0.555	0.706
14	0.951	0.696	0.591	0.911	0.622	0.550	0.694
15	1.000	0.711	0.559	1.000	0.634	0.531	0.722

Table 13: GRG, GRC and GR-grades for MBCF

	GRG			GRC			**GR-grade**
Sn	**Ra**	**Tc**	**MRR**	**Ra**	**Tc**	**MRR**	
X_o	1.000	1.000	1.000				
1	0.244	0.160	0.042	0.398	0.373	0.343	0.371
2	0.352	1.000	0.398	0.435	1.000	0.454	0.630
3	0.368	0.095	0.602	0.442	0.356	0.557	0.451
4	0.239	0.971	0.957	0.397	0.945	0.921	0.754
5	0.568	0.010	0.000	0.536	0.336	0.333	0.402
6	0.683	0.712	0.343	0.612	0.634	0.432	0.560
7	0.470	0.000	0.528	0.485	0.333	0.514	0.444
8	1.000	0.881	0.869	1.000	0.808	0.792	0.867
9	0.139	0.986	0.469	0.368	0.972	0.485	0.608
10	0.495	0.268	0.456	0.498	0.406	0.479	0.461
11	0.502	0.425	0.436	0.501	0.465	0.470	0.479
12	0.000	0.599	1.000	0.333	0.555	1.000	0.630
13	0.812	0.680	0.555	0.727	0.610	0.529	0.622
14	0.784	0.696	0.547	0.698	0.622	0.525	0.615
15	0.823	0.712	0.511	0.739	0.634	0.506	0.626

Table 14: Resulting factor effects of cutting parameters

Level	PBCF			MBCF		
	dc (mm)	Fr (mm/rev)	Cv (rev/min)	dc (mm)	Fr (mm/rev)	Cv (rev/min)
1	0.4043	0.5624	0.5076	0.4172	0.5220	0.5076
2	*0.6664*	0.5996	0.6174	0.5772	*0.5908*	0.5814
3	0.6648	*0.6236*	*0.6472*	*0.7025*	0.5739	*0.6048*

