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Performance evaluation of jatropha oil-based cutting fluid in turning AISI 1525 steel alloy

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ABSTRACT

Applications of vegetable oil-based cutting fluids are becoming increasingly popular in machining due to negative environmental and health effects caused by the conventional mineral oils. However, suitability of lesser-known vegetable oils as cutting fluids has been minimally reported. This study was designed to investigate the performance of a lesser-known vegetable oils as cutting fluids in machining. The jatropha oil was characterized to identify phytochemical, physiochemical and lubricity related properties. The effects of jatropha oil emulsion on surface roughness, cutting temperature and chip formation in turning AISI 1525 steel alloy with coated carbide tool were investigated and compared with mineral oil. Taguchi L_9 (3^3) orthogonal array was used for the experimental plan. In addition, multi-response optimization was conducted using Grey relational analysis (GRA). Jatropha oil-based cutting fluid achieved better performance than mineral oil-based cutting fluid in most machining conditions. The GRA results revealed that optimal multi-response performance of the jatropha oil-based cutting fluid and commercial mineral oil-based cutting fluid can be achieved using the same cutting velocity (355 m/min) and feed rate (0.10 mm/rev) but with varying depth of cut of 1.00 and 1.25 mm, respectively.

Introduction

Cutting fluids are complex mixtures of oils, detergents, surfactants, biocides, lubricants, anti-corrosive agents, and other potentially toxic ingredients [1]. As a result of the intensive contact between workpiece and cutting tool, cutting fluids are of high importance in forming processes and metal machining since they are needed for lubrication, cooling, and for chip removal in the cutting zone [2]. There are several types of cutting fluids which may be used to carry out these tasks [3]. The most common cutting fluids are mineral oil-based fluids and these fluids increase productivity and the quality of manufacturing operations during metal cutting and forming processes. Due to their advantages, the consumption of cutting fluids is increasing in machining industry. It is reported that the European Union alone consumes approximately 320,000 tonnes per year of cutting fluids out of which at least two-thirds need to be disposed [4]. The three classifications of cutting fluids include neat cutting oils, water-soluble fluids (emulsifiable oils, chemical or semi-chemical fluid) as well as gases [5].

To overcome the challenges associated with the use of cutting fluid, various alternatives cutting fluids are currently being explored by scientists and tribologists. Such alternatives include synthetic lubricants, solid lubricants and vegetable-based lubricants. The growing demand for biodegradable materials has opened an avenue for using vegetable oils as an alternative to petroleum-based polymeric materials, most especially in machining operations [6]. The public awareness in environmental issues has been constantly growing [7]. Lubricants are used in many diverse areas; therefore, their environmental acceptability has become increasingly important. As a result, research on biodegradable functional fluids emerged as one of the top priorities in lubrication in the early 1990s, which led to a lot of growing number of environmentally friendly fluids and lubricants in the market [8]. Vegetable based cutting fluids have been successfully applied in various machining operations such as turning [9], milling, and drilling [10]. They often show quite acceptable performance as lubricant. Vegetable oils are readily biodegradable and less costly than synthetic base stocks.

Also, mineral oil-based cutting fluids have been mostly utilized in metal cutting operations. But recently the use of mineral-based oil has been questioned as a result of the different negative effects

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it poses to the environment and health workers. Lawal et al. [11] observed that there are literatures on metalworking fluids, which are vegetable oil-based, that could be an environmentally friendly mode of machining with similar performance with mineral oil-based metalworking fluids. Hence, several alternatives cutting fluids have been developed with the aim of avoiding environmental and health damages. Alves and Oliveira [12] have formulated vegetable based-oil using sulfonate castor oil and polyglycol of synthetic ester. Manoj et al. [13] also investigated the potential of vegetable oils as micro lubrication/cooling medium for small quantity lubrication grinding of hardened AISI 52100 steel with alumina wheel in its plunge mode, while Rohit and Kuppa [14] conducted an experiment on two different vegetable based cutting fluids (VBCFs) developed from refined rapeseed and sunflower oil and a commercial type mineral cutting fluid to determine the optimum conditions for surface roughness, tool wear and cutting forces during turning of SS316L with carbide cutting inserts. Gurpreet et al. [15] conducted experiments on the performance of vegetable and mineral oils on surface roughness during turning of EN31 steel under dry and MQL conditions using three different cutting inserts (SNMG120408, CNMG120408 and CNMG120412). The experimental results indicated that the performance of the formulated vegetable oil-based cutting fluid compared favourably with mineral based cutting fluids. Also, Carlos et al. [16] studied the performance of the jatropha oil-based soluble cutting oil as a renewable source in the aluminium alloy 7050-T7451 milling and found that jatropha cutting oil besides being produced from a renewable and clean source, has the inherent characteristics that can help attain a sustainable manufacturing which perform effectively when used as cutting fluid or lubricant.

Aguet al. [17] suggested that in machining operation, minimal cutting temperature at the cutting zone and better surface finish of workpiece are required in order to avoid any damage to the quality of a machined surface. Therefore, in this study, a vegetable oil-based cutting fluid (jatropha oil) was extracted, characterized and formulated and the performance of the developed vegetable oil-based cutting fluid in terms of surface roughness, cutting temperature and type of chips was compared with conventional mineral oil based cutting fluid in turning of low carbon steel as workpiece under different application conditions such as flood cooling and minimum quantity lubrication (MQL) pulse jet techniques. Experimental results were analyzed using a multi-response optimization technique (Grey relational analysis).

Materials and methods

Materials and methods for cutting fluids formulation

The materials used in this study for the formulation of the cutting fluid include jatropha oil (*Jatropha cursas*) which was purchased from Ojoomarket, Ibadan, Oyo State, Nigeria and other additives such asemulsifier (washingsoap), corrosioninhibitor (sodium molybdate), biocide (trizaine) andanti–formagent (silicones).

Extraction of seeds oil

Oils samples were extracted in accordance with AOAC [18] standard procedure using soxhlet apparatus with 5 L sized round bottom flask and analytical grade *n*-hexane of boiling range between 40 and 60 °C. The seed oil extraction set-up is as shown in Fig. 1.

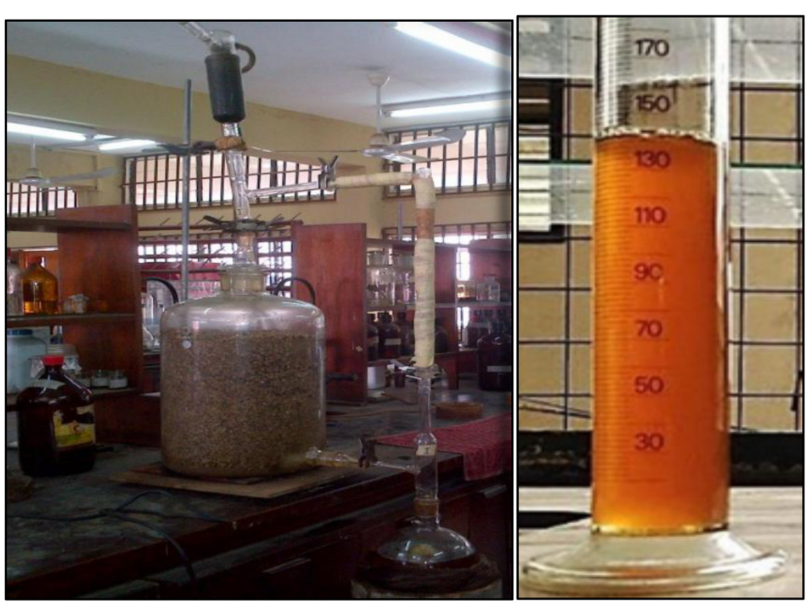
Characterization of jatrophaoil

The extracted jatropha crude oil was characterized to identify phytochemical (Fourier transform infrared and gas chromatography/mass spectra), physiochemical (oil colour, odour, relative density, oil pH, viscosity, specific gravity oil yield, refractive index, acid value and congealing temperature) and lubricity related properties (pour, cloud, flash, fire points) of jatropha seed oil. This was carried out with the aim of establishing viable parameters for the formulation of a cutting fluid. Several tests were carried out on the extracted crude oil. The characterization of crude jatropha oil is shown in Table 1:

$$\rho = \frac{m}{V} \tag{1}$$

where ρ = density (kg/cm^3), m = mass (kg) and V = volume (cm^3)

$$Yield\ \% = \frac{W_o}{W_{ps}} \times 100 \tag{2}$$



(a) (b)

Fig. 1. Seeds oil extraction process (a) soxhlet extraction set-up and (b) jatropha crude oil extracts.