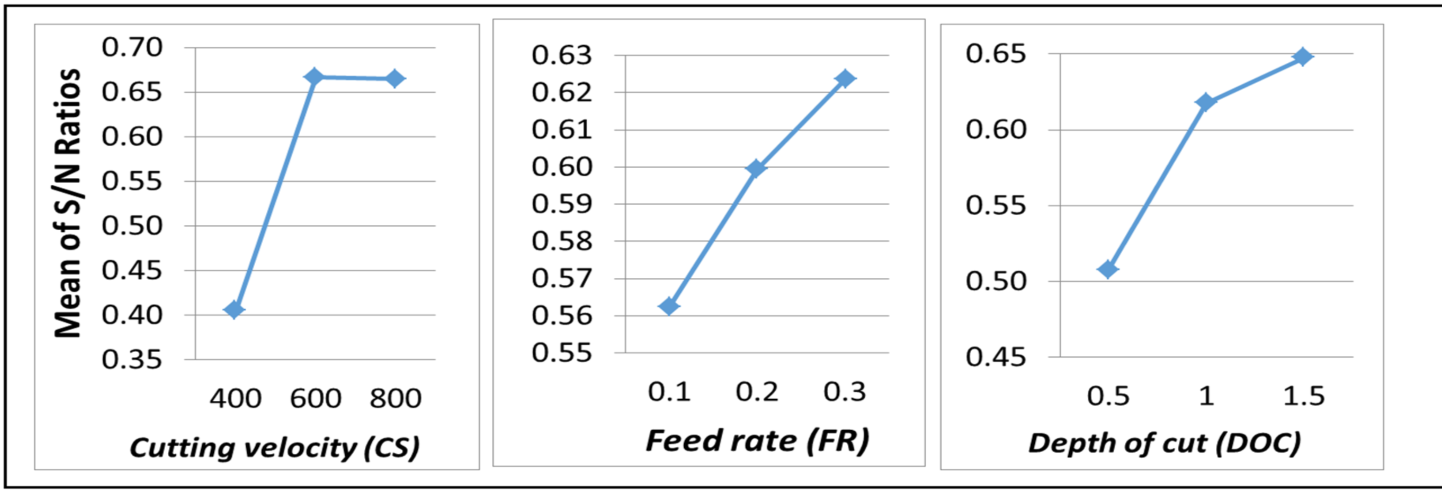


Figure 2: Main effect plots for PBCF

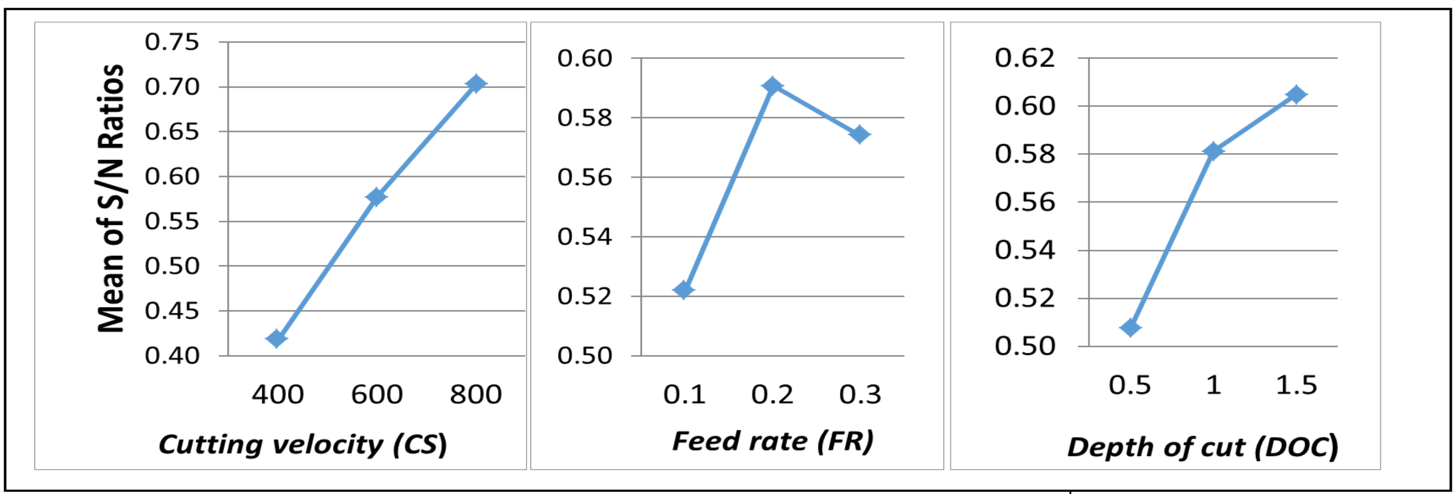


Figure 3: Main effect plots for MBCF

The main effects plots represented in Figure 2 revealed that using the formulated PBCF as cutting fluid in the turning of AISI 1030, optimum multi-response performance can be achieved using cutting speed (600 rev/min), feed rate (0.3mm/rev) and depth of cut (1.5mm) as cutting conditions while Figure 3 showed that optimum multi-response performance of the conventional mineral based cutting fluid (MBCF) can be achieved using cutting speed (800rev/min), feed rate (0.2mm/rev) and depth of cut (1.5mm). Kaladhar et al [34] suggested that any alteration of these optimal cutting conditions obtained from this optimisation process may lead to poor performance of the machining process.

3.5.2 *Confirmation test*

Mathematical models for cutting parameters (depth of cut, feed rate and cutting speed) were obtained from the regression analysis of empirical experimental data using MINITAB 17 statistical software. Experiments were conducted based on the optimized values obtained from GRA to validate the regression equations for surface finish, cutting temperature and material removal rate.

The percentage errors obtained during this validation are shown Table 15. dc (depth of cut), Fr (feed rate), Cv (cutting speed), Ra (surface finish), Tc (cutting temperature) and MRR (material removal rate) were used as notations in the mathematical models shown Equation 5-10.

PBCF

i. Ra (µm) = -15.66 + 0.04709 Cv + 34.87 Fr + 1.90 dc - 0.000041 Cv*Cv - 61.2 Fr*Fr- 0.597 dc*dc - 0.00187 Cv*Fr + 0.00290 Cv*dc - 8.85 Fr*dc (5)

Rsq= 95.45% and Rsq (adj) = 87.27%

ii. Tc (˚0C) = 31.6 + 0.0752 Cv - 84.6 Fr - 1.51 dc - 0.000046 Cv*Cv + 25.1 Fr*Fr - 7.45 dc*dc + 0.0040 Cv*Fr + 0.00643 Cv*dc + 61.2 Fr*dc(6)

Rsq= 96.80% and Rsq (adj) = 91.05%

iii. MRR (mm3/min) = 13967 - 17.8 Cv - 108489 Fr - 7196 dc + 0.00130 Cv*Cv + 135350 Fr*Fr - 1297 dc*dc + 96.9 Cv*Fr + 15.52 Cv*dc + 56273 Fr*dc (7)

Rsq= 99.63% and Rsq (adj) = 98.97%

When *Cv* = 600 rev/min, *Fr* = 0.3mm/rev and *dc* = 1.5mm;

Ra = 2.5847 µm, Tc = 54.093 ºC and MRR = 26410.4 mm^3/min

MBCF

iv. Ra (µm) = -4.73 + 0.00483 Cv + 66.2 Fr + 1.52 dc - 0.000005 Cv*Cv - 130.3 Fr*Fr - 0.750 dc*dc - 0.0071 Cv*Fr + 0.00362 Cv*dc - 10.20 Fr*dc (8)

Rsq= 91.42% and Rsq (adj) = 75.99%

v. Tc (˚0C) = 35.2 + 0.0836 Cv - 94.3 Fr - 1.64 dc - 0.000051 Cv*Cv + 28.0 Fr*Fr - 8.29 dc*dc + 0.0048 Cv*Fr + 0.00712 Cv*dc + 68.0 Fr*dc (6)

Rsq= 96.80% and Rsq (adj) = 91.05%

vi. MRR (mm3/min) = 21780 + 6.4 Cv - 172756 Fr - 20815 dc - 0.0184 Cv*Cv + 204566 FR*FR+ 1904 dc*dc + 93.2 Cv*Fr + 14.73 Cv*dc + 84275 Fr*dc (10)

Rsq= 98.56% and Rsq (adj) = 95.98%

When *Cv* = 800rev/min, *Fr* = 0.2mm/rev and *dc* = 1.5mm;

Ra = 4.7025 µm, Tc = 57.9895 ºC and MRR = 19687.44 mm^3/min

Montgomery et al [35] suggested that in every multiple linear regression model, the Rsq (adj) (correlation coefficient) value should be between 80 and 100%. Though, some of the Rsq (adj) values obtained in this study were slightly below 80%, this may be attributed to noise which may arise from experimental uncertainty [32].

Table 15: Percentage errors for confirmation test

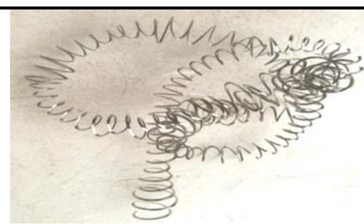
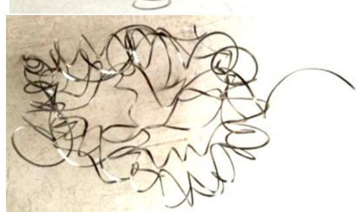
Parameters	PBCF			MBCF		
	Cal. value	Exp. value	Error (%)	Cal. value	Exp. value	Error (%)
Ra (µm)	2.5847	2.71	4.624	4.7025	4.901	4.050
Tc (ºC)	54.093	53.81	0.526	57.9895	60.701	4.481
MRR (mm^3/min)	26410.4	25563.4	3.313	19687.4	19775.7	0.447