Table 1
Characterization of crude jatropha oil.

S/N	Characteristics	Purpose of test	Parameter measured	Relevant standard	Special consideration
1.	Physiochemical test	To evaluate the compositional quality of oils	pH		Handheld pH metres was used
			Relative density	ASTM D1298-12b [18] method and calculation was effected using Eq. (1)	
			% Oil yield	Using Eq. (2)	
			Kinematic viscosity		Oswald kinematic viscometer and subsequently effected with Eq. (3)
			Specific gravity	Method recommended by ASTM D287 [19] and calculation was carried out using Eq. (4)	
			Acid value	AOAC [20] and calculated with Eq. (5)	
			Colour	AOCS Cc 13c -50 [21] with the aid of spectrophotometer	
			Congealing temperature	In agreement with the norm AOCS Cc 14-59 [21]	
			Refractive index		The capillary tube interferometer was used
			Appearance at room temperature	Visual Method	
			Odour	Based on the norm AOCS Cc 13c -50[21]	
2.	Phytochemical test	To study the saturation and unsaturation composition of heated and unheated oils at room temperature for monitoring the oxidation process in oils.	Fourier Transform Infrared (FTIR) Spectroscopy		Using a FTIR Perkin Elmer Model. Spectrum, in the range 4000–400 cm^{-1}. The resolution was eight and two scans.
			Gas chromatography/mass spectra (GCMS)		Gas chromatography detector (coupled 7890A Agilent Technology GC system)
3.	Lubricity related properties	Tests are performed to quantify a lubricant's performance for machining	Pour point	According to the norm ASTM D97 [22] procedure	Stanhope Seta Cloud and Pour Point KT168AP equipment
			Flash point	In line with ASTM D92 [23] procedure	Pensky Martens equipment
			Fire point	Using ASTM D92 [23] procedure	Pensky Marten equipment
			Cloud point	In agreement with ASTM D2500 [24] Procedure	Stanhope Seta Cloud and Pour Point KT16 8AP equipment

ASTM – American Society for Testing and Materials.
AOCS – American Oil Chemists Society.
AOAC – Association of Official Agricultural Chemists.

where W_o = weight of extracted oil (g), W_{ps} = weight of powder sample (g)

$$\eta = Adt - \frac{Bd}{t} \tag{3}$$

where d = density (g/ml), η = viscosity (cP), t = time (s), A and B are constants

$$\text{Specific gravity} = \frac{W_o}{W_{vw}} \tag{4}$$

where W_o = weight of extracted oil (g), W_{vw} = weight of an equal volume of water (g)

$$\text{Acid value} = \frac{kMV}{W} \tag{5}$$

where k is a constant known as molecular weight of KOH and in this case, k taken as 56.1 (g/mol), M = molarity of KOH (M), V = volume of KOH (ml), W = weight of sample (g).

Formulation of emulsion cutting fluids

The formulation of cutting fluid was carried out as a jatropha emulsion cutting fluid. The emulsion cutting fluids was formulated by mixing additives, distilled water and jatropha oil. The cutting fluids formulation was prepared from factorial planning indications, whereby the effects of four variables were examined at two levels were examined (2^4 planning). The four variables include the emulsifying agent, anticorrosion agent, biocide and antifoam agent. Cutting fluids emulsions (with 20% oil to water volumetric concentrations) and were prepared separately with 16 formulations obtained from full factorial techniques. Table 2 shows variables of additives and levels employed in the factorial design. Each assay contained a total volume of 100 ml. A homogeneous mixture was obtained with the aid of mechanical stirrer at 760 rpm for 10 min at room temperature of 25 °C. However, the formulation of mineral based cutting fluid involved mixing the soluble oil (concentrate) with water at the ratio of 1:9.

Characterization of formulated cutting fluid

The preliminary cutting fluids prepared with experimental matrix shown in Table 3 were characterized in terms of stability, percentage of foam formed, viscosity and pH. However, it is not all these relevant parameters that were optimized in this study. The pH was chosen to optimize the process. This is because a decrease in the pH value indicates a fall in the performance of the cutting fluid. Extremely high or low pH values can prove hazardous to human operator and pose a problem in waste disposal. A digital pH metre is used to estimate the pH value. The results obtained from the pH values were analyzed statistically using Minitab 16 software (design of experiment). The software used for the analysis uses a second-degree polynomial, approximated by Eq. (6), to predict the response, Y, which includes all factors as well as the most effectual way the factors interact [25]:

$$Y = \beta_o + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum \beta_{ij} X_i X_j \tag{6}$$

Table 2
Factors and levels examined in the factorial planning.

Factor	Symbol	Level	
		Minimum	Maximum
Emulsifying agent	A	8.0%	12.0%
Anticorrosive agent	B	1.0%	2.0%
Biocide	C	0.5%	1.0%
Antifoam agent	D	0.5%	1.0%

where β_o is constant, β_i and β_{ij} are coefficient of *ij*, X_i, represents independent variables and X_{ij} denotes the interactions thereof [26].

The optimal values of additives after the validation were used to formulate and characterize the final jatropha emulsion cutting fluid used for experimentation.

Materials and methods for machining process

Machining processes

Machining operation was performed on a 3-jaw AJAX Lathe Machine (Model No. 20186; variable spindle: 16–2000 rpm and 5Hp rated power) domiciled at the Maintenance Section, University of Ibadan, Nigeria. A tungsten carbide inserts tools (insert model: CNMG12040408, tool holder model: MCLNR2020K12, shank length: 100 mm, insert size: 12 and insert thickness of 4.7624 mm) was used for used for the machining process. The investigation of surface roughness, cutting temperature, and chips analysis were conducted on AISI 1525 steel alloy round bars 80 mm diameter and 1500 mm length which were reduced to a length of 320 mm and while diameter remained 80 mm in order ensures rigidity and eliminates flexing during the turning operation. Each test specimen was mounted on the lathe between the chuck and the live centre to ensure greater clamping force during turning. A thin outer surface of each specimen was machined off before the start of the experiments. The workpiece was afterward turned at different depths, cutting velocity and feed rates. The experimental set-up for turning process showing all components is shown in Fig. 2.

Design of experiment

The experimental set up was based on design of experiment (DOE) via Taguchi method and three cutting parameters namely; cutting velocity, feed rate and depth of cut were considered for experimentation. Taguchi design method involved specifying the design parameters (design variables) which mainly affect the output of the objective function [40]. Hence, there were three input parameters and for each parameter, three levels were assumed as shown in Table 4. For an L9 you need at least 27 tests. This is because each of the runs has to be repeated at least 3 times. Each cutting fluid was evaluated by using input parameters in Table 5 with fresh cutting tool and workpiece material.

Surface roughness measurement

Surface roughness of the machined portion of the workpiece was measured using a portable surface roughness tester (SRT-6200) as shown in Fig. 3a. Three measurements were taken along the shaft axis for each sample and the average value was selected and used for the analysis.