The confirmatory test results presented in Table 15 showed that the use of PBCF in the turning of the AISI 1030 steel workpiece produced percentage errors of 4.624% (surface finish), 0.526% (cutting temperature) and 3.313% (material removal rate) while the use of conventional MBCF gave a percentage error of 4.050% (surface finish), 4.481% (cutting temperature) and 0.447% (material removal rate). These results therefore showed that a low percentage error (>5%) was achieved thereby indicating that there is a good correlation between the experimental results and the predicted regression models. In addition, the turning operation conducted using the formulated PBCF produced better surface finish, lesser cutting temperature and higher material removal rate compared to the turning operation done using the conventional MBCF. These findings revealed that the formulated PBCF can serve as a possible substitute for conventional mineral based cutting fluid in the turning of low carbon steel such as AISI 1030 alloy steel.

3.5.3 Chip formation Analysis

The type, colour and form of chips produced in any machining process are critical features which strongly influence the stability of cutting process [36-38]. Though, chips are considered as wastes as a result are not important in machining processes but it has been observed that some chips formed during any metal cutting operation could hamper the cutting process especially the very long chips which has the tendency of curling on the workpiece. Segreto et al [38] revealed that long chips can interfere with workpiece as well as machine tool and have harmful impacts on the product quality and the material removal rate, thereby posing great effects on the machining operation. In this study, chips formation analysis was conducted on the two cutting conditions obtained from Grey relational analysis for PBCF and MBCF. The chips produced after the cutting operations conducted under different cutting conditions of dc (depth of cut), Fr (feed rate) and Cv (cutting speed) are shown in Table 16. The comparison and categorisation of these chips were carried out in accordance with ISO 3685chip form classification standards. Based on the results presented in Table 16, it can be observed that the type of chips produced at each experimental runs comprise of different forms of continuous chips with the chip length ranging from 1300mm to 1450mm. Snarled washer chip and snarled tubular chip were produced using PBCF and MBCF respectively. In addition, in the metal cutting process, two different colours of chips were observed. The machining process conducted using PBCF produced bright and smooth chip while the use of MBCF produced burnt and black chip. Segreto et al [38] and Kazeem et al [18] have revealed that the use of insufficient lubricant or high feed or high cutting speed or high wear at cutting edge lead to the production of burnt and black chips during machining process. Also, Singh et al [39] reported that black colour of chip indicates that high heat is generated during machining operation which is not kept in the workpiece material or the insert but directed into the chip thereby instigating oxidation of the chip. This implies that the palm kernel oil -based cutting fluid was sufficiently able to penetrate into the chip/workpiece boundary. As a result, compared to the mineral oil-based cutting fluids, the formulated cutting fluids produce favourable chips during the machining of AISI 1030 steel alloy under the optimal cutting conditions.

Table 16: Types and colour of chips produced during machining

Type of cutting fluid	Cutting parameters	Chip formed	Type of chip	Colour
PBCF	dc = 1 mm Fr = 0.3 mm/rev Cv =600 rev/min		Snarled washer chip	bright and smooth chip
MBCF	dc = 0.5 mm Fr = 0.2 mm/rev Cv =800 rev/min		Snarled tubular chip	burnt and black chips

4 CONCLUSIONS

In this work, non-edible seed oils (palm kernel oil) was locally sourced and characterised by determining its physio-chemical properties. The effects of the formulated and conventional mineral oil based cutting fluid on machining performance (material removal rate, cutting temperature and surface finish) were investigated by turning AISI 1030 alloy steel using coated carbide tool insert. Box Behnken's design (BBD) technique via Response surface methodology (RSM) was used for design of experiment. The following conclusions can be drawn based on the findings from this work:

i. The physio-chemical and lubricity related properties of palm kernel oil proved to be satisfactory and human-friendly as a result, can be adopted as base oil for cutting fluid formulation while the physical and chemical analyses performed on the formulated palm kernel oil based cutting fluid showed a satisfactory performance in terms of the excellent results as compared to the conventional mineral cutting fluid.

ii. The use of palm kernel oil-based cutting fluid in the turning of AISI 1030 produced; 3.67±0.98µm, 56.38±43.03°C and 26701.5±3287.32mm^3/min for surface finish, cutting temperature and material removal rate respectively while the use of mineral oil based cutting fluid produced; 4.61±2.41µm, 62.45±47.85°C and 25352.64±3828.84mm^3/min for surface finish, cutting temperature and material removal rate respectively.