Cutting temperature measurement

Cutting temperature was measured with a PeakTech Infra-red thermometer (Fig. 3b) using an emissivity value of 0.12 specified for AISI 1525 steel by Calex Electronic Limited [41]. Measurement was carried out by pointing the thermometer's probe at the chip-tool interface during machining which will give the degree of hotness at the interface. The infrared thermometer was held at distance of 5 cm manually from the chip tool interface. These three measurements were taken for each sample and the average value was recorded.

Results and discussion

Phytochemical tests

Fourier transform infrared

The FTIR spectra in the mid-infrared region have been used to identify the functional groups and the bands corresponding to various stretching and bending vibrations in the sample of jatropha oil. The FTIR analysis (see Table 6) justified the basic functional moieties associated with the elucidation of oils. Asymmetry stretching vibration $\sim$1745 cm^{-1} in the sample, is diagnostic for the carbonyl moiety of an ester. The presence of both asymmetry and symmetry stretching vibrations in the range 3010.0–2852.0 cm^{-1} and their respective bending vibrations in the finger print region, suggests the presence of carbon atoms with 75% and 66.6% p-orbital characteristics. A representative spectrum of FTIR of the oil sample is as shown in Fig. 4.

Gas chromatography and mass spectra of crude oil extract

The results of GCMS analysis of the jatropha oil carried out is presented in Table 7. The chromatogram obtained revealed the presence of three phytocompounds in jatropha oil. The

Table 3
Cutting fluids preliminary preparation volumes.

Assay no.	A (ml)	B (ml)	C (ml)	D (ml)	Volume of oil in container (ml)	Volume of water in container (ml)	Total volume of fluid in a container (ml)
1	8	1	0.5	0.5	20	70.0	100
2	12	1	0.5	0.5	20	66.0	100
3	8	2	0.5	0.5	20	69.0	100
4	12	2	0.5	0.5	20	65.0	100
5	8	1	1.0	0.5	20	69.5	100
6	12	1	1.0	0.5	20	65.5	100
7	8	2	1.0	0.5	20	68.5	100
8	12	2	1.0	0.5	20	64.5	100
9	8	1	0.5	1.0	20	69.5	100
10	12	1	0.5	1.0	20	65.5	100
11	8	2	0.5	1.0	20	68.5	100
12	12	2	0.5	1.0	20	64.5	100
13	8	1	1.0	1.0	20	69.0	100
14	12	1	1.0	1.0	20	65.0	100
15	8	2	1.0	1.0	20	68.0	100
16	12	2	1.0	1.0	20	64.0	100

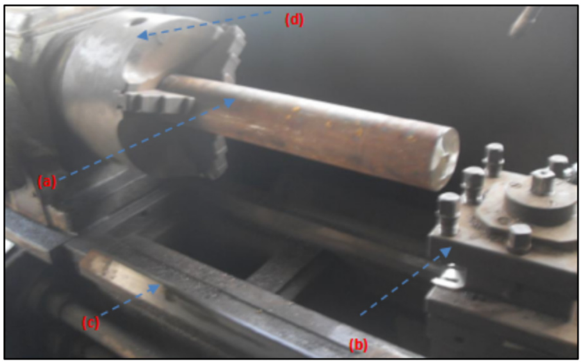


Fig. 2. Experimental set-up for turning process (a) AISI 1525 steel alloy workpiece clamped on 3-jaw chuck, (b) Tool post, (c) Lathe bed and (d) 3-jaw chuck.

Table 4
Machining parameters and their levels.

Factor	Level 1	Level 2	Level 3
Cutting velocity, V_c (m/min)	355	500	710
Feed rate, f (mm/rev)	0.10	0.15	0.20
Depth of cut, a_p (mm)	0.75	1.00	1.25

Table 5
Standard L_9 (3^3) orthogonal array for machining process.

Trial no.	Cutting velocity (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
1	355	0.10	0.75
2	355	0.15	1.00
3	355	0.20	1.25
4	500	0.10	1.00
5	500	0.15	1.25
6	500	0.20	0.75
7	710	0.10	1.25
8	710	0.15	0.75
9	710	0.20	1.00

composition of jatropha crude oil include 41.65% of 9,12-octadecadienoic acid, 35.06% of *n*-hexadecenoic acid and 23.29% of 2,6,10,14,18,22 tetracosahexane acid. 9,12-Octadecadienoic acid was the most abundant compounds present in jatropha oil. The 9, 12-octadecadienoic acid has become increasingly popular in the beauty products industry because of its beneficial properties on the skin.

Research points to 9, 12-octadecadienoic acid as anti-inflammatory, acne reductive, and moisture retentive properties when applied topically on the skin [27–29]. 9, 12-Octadecadienoic acid in jatropha oil will help to eliminate the problems of skin cancer and respiratory challenges especially acne associated with the use of mineral oil-based cutting fluids. *n*-Hexadecenoic acid have numerous applications in soap, cosmetics and release agents. *n*-Hexadecenoic acid has not been reported in the application of cutting fluids but it can be given a trial because of its application in skin products, i.e. it is human friendly. The extracted oil is bio-based mixtures whose synergistic penetrating capacity could be a better substantial substitute for the mineral-based lubricants with eco-depleting antecedents.

Physiochemical and properties of crude oil extract

The physicochemical properties of the jatropha oil extract are shown in Table 8. The colour of the oil is clear yellow. The condition of the oil extracts at room temperature was liquid. Oil yield from jatropha can be considered economical for commercial production of cutting fluids. The oil content in jatropha seeds was observed to be 46% by weight of their seeds. The oil yield of jatropha is similar to that by Pramanik [30] which ranges from 45% to 60% by weight of the kernel. The oil content of jatropha is even higher than that of many vegetable oils that have been used in literature for machining purpose. For instance, soybean oil ranges from 11% to 25% [31]. The specific gravity of the oil extracts was 0.89. This value is within the range of specific gravities reported for related vegetable oil extracts of some selected tropical seeds [32]. The pH of the oil extract was 9.1. The pH values less than 7.0 may tend to corrode metal during machining processes. Jatropha oils are in the alkaline state. The refractive index which is the ratio of the velocity of light in vacuum to the velocity of light in a medium is an indication of the level of saturation of the oil [33]. The refractive index analysis showed that jatropha oil extracts has not met the ASTM values that range from 1.476 to 1.479 [34]. This could be attributed to the presence of some impurities and other components of the crude oil mixture such as the solvent used in the extraction. The refractive index value was similar to that by Eze [32] for pumpkin seed oil.

Acid value represents free fatty acid content due to enzymatic activity, and is usually indicative of spoilage. Its maximum acceptable level is 4 mg KOH/g oil [35], for recommended international standards. Results obtained from this work indicate that the acid value of jatropha oil as determined is 5.22 mg KOH/g for jatropha. The acid value is a bit on the high side for jatropha (5.22 mg KOH/g oil). Higher acid value is due to free fatty acid

(a) (b)

Fig. 3. Measuring equipment used during machining process (a) SRT surface roughness tester and (b) PeakTech infra-red thermometer.

Table 6
Summarized FTIR analysis of the watermelon oil samples.