iii. The Analysis of Variance (ANOVA) results showed that cutting temperature is greatly affected by cutting speed while material removal rate is most influenced by feed rate for both palm kernel oil and mineral oil-based cutting fluids. In addition, the surface finish of the formulated and conventional oil based cutting fluid was most influenced by cutting speed and feed rate respectively.

iv. The optimal multi-response machining parameters can be obtained with palm kernel oil-based cutting fluid using of using depth of cut, feed rate and cutting speed of 1.5mm, 0.3mm/rev and 600rev/min respectively while, the optimal multi-response machining parameters can be achieved with using mineral based cutting fluid using depth of cut, feed rate and cutting speed of 1.5 mm, 0.2mm/rev, 800rev/min respectively.

v. The confirmatory test for the two cutting fluids showed low percentage error (>5%) indicating that there was a good correlation between the experimental results and the predicted regression models.

vi. Also, the turning operations conducted on the AISI 1030 alloy steel workpiece using optimal conditions specified by Grey relational analysis (GRA) produced continuous snarled washer chip with bright and smooth colour for Palm kernel oil based cutting fluid (PBCF) as well as continuous snarled tubular chip with burnt and black colour for Mineral oil based cutting fluid (MBCF) which are in conformity with ISO 3685 standards.

vii. Finally, in the future, type of cutting fluid should be set as an experimental factor along with depth of cut, feed rate and cutting speed so as to statistically evaluate its significance in machining operation.

REFERENCES

[1] Vahid, A. Mojtaba, F., Abbas, S. And Reza, K. “Evaluation of The Metalwork Cutting Fluid Treatment Performance using Fenton Oxidation Process in Comparison with Coagulation Flocculation”, *Caspian Journal of Applied Sciences Research,* 2(5), 2013, pp. 90-98.

[2] Occupational Safety and Health Administration. *Metalworking Fluids: Safety and Health Best Practices Manual.* U.S Department of Labor, *1999.*

[3] Pei, Y., Yiming, R. And Gang, W. “The Effect of Cutting Fluids Applied in Metal Cutting Process, Proceedings of The Institution of Mechanical Engineers”, *Part B: Journal of Engineering Manufacture,* 230(1), 2016, pp.19-37

[4] Iowa Waste Reduction Center, “Cutting Fluid Management: Small Machining Operations”, *Iowa Waste Reduction Center Book Gallery*. 12, 2003, pp. 1-69.

[5] Lawal, S.A., Choudhury, I.A. And Nukman, Y. Application of Vegetable Oil-Based Metalworking Fluids in Machining Ferrous Metals—A review, *International Journal Of Machine Tools And Manufacture,* 52(1), 2012, pp. 1-12.

[6] Benedicto, E., Carou, D. And Rubio, E.M. “Technical, Economic And Environmental Review of the Lubrication/Cooling Systems used in Machining Processes”, *Procedia Engineering,* 184, 2017, pp. 99-116.

[7] Heisel, U.; Lutz, M., Spath, D., Wassmer, R., Walter, U. "A Técnica Da Quantidade Mínima De Fluidos E Sua Aplicação Nos Processos De Corte", [The Minimum Quantity of Fluid Technique and its Application to Metal Cutting], *Máquinas E Metais, Aranda Publisher*, February, 1998, pp. 22 – 38.

[8] Kalhöfer, E., "Dry Machining - Principles and Applications", 20. Seminário International De Alta Tecnologia, [2th International Seminar on High Technology], Unimep, Santa Barbara D’oeste – Sp, Brazil, 1997.

[9] Klocke, F., Eisenblätter, G. “Presented at The Opening Session Dry Cutting”, *Annals of The Cirp,* 46(2), 1997, 519-526.

[10] Brajendra, K. S., Adhvaryu, A. and Sevim, Z..E. (2009). Friction and Wear Behavior Of Thioether Hydroxy Vegetable Oil, *Tribology International Journal*, 42(2), pp.353-358.

[11] Sullivan, P.A., Eisen, E.A., Woskie, S.R., Kriebel, D. Wegman, D.H., Hallock, M.F., Hammond, S.K., Tolbert, P.E., Smith, T.J. and Monson, R.R. “Mortality Studies of Metalworking Fluid Exposure in the Automobile Industry: Vi, A Case-Control Study of Esophageal Cancer”, *American Journal of Industrial Medicine.* 34, 1998, pp. 36–48.

[12] Lawal, S.A., Choudhury, I.A. And Nukman, Y. “Evaluation of Vegetable and Mineral Oil-n-Water Emulsion Metal Cutting Fluids in Turning Aisi 4340 Steel with Coated Carbide Tools”. *Journal of Cleaner Production,* 66, 2014, pp. 610-618.

[13] Sujan, D., Moola, M. R. and Qua, S. “Environmental Friendly Cutting Fluids And Cooling Techniques In Machining: A Review”, *Journal Of Cleaner Production,* 83, 2014, pp. 33-47.

[14] Yashvir, S., Abid, F., Aamir, R., Muhammad, A. M. and Surbhi, J. "Sustainability of a Non-Edible Vegetable Oil Based Bio-Lubricant for Automotive Applications: A Review", *Process Safety And Environmental Protection*, 111, 2017, pp. 701-713.

[15] Wisley, F. S., Anselmo, E. D. And Álisson, R. M. "Application of Cutting Fluids in Machining Processes" *Journal of the Brazilian Society Of Mechanical Sciences*, Vol. 23, No. 2, 2001, 227-240.

[16] Prakash J.R.S., Rahman M., Kumar A.S., Lim S.C. "Effect of Minimal Quantities of Lubricant in Micro Milling". *In: Inasaki I. (Eds) Initiatives of Precision Engineering At The Beginning Of A Millennium. Springer, Boston*, Ma, 2002, Available at Https://Doi.Org/10.1007/0-306-47000-4_60

[17] Weingaernter, W.; Schroeter, R.; Teixeira, C.R. "A Influência Da Minimização Do Fluido De Corte (Effects of Cutting Fluids Minimization)", Máquinas E Metais, Aranda Publisher, Janeiro, 2000, pp. 52 – 59.

[18] Kazeem, R.A., Fadare, D.A., Abutu, J., Lawal, S.A. And Adesina, O.S. "Performance Evaluation of Jatropha Oil-Based Cutting Fluid in Turning Aisi 1525 Steel Alloy", *Cirp Journal Of Manufacturing Science And Technology*, 31, 2020, pp. 418–430.

[19] Frederique, R. A., Daniella, G. L., Elias, H. H., Carlos, W. and Paulo, A. Z. S. "Utilization of Metal Complexes as Catalysts in the Transesterification of Brazilian Vegetable Oils with different Alcohols", *Journal Of Molecular Catalysis A: Chemical*, 209(1–2), 2004, pp. 29-33.

[20] Carlos, A. S. B., Janaina, F. S. G., Jefferson, O. G. And Jordao, G. "Performance of the Jatropha Vegetable-Base Soluble Cutting Oil as a Renewable Source In The Aluminum Alloy 7050-T7451 Milling", *Cirp Journal Of Manufacturing Science And Technology*, 7, 2014, pp. 210–221.

[21] Ojolo, S., Amuda, M., Ogunmola, O. and Ononiwu, C. "Experimental Determination of the Effect of Some Straight Biological Oils on Cutting Force during Cylindrical Turning". *Materia (Rio De Janeiro)*, 13(4), 2008, pp 650-663.

[22] Winter, M., Bock, R. And Herrmann, C. "Investigation of a New Polymer-Water Based Cutting Fluid to Substitute Mineral Oil Based Fluids in Grinding Processes", *Cirp Journal Of Manufacturing Science And Technology*, 6(4), 2013, pp 254-262.

[23] Mahadi, M.A., Choudhury, I.A., Azuddin, M. And Nukman, Y. "Use of Boric Acid Powder Aided Vegetable Oil Lubricant in Turning Aisi 431 Steel", *Procedia Engineering*, 184, 2017, pp. 128 – 136.