Oil sample	FT-IR results/cm^{-1}			
Jatropha	3010.0–2852.0	1745.9, 1709.1, 1297.0	–	1463.1, 1378.8

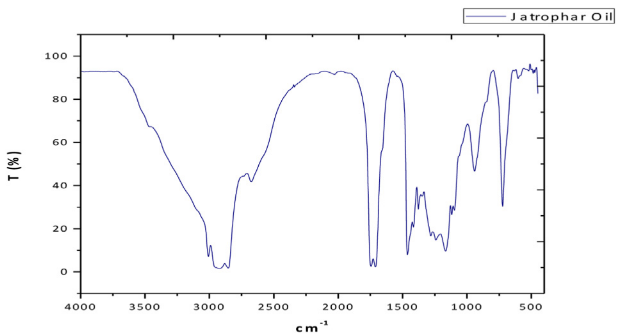


Fig. 4. Fourier transform infrared for jatropha crude oil.

present in the oil. This acid value can be made fit by subjecting the oil to refining and this may also improve its quality for industrial purposes [33]. Viscosity is a measure of the resistance of a fluid to deform under shear stress. It is commonly perceived as thickness, or resistance to pouring. Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction [39]. The viscosity measured at 40–80 °C for raw jatropha oil is presented. As the temperature increase the viscosity of oil reduces. The viscosity reduction for jatropha oils was 0.6 times with increase in temperature from 40 to 80 °C. Another important characteristic measured was the congealing temperature, jatropha oil had 15 °C. Lower congealing temperature is better; this means the jatropha oil can still be workable at relatively low temperature.

Lubricity related properties

The lubricity related properties of the oil extracts from Jatropha is shown in Table 9. The obtained results are within ASTM standard for oils (Table 9)

Formulation of emulsion fluids for machining

The optimum values for additives obtained for jatropha emulsion cutting fluid, the optimal values were emulsifier (12.0 vol.%); anticorrosion (1.0 vol.%); antioxidant (0.5 vol.%), biocide (0.5 vol.%). The mineral oil which was sourced as concentrated oil was used to prepare emulsion metal cutting fluid without any addition of additives. Some of the properties of the developed emulsion vegetable oil cutting fluids in comparison with the conventional mineral oil emulsion are presented in Table 10. In addition to the properties listed, the pH of the water used for dilution is 7.5. These values are within the range for a standard pH for conventional cutting fluids, and are also close to the values reported by Kuramet al. [36] and Lawal et al. [5]. Moreover, density of the sample fluids recorded are close to that reported by Kuram et al. [36]. The fluids density aids the machinability of the work piece during cutting operation [37]. The mineral oil emulsion had a density value of 0.9205 g/cm^3 at 25 °C. More so, the viscosity of jatropha emulsion at room temperature is also comparable to that of mineral oil emulsion. This means that even at temperatures above room conditions, the fluids can still flow to cover the entire machined metallic surface thereby enhancing the cooling and lubricating capabilities.

Experimental results and S/N ratios

The results of the experiment carried out using the formulated jatropha oil and mineral oil along with their respective signal-to-noise (S/N) ratio values are shown in Tables 11 and 12, respectively. Signal-to-noise ratios of individual responses were calculated using Eq. (7). Also, the experimental results presented in Tables 11 and 12 are represented in Figs. 5 and 6:

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum y_i^2\right) \quad (7)$$

where n = number of experimental samples and y = responses of given factor level combination.

The results obtained for surface roughness and cutting temperature using jatropha and mineral oils emulsion cutting fluids are presented in Tables 10 and 11. It can be observed that surface roughness and cutting temperature emulsion cutting fluids falls within the range of 2.445–8.810 μm, 37.1–83.3 °C; and 2.545–8.830 μm, 46.8–111.8 °C for jatropha and mineral oil-based cutting fluids, respectively. Fig. 5 shows the results of the surface roughness for the two emulsion cutting fluids during nine trials. Jatropha oil-based cutting fluids was observed to have the least measure of surface roughness in six out of the nine conducted

Table 7
Gas chromatography analysis of phytocompounds isolated from jatropha oil.

Oil sample	Chromatography peak	Compound Nomenclature	Molecular formula	Molecular weight	Retention time (min)	% content
Jatropha	1	*n*-Hexadecenoic acid	$C_{16}H_{32}O_2$	256	17.881	35.06
	2	9,12-Octadecadienoic acid	$C_{18}H_{32}O_2$	280	19.758	41.65
	3	2,6,10,14,18,22 tetracosahexane	$C_{24}H_{38}$	326	30.075	23.29

Table 8
Physicochemical properties of crude oil extract.

Parameter measured	Jatropha oil
Appearance at room temperature	Liquid form
Colour	Clear yellow
Odour	Slightly irritating
Percentageoilyield	46%
pH	9.3
Specific gravity	0.89
Refractive index at 20 °C	1.4675
Kinematic viscosity (cP) at 40 °C Kinematic viscosity (cP) at 80 °C	32.4 19.2
Relative density (g/cm^3)	0.913
Acid value (mg KOH/g)	5.22
Congealing temperature (°C)	15

Table 9
Lubricity related properties of crude oil extracts.

Parameter measured	Jatropha oil
Cloud point	20
Pour point	17
Fire point	178
Flash point	165

experiments, making up to approximately 67% better than the mineral oil. In terms of cutting temperature, jatropha oil outsmarted the mineral oil emulsion in all cases (as shown in Fig. 6). This better performance of vegetable oil can be attributed to the viscosities of the oil developed which possesses better fluidity and faster cooling capacity than the mineral oil. This can be explained in agreement with earlier experiments carried out by Carlos et al. [16] which revealed that jatropha oil-based cutting fluid performed better than mineral oil-based cutting fluid because it does not present any chlorine element in its composition and does not display any acidity level.

Analysis of variance

Experimental results were analyzed using analysis of variance (ANOVA) with the aim of investigating the significant effects as well as percentage contributions of individual machining parameters. This analysis was conducted using 95% confidence level and 5% significance level. Tables 13 and 14 show the degree of freedom (DOF), sum of square (SS), mean square (MS), *F*-value (F) and percentage contribution (P) for individual responses of jatropha oil-based cutting fluid and mineral oil-based cutting fluid.

The analysis of variance for surface roughness presented in Table 13 shows the contribution of each input parameters as: cutting velocity (44.027%), feed rate (44.413%), depth of cut (7.622%) for jatropha oil-based cutting fluid. It shows that feed rate and cutting velocity have significant influence on the surface roughness during the turning process. The influence of depth of cut on surface roughness is less significant. The ANOVA for mineral oil-based cutting fluid (surface roughness) on the other hand measures the contribution of each input parameter as: cutting velocity (41.25%); feed rate (49.44%); depth of cut (7.57%). This indicates that feed rate (49.44%) and cutting velocity (41.25%) during the turning cycle have a major effect on surface roughness. Less important is the effect of feed rate on cutting temperature. The level of confidence specified for these analyses is 95%.

Table 14 shows the ANOVA for cutting temperature for the two lubricating conditions. Cutting velocity has the most significant influence on the performance of the jatropha-oil based cutting fluid (41.669%) and mineral oil-based cutting fluid (81.09%). This is followed by depth of cut for jatropha oil-based cutting fluid (26.124%) and feed rate for mineral oil-based cutting fluid (15.5%)

Table 10
Characteristics of emulsion cuttingfluids.

Parameter measured	Jatropha oil-based cutting fluid	Mineral oil-based cutting fluid
pH	9.8	8.5
Density (g/cm^3) at 25 °C	0.9182	0.9205
Viscosity (Cst) at 25 °C	1.4	1.0
Stability	Stable	Stable
Colour	Whitish	Milky white

Table 11
Experimental processparameters, results and S/N ratios (jatropha oil-basedcuttingfluid).

Trial no.	Cutting parameters			Surface roughness (Ra)		Cutting temperature (T)	
	Cutting velocity (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Ra (μm)	S/N for Ra (dB)	T (°C)	S/N for T (dB)
1	355	0.10	0.75	2.445	−7.766	38.9	−31.799
2	355	0.15	1.00	3.410	−10.655	43.6	−32.790
3	355	0.20	1.25	8.120	−18.191	37.1	−31.387
4	500	0.10	1.00	6.190	−15.834	40.6	−32.171
5	500	0.15	1.25	7.650	−17.673	49.9	−33.962
6	500	0.20	0.75	8.810	−18.900	43.7	−32.810
7	710	0.10	1.25	6.490	−16.245	45.9	−33.236
8	710	0.15	0.75	7.730	−17.764	45.7	−33.198
9	710	0.20	1.00	8.650	−18.740	83.3	−38.413

Table 12
Experimental processparameters, results and S/N ratios (mineraloil-based cutting fluid).

Trial no.	Cutting parameters			Surface roughness (Ra)		Cutting temperature (T)	
	Cutting velocity (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Ra (μm)	S/N for Ra (dB)	T (°C)	S/N for T (dB)
1	355	0.10	0.75	2.545	−8.114	46.8	−33.405
2	355	0.15	1.00	3.521	−10.933	57.2	−35.148
3	355	0.20	1.25	8.470	−18.558	59.8	−35.534
4	500	0.10	1.00	6.220	−15.876	76.6	−37.685
5	500	0.15	1.25	7.410	−17.396	60.2	−35.592
6	500	0.20	0.75	8.830	−18.919	105.5	−40.465
7	710	0.10	1.25	6.500	−16.258	106.2	−40.522
8	710	0.15	0.75	7.700	−17.730	109.2	−40.764
9	710	0.20	1.00	8.800	−18.890	111.8	−40.969

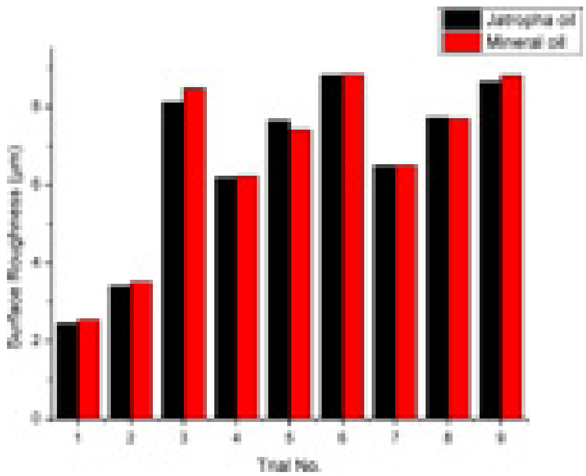


Fig. 5. Effect of emulsion cutting fluids on surface roughness.

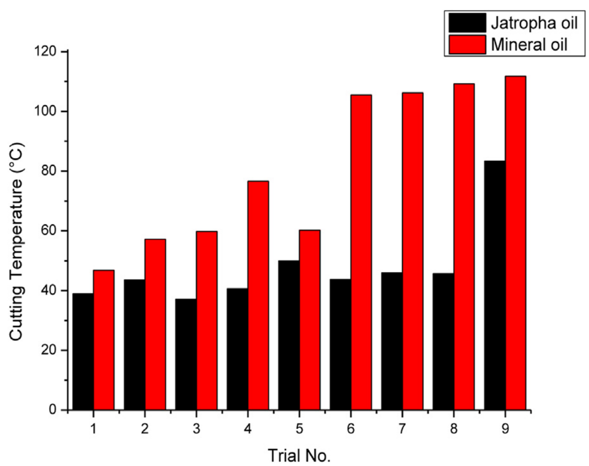


Fig. 6. Effect of emulsion cutting fluids on cutting temperature.

while the least significant factor is feed rate for jatropha oil-based cutting fluid (23.367%) and depth of cut for mineral oil-based cutting fluid (1.38%). The effects of all the factors are significant since their *p*-values are greater than 5%.

Grey relational analysis

As reported in the work of Abutu et al. [38] and Agu et al. [17] GRA multi-response optimization procedure involves using smaller-the-better attributes (Eq. (8)) to calculate the Grey relational generation (GRG) of individual responses using the S/N ratios values. This was followed by the calculation of Grey relational coefficient (GRC) using Eq. (9). The last phase of GRA was the calculation of Grey relational grade (GR-grade) using Eq. (10). The GRA results for jatropha oil-based cutting fluid and mineral oil-based cutting fluid are shown in Tables 15 and 16.

For GRG, smaller-the-better,

$$(d_{ij}) = \frac{\overline{t_{ij}} - t_{ij}}{\overline{t_j} - \underline{t_j}} \tag{8}$$

$(i = 1, 2, \ldots, v$ and $j = 1, 2, \ldots, u)$. Where, $t_i = (t_{i1}, t_{i2}, \ldots, t_{ij}, \ldots t_{in})$, t_{ij} represents the performance value of alternative i attribute j and $\overline{t_j} = \max\{t_{ij,} i = 1, 2, \ldots, v\}$ and $\underline{t_j} = \min\{t_{ij}, \ i = 1, 2, \ldots, v\}$.

For GRC,

$$\gamma(d_{oj}, d_{ij}) = \frac{\hbar_{\min} + \eta \ \hbar_{\max}}{\hbar_{ij} + \eta \ \hbar_{\max}} \tag{9}$$

$j = 1, 2, \ldots, v$ and $i = 1, 2, \ldots, u,$ $\hbar_{ij} = d_{oj} - d_{ij}$, $\hbar_{\min} = \min(\hbar_{ij}, i = 1, 2, \ldots, v; j = 1, 2, \ldots u)$, $\hbar_{\max} = \max(\hbar_{ij}, i = 1, 2, \ldots, v; j = 1, 2, \ldots, u)$ and η.

The above is the distinguish coefficient $\eta \in [0, 1]$. Distinguishing coefficient compresses or expands the range of the grey relational coefficient and 0.5 is the widely accepted value [38]:

$$GR \ \ Grade = \frac{\sum GRC}{No \ \ of \ \ responses} \tag{10}$$

The resulting factor effects of the process factors obtained for jatropha oil-based cutting fluid and mineral oil-based cutting fluid using the grey relational grades in Tables 15 and 16 are presented in Table 17 with values highlighted in bold representing the optimal factor level. Also, the main effect plots obtained using Table 17 is represented in Figs. 6 and 7, respectively.

The main effect plots shown in Fig. 7 indicates that using jatropha oil-based cutting fluid, the optimum multi-response machining performance can be achieved using cutting velocity of 355 m/min, feed rate of 0.1 mm/rev and depth of cut of 1 mm while Fig. 8 indicates that using mineral oil-based cutting fluid, the

Table 13
ANOVA for surfaceroughness.

Factor	Jatropha oil-based cutting fluid					Mineral-oil based cutting fluid				
	DOF	SS	MS	F	P%	DOF	SS	MS	F	P%
Cutting velocity	2.00	25.10	12.55	11.18	44.027	2.00	23.35	11.68	23.78	41.25
Feed rate	2.00	25.32	12.66	11.28	44.413	2.00	27.99	14.00	28.50	49.44
Depth of cut	2.00	4.345	2.173	1.935	7.622	2.00	4.29	2.14	4.37	7.57
Error	2.00	2.245	1.123		3.94	2.00	0.98	0.49		1.73
Total	8.00	57.01	7.126		100	8.00	56.61	7.08		100.00

Table 14
ANOVA for cutting temperature.

Factor	Jatropha oil-based cutting fluid					Mineral-oil based cutting fluid				
	DOF	SS	MS	F	P%	DOF	SS	MS	F	P%
Cutting velocity	2.00	675.5	337.75	4.714	41.669	2.00	6016	3008	40.03	81.09
Feed rate	2.00	378.8	189.40	2.643	23.367	2.00	1150	575	7.65	15.50
Depth of cut	2.00	423.5	211.75	2.955	26.124	2.00	102.7	51.35	0.68	1.38
Error	2.00	143.3	71.650		8.840	2.00	150.3	75.15		2.03
Total	8.00	1621.1	202.63		100.00	8.00	7419	927.38		100.00

Table 15
Values of GRG, GRC and GR-grades of responses for jatropha oil-based cutting fluid.