[24] Kamal, H., Anish, K., And Garg, M.P. "Experimental Investigation of Material Removal Rate in Cnc Turning using Taguchi Method", *International Journal of Engineering Research*, 2(2), 2012, pp. 2248 – 9622.

[25] Xavior, M.A. And Adithan, M. "Determining the Influence of Cutting Fluids on Tool Wear and Surface Roughness During Turning of Aisi 304 Austenitic Stainless Steel". *Journal of Materials Processing Technology*, 209(2), 2009, pp. 900-909.

[26] Papiya, B., Gaurav, A., Nitesh, P., Nitin, B. "Improving the Surface Texture of Mild Steel Using Vegetable Oil as Cutting Fluid". *International Journal of Applied Engineering Research.* 9(8), 2014, 883-888.

[27] Cox, H. E. and Pearson, D. The Chemical Analysis of Foods, *Chemical Publishing Co. Inc.*, New York, pp.421, 1962.

[28] Agu C. K., Lawal S. A., Abolarin M. S., Agboola J. B., Abutu J. And Awode E. I. "Multi-Response Optimisation of Machining Parameters in Turning Aisi 304l using different Oil-Based Cutting Fluids", *Nigerian Journal of Technology* 38(2), 2019, pp.364-375.

[29] Dhabale, R. And Jatti, V. S. "Optimization of Material Removal Rate of Almg1sicu In Turning Operation using Genetic Algorithm", *Wseas Transactions on Applied and Theoretical Mechanics*, 10, 2015, pp.95-101.

[30] John, J. M. "Evaluation of the Lubricating Properties of Palm Kernel Oil, Leonardo Electronic *Journal of Practices and Technologies*", 7(14), 2009, pp.107-114.

[31] Chin, P.F. "Manufacturing Process Optimization for Wear Property of Fiberrein forced Polybutylene Terephthalate Composites with Grey Relational Analysis", *Wear Journal*, 25, 2003, pp. 298–306.

[32] Abutu J., Lawal S.A., Ndaliman M.B., Lafia-Araga R.A., Adedipe O. & Choudhury I. A. "Production and Characterization of Brake Pad Developed from Coconut Shell Reinforcement Material using Central Composite Design". *Sn Applied Sciences.* 1,18, 2019.

[33] Yiyo, K., Taho, Y. And Guan, W.H. "The Use of A Grey-Based Taguchi Method For Optimizing Multi-Response Simulation Problems", *Eng. Optim.* 40(6), 2008, pp.517–528.

[34] Kaladhar, M., Subbaiah, K.V. and Rao, C.S. "Determination Of Optimum Process Parameters During Turning of Aisi 304 Austenitic Stainless

Steels Using Taguchi Method And Anova". *International Journal of Lean Thinking,* 3(1), 2012, pp. 1-19.

[35] Montgomery, D.C., Runger, G.C., Hubele, N.F. "Engineering Statistics", First Ed. John Wiley & Sons, Inc., New York, 1998.

[36] Jawahir, I.S., Van Luttervelt, C.A. Recent Developments in Chip Control Research and Applications, *Annals of The Cirp,* 42(2), 1993, pp. 659-693.

[37] Viharos, Z. J.M Markos, S., Szekeres, C. "Ann-Based Chip-Form Classification in Turning", *Proc. Of The Xvii Imeko World Congress,* June 22 – 27, Dubrovnik, pp. 1469-1473, 2003.

[38] Segreto, T., Simeone, A. and Teti, R. "Chip Form Classification in Carbon Steel Turning Through Cutting Force Measurement and Principal Component Analysis", *Procedia Cirp,* 2, 2012, pp.49 – 54.

[39] Singh, T., Dureja, J. S., Dogra, M. and Bhatti, M. S. "Environment Friendly Machining of Inconel 625 Under Nano-Fluid Minimum Quantity Lubrication (Nmql)", *International Journal of Precision Engineering and Manufacturing*, 19, 2018, Pp 1689–1697.