Seq.	GRG		GRC		Grade
	Ra (μm)	*T* (°C)	Ra (μm)	*T* (°C)	
X_0	1.000	1.000	–	–	–
1	0.000	0.059	0.333	0.347	0.338
2	0.134	0.200	0.366	0.384	0.408
3	0.484	0.000	0.492	0.333	0.443
4	0.375	0.111	0.444	0.360	0.518
5	0.460	0.366	0.481	0.441	0.620
6	0.517	0.202	0.509	0.385	0.554
7	0.394	0.263	0.452	0.404	0.619
8	0.464	0.258	0.483	0.402	0.610
9	0.509	1.000	0.505	1.000	0.834

Table 16
Values of GRG, GRC and GR-grades of responses for mineral oil-based cutting fluid.

Seq.	GRG		GRC		Grade
	Ra (μm)	*T* (°C)	Ra (μm)	*T* (°C)	
X_0	1.000	1.000	–	–	–
1	0.000	0.000	0.333	0.333	0.4378
2	0.261	0.230	0.404	0.394	0.3769
3	0.967	0.281	0.937	0.410	0.6751
4	0.718	0.566	0.640	0.535	0.5429
5	0.859	0.289	0.780	0.413	0.7310
6	1.000	0.933	1.000	0.882	0.8104
7	0.754	0.941	0.670	0.894	0.7506
8	0.890	0.973	0.820	0.949	0.7271
9	0.997	1.000	0.995	1.000	0.8988

optimum multi-response machining performance can be achieved using cutting velocity of 355 m/min, feed rate of 0.1 mm/rev and depth of cut of 1.25 mm. Agu et al. [17] reported that any change in these optimal parameters may lead to poor performance of the turning process. Regression model was used to obtain the optimum values of machining performance for the formulated jatropha oil-based cutting fluid and commercial mineral oil-based cutting fluid by using the optimum values of machining parameters obtained from GRA. The comparison between the two cutting fluids was made using the optimum values of responses in Table 18.

From the results presented, it can be observed that the formulated jatropha oil-based cutting fluid showed better surface roughness and cutting temperature (3.5719 μm and 37.363 °C) compared to the commercial-based cutting fluid which produced a surface roughness and temperature of 4.1612 μm and 42.3505 °C, respectively. Therefore, it concluded that the formulated jatropha oil-based cutting fluid compared favourably with commercial mineral oil-based cutting fluid and can be recommended for use as cutting fluid in machining operations.

Chip formation analysis

The experiments were conducted under different cutting conditions and cutting fluids. The chips collected after machining are shown in Table 19. These chips are compared and categorized with ISO 3685 standards for chip form classification. It is observed that the nature of chips obtained are different forms of continuous chips with length ranging from 3 to 15 cm. The chips formed under jatropha emulsion machining and the number of appearances of each include; long ribbon (3), short washer (1), snarled ribbon (2), long tubular (2), and long tubular helical chips (1). From Table 5, it can be observed that the two snarled ribbon chips obtained for jatropha oil-based cutting fluids were produced at the same depth of cut of 0.75 mm but different cutting velocity and feed rates. Also, long ribbon chips were generated under three different cutting velocities and feed rates, but at equal depth of cut (moderate). The formation of long tubular was at moderate cutting velocity. On the other hand, mineral oil emulsion cutting fluids produced mostly snarled ribbon in five of the nine trials conducted. Among the chips produced are long ribbon, short ribbon and snarled washer. The variation of chips produced are due to (i) different cutting conditions (ii) different normal and frictional forces at tool and chip interface and (iii) different coefficient of friction developed at chip and tool interface under the two cutting fluids conditions. The colour of chips produced is another way of assessing machined chips of a material. Two colours of chips were observed in the metal cutting process. These are burnt and blue chips and; the bright and smooth chips. Table 20 shows analysis of chips colour produced.

The burnt and black chips are unfavourable chips that appear during machining process. Burnt and black chips indicate that the

Table 17
Resulting factor level of experimental parameters.

Level	Jatropha oil-based cutting fluid			Mineral oil-based cutting fluid		
	Cuttingvelocity (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Cutting velocity (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
1	**0.6875**	**0.6101**	0.5004	**0.7921**	**0.7947**	0.6584
2	0.5639	0.5460	**0.5869**	0.6947	0.6117	0.6062
3	0.3965	0.4917	0.5605	0.4966	0.5771	**0.7189**

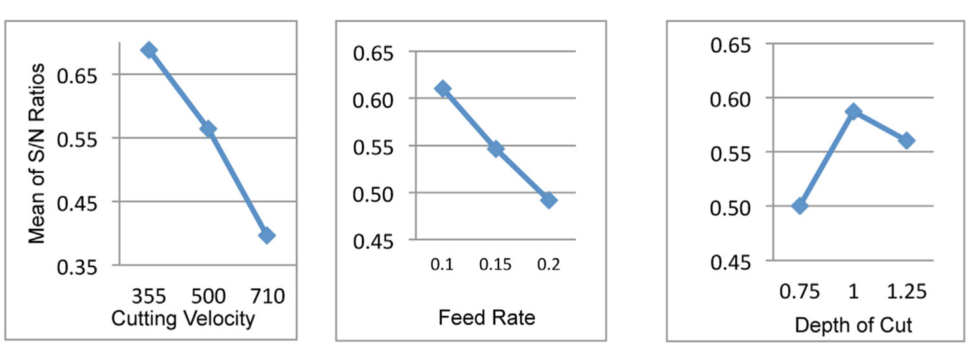


Fig. 7. Main effect plots for jatropha oil-based cutting fluid.

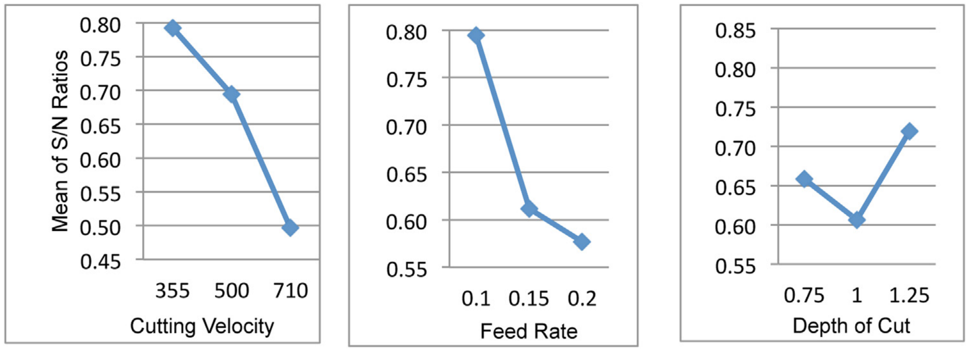


Fig. 8. Main effect plots for mineral oil-based cutting fluid.

Table 18
Optimal values of responses.

Responses	Jatropha oil-based cutting fluid	Mineral oil-based cutting fluid
Surface roughness (μm)	3.5719	4.1612
Cutting temperature(°C)	37.363	42.3505

Table 19
Shapes and types of chip generated during machining.

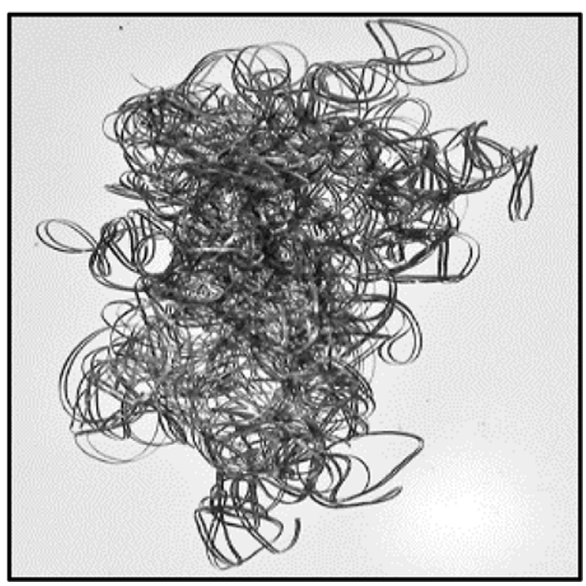
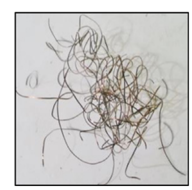
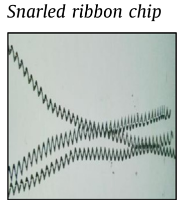
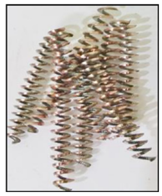
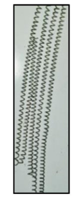
Trial No.	Cutting parameters	Chip shape and type	
		Jatropha oil-based cutting fluid	Mineral oil-based cutting fluid
1.	$V_c = 355$ m/min $f = 0.10$ mm/rev $a_p = 0.75$ mm	 *Snarled ribbon chip*	 *Snarled ribbon chip*
2.	$V_c = 355$ m/min $f = 0.15$ mm/rev $a_p = 1.00$ mm	 *Long ribbon chip*	 *Snarled ribbon chip*
3.	$V_c = 355$ m/min $f = 0.20$ mm/rev $a_p = 1.25$ mm		

Table 19 (*Continued*)

Trial No.	Cutting parameters	Chip shape and type	
		Jatropha oil-based cutting fluid	Mineral oil-based cutting fluid
		 *Short washer chip*	 *Snarled ribbon chip*
4.	$V_c = 500$ m/min $f = 0.10$ mm/rev $a_p = 1.00$ mm	 *Long ribbon chip*	 *Snarled washer chip*
5.	$V_c = 500$ m/min $f = 0.15$ mm/rev $a_p = 1.25$ mm	 *Long tubular chip*	 *Short ribbon chip*
6.	$V_c = 500$ m/min $f = 0.20$ mm/rev $a_p = 0.75$ mm	 *Long tubular chip*	 *Short ribbon chip*
7.1	$V_c = 710$ m/min $f = 0.10$ mm/rev $a_p = 1.25$ mm	 *Long tubular helical chip*	 *Long ribbon chip*

actual process use high cutting speed and/or high feed and/or insufficient lubricant and/or cutting edge with high wear. The black colour indicates high temperature, i.e. the high heat generated in the cut is being directed into the chip and not being kept in the insert or the workpiece material. Chips gets oxidized at high temperature. Over 66% of the chips generated with mineral oil-based cutting fluids were burnt and black chips. Jatropha oil-based cutting fluids had just three cases of burnt and black chips. This implies that the vegetable oil-based cutting fluids (jatropha) was able to penetrate into the work/chip interface sufficiently. Jatropha

Table 20
Analysis of chips colour.

Chips colour	Trial no.	
	Jatropha oil-based cutting fluids	Mineral oil-based cutting fluids
Burnt and black chips	1, 2 and 9	2, 3, 4, 5, 6 and 7
Bright and smooth chips	3, 4, 5, 6, 7 and 8	1, 8 and 9

oil-based cutting fluids produce favourable chips more than the mineral oil-based cutting fluids during the machining of AISI 1525 steel alloy under the same cutting conditions. Jatropha reduces cutting temperature adequately than mineral oil emulsion cutting fluids. Jatropha had a stable lubricity than mineral oil-based cutting fluids. The thin lubrication film formed by jatropha was able to withstand the friction at the tool-workpiece interface, resulting in low surface roughness, low temperature and increase tool life.

Conclusions

Indigenous Nigerian non-edible seed (jatropha) oil was analyzed with respect to their physicochemical, phytochemical and lubricity related properties. Various oil properties of the bio-lubricant were determined using ASTM standards. The effects of jatropha oil on surface roughness, cutting temperature and chip formation were investigated in turning AISI 1525 steel alloy with coated carbide tool and compared with mineral oil. Taguchi L_9 (3^3) orthogonal array was used for the experimental plan. Based on the findings from this work, the following conclusions can be drawn:

The gas chromatography and mass spectra confirmed the presence of fatty acids such as *n*-hexadecenoic acid, 9, 12-octadecadienoic acid and 2, 6, 10, 14, 18, 22 tetracosahexaene in the three oil seeds considered. 9, 12-octadecadienoic acid is the most abundant compound in jatropha oil. Fatty acids content jatropha oils have great applications as vegetable oil and could be utilized for lubricating purpose.

Surface roughness and cutting temperature were 6.61 ± 2.27 and $6.67 \pm 2.27\,\mu$m; and 47.63 ± 13.93 and $81.48 \pm 26.49\,°$C for jatropha and mineral oil emulsion cutting fluids, respectively.

The physical and chemical analyses performed have proven to be satisfactory in terms of the excellent results as compared to the commercial mineral cutting fluid.

The analysis of variance results revealed that surface roughness is greatly affected by feed rate while cutting temperature is most influenced by cutting velocity for both jatropha and mineral oil-based cutting fluids.

Using jatropha oil-based cutting fluid, the optimal multi-response machining parameters can be obtained using cutting velocity, feed rate and depth of cut of 355 m/min, 0.10 mm/rev and 1.00 mm, respectively while using mineral based cutting fluid, the optimal multi-response machining parameters can be achieved with cutting velocity, feed rate and cutting depth of 355 m/min, 0.10 mm/rev and 1.25 mm, respectively.

Machining test carried out on AISI 1525 steel alloy under both cutting fluids conditions produced snarled ribbon, long ribbon, short washer, long tubular and long tubular helical chips which are in conformity with ISO 3685 standards for chips. However, mineral oil produced more of burnt and black coloured chips which indicates that the temperature developed at the chip-tool interface is higher than that of jatropha oil-based cutting fluid which produced more of bright and smooth chips.

In the future it is necessary to have in the experimental design and analysis of variance, the cutting fluid type set as a factor in order to statistically evaluate the significance of the cutting fluid.

Competing interests

The authors declare that they have no conflict of interest.

References

[1] Occupational Safety and Health Administration. 1999, Metalworking fluids: safety and health best practices manual. U.S. Department of Labor: 1–7.
[2] Marius, W., Ralf, B., Christoph, H., 2013, Investigation of a new polymer-water based cutting fluid to substitute mineral oil based fluids in grinding processes. CIRP J Manuf Sci Technol, 6/4: 254–262.
[3] Abdalla, H.S., Patel, S., 2006, The performance and oxidation stability of sustainable metalworking fluid derived from vegetable extracts. Proc Inst Mech Engrs Part B: J Eng Manuf, 220/12: 2027–2040.
[4] Abdalla, H.S., Baines, W., McIntyre, G., Slade, C., 2007, Development of novel sustainable neat-oil metal working fluids for stainless steel and titanium alloy machining. Part 1. Formulation development. Int J Adv Manuf Technol, 34/1–2: 21–33.
[5] Lawal, S.A., Choudhury, I.A., Nukman, Y., 2014, Evaluation of vegetable and mineral oil-in-water emulsion metal cutting fluids in turning AISI 4340 steel with coated carbide tools. J Clean Prod, 66:610–618.
[6] Bisio, A.L., Xanthos, M., 1995, How to manage plastics wastes, technology and market opportunities.Hanser, New York: 7–12.
[7] Eichenberger, H.F., 1991, Biodegradable hydraulic lubricant an overview of current developments in Central Europe (no. 910962). SAE technical paper.1–11.
[8] Busch, C., Backe, W., 1994, Rapidly biodegradable hydraulic fluids. Tribol Schmid, 41/1: 17–23.
[9] Krishna, P.V., Srikant, R.R., Rao, D.N., 2010, Experimental investigation on the performance of nanoboric acid suspensions in SAE-40 and coconut oil during turning of AISI 1040 steel. Int J Mach Tools Manuf, 50/10: 911–916.
[10] Sharif, S., Yusof, N.M., Idris, M.H., Ahmad, Z.A., Sudin, I., Ripin, A., et al, 2009, Feasibility study of using vegetable oil as a cutting lubricant through the use of minimum quantity lubricant during machining. Research VOT No.78055 (Department of Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia), pp.1–51.
[11] Lawal, S.A., Choudhury, I.A., Nukman, Y., 2012, Application of vegetable oil-based metalworking fluids in machining ferrous metals – a review. Int J Mach Tools Manuf, 52:1–12.
[12] Alves, S.M., de Oliveira, J.F.G., 2006, Development of new cutting fluid for grinding process adjusting mechanical performance and environmental impact. J Mater Process Technol, 779/1: 185–189.
[13] Manoj, K., Jeewan, S., Amitava, G., 2014, Potential of vegetable oils as micro lubrication/cooling medium for SQL grinding. 5th international & 26th All India manufacturing technology, design and research conference (AIMTDR 2014) (December 12th–14th, IIT Guwahati, Assam, India, vol. 387), pp.1–5.
[14] Precht, D., Molkentin, J., 1999, C18:1, C18:2 and C18:3 trans and cis fatty acid isomers including conjugated cis A9, trans A11 linoleic acid (CLA) as well as total fat composition of German human milk lipids. Mol Nutr Food Res, 43/4: 233–244.
[15] Gurpreet, S., Singh, S., Singh, M., Kumar, A., 2013, Experimental investigations of vegetable & mineral oil performance during machining of EN-31 steel with minimum quantity lubrication. Int J Res Eng Technol, 2/6: 1030–1037.
[16] Carlos, A.S.B., Janaina, F.S.G., Jefferson, O.G., Jordao, G., 2014, Performance of the jatropha vegetable-base soluble cutting oil as a renewable source in the aluminum alloy 7050-T7451 milling. CIRP J Manuf Sci Technol, 7:210–221.
[17] Agu, C.K., Lawal, S.A., Abolarin, M.S., Agboola, J.B., Abutu, J., Awode, E.I., 2019, Multi-response optimisation of machining parameters in turning AISI 304l using different oil-based cutting fluids. Nigerian J Technol, 38/2: 364–375.
[18] ASTM D1298-12b. 2012, Standard test method for density, relative density, or API gravity of crude petroleum and liquid petroleum products by hydrometer method.ASTM International, West Conshohocken, PA. Retrieved from www.astm.org.
[19] ASTM D287-92. 2006, Standard test method for API gravity of crude petroleum and petroleum products (hydrometer method).ASTM International, West Conshohocken, PA. Retrieved from www.astm.org.
[20] AOAC. 1984, Official methods of analysis. 14th ed. Association of Official Analytical Chemists, AOAC, Arlington.
[21] American Oil Chemists' Society. 1998, Official methods and recommended practices of the AOCS.American Oil Chemists' Society, Champaign, IL.
[22] American Society for Testing and Material (ASTM D 97). Standard test method for Pour Point of Petroleum Products 2005.
[23] American Society for Testing and Material (ASTM D 92). Standard test method for Flash and Fire Points by Cleveland Open Cup Tester 2005.
[24] American Standard Testing Methods (ASTM) D2500-16a. 2016, Standard test method for cloud point of petroleum products and liquid fuels.ASTM International, West Conshohocken, PA.
[25] Muniz, C.A.S., Dantas, T.N.C., Moura, E.F., Neto, A.D., Gurgel, A., 2009, Novel formulations of cutting fluids using naphtenic basic oil. Braz J Petrol Gas, 2/4.
[26] Montgomery, D.C., 2009, Design and analysis of experiments. 7th ed. John Wiley and Son (Asia) Pte Ltd.
[27] Diezel, W.E., Schulz, E., Skanks, M., Heise, H., 1993, Plant oils: topical application and anti-inflammatory effects (croton oil test). Dermatol Monatssch, 179:173.
[28] Letawe, C., Boone, M., Pierard, G.E., 1998, Digital image analysis of the effect of topically applied linoleic acid on acne microcomedones. Clin Exp Dermatol, 23/2: 56–58.
[29] Darmstadt, G.L., Mao-Qiang, M., Chi, E., Saha, S.K., Ziboh, V.A., Black, R.E., et al, 2002, Impact of tropical oils on the skin barrier: possible implications for neonatal health in developing countries. Acta Paediatr, 91/5: 546–554.
[30] Pramanik, K., 2003, Properties and use of *Jatropha curcas* oil and diesel fuel blends in compression ignition engine. Renew energy, 28/2: 239–248.
[31] Aouici, H., Yallese, M.A., Belbah, A., Ameur, M.F., Elbah, M., 2013, Experimental investigation of cutting parameters influence on surface roughness and cutting forces in hard turning of X38CrMoV5-1 with CBN tool. Sadhana, 38/3: 429–445.

[32] Eze, S.O.O., 2012, Physico-chemical properties of oil from some selected underutilized oil seeds available for biodiesel preparation. Afr J Biotechnol, 11/42: 10003–10007.
[33] Oderinde, R.A., Ajayi, I.A., Adewuyi, A., 2009, Characterization of seed and seed oil of Huracrepitans and the kinetics of degradation of the oil during heating. Electron J Environ Agric Food Chem, 8/3: 201–208.
[34] American standard testing methods reports..
[35] CODEX Alimentarius Commission. 1982, Recommended International standards for edible arachis oil, 11. 1st ed. FAO/WHO, Rome.
[36] Kuram, E., Simsek, B.T., Ozcelik, B., Demirbas, E., Askin, S., 2010, Optimization of the cutting fluids and parameters using Taguchi and ANOVA in milling. Proc World Congress Eng, 2:1–5.
[37] Negm, N.A., Kandile, N.G., Abd El Salam, A.M., Mansour, S.A., 2014, Performance evaluation of cutting fluids additives developed from recycling of polyethylene terephthalate. J Appl Chem, 2:69–79.
[38] Abutu, J., Lawal, S.A., Ndaliman, M.B., Lafia-Araga, R.A., Adedipe, O., Choudhury, I.A., 2018, Effects of process parameters on the properties of brake pad developed from seashell as reinforcement material using grey relational analysis. Eng Sci Technol Int J, 21:787–797.
[39] Nzikou, J.M., Mvoula-Tsiér&TDREFS;i, M., Ndangui, C.B., Pambou-Tobi, N.P.G., Kimbonguila, A., Loumouamou, B., et al, 2010, Characterization of seeds and oil of sesame (*Sesamum indicum* L.) and the kinetics of degradation of the oil during heating. Res J Appl Sci Eng Technol, 2/3: 227–232.
[40] Yung-Tien, L., Wei-Che, C., Yutaka, Y., 2010, A study on optimal compensation cutting for an aspheric surface using the Taguchi method. CIRP J Manuf Sci Technol, 3:40–48.
[41] Calex Electronics Limited. 2015, Emissivity Table.1–4. Retrieved from https://www.calex.co.uk/site/wp-content/uploads/2015/07/emissivity-tables.pdf [Accessed 06 January 2016].