Performance Evaluation of Rubber Seed Oil Based Cutting Fluid in Turning Mild Steel

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Abstract
Due to the negative effects associated with the wide use of mineral oil, the desire for eco - friendly cutting fluids as alternative to mineral oil has become a global issue. In this study, rubber seed oil was used to formulate oil-in-water emulsion cutting fluid. Full factorial design was used for the formulation of the oil-in-water emulsion cutting fluid. The optimal process parameters obtained were used for the formulation of the novel cutting fluid and the cutting fluid was characterised. The characteristics of the formulated cutting fluid shows viscosity of 4.25 mm^2/s, pH value of 8.3, high stability and corrosion resistant. Box-Behnken design was used for the turning operation and the performance of the rubber seed oil cutting fluid was compared with mineral oil. The input parameters were cutting speed, feed rate and depth of cut, while the responses were surface roughness and cutting temperature. Coated carbide insert was used as cutting tool. The ANOVA results show that the feed rate had the most significant effect on the surface roughness and cutting temperature followed by the cutting speed and depth of cut during the turning process. It was observed that the rubber seed oil based cutting fluid reduced surface roughness and cutting temperature by 9.79% and 1.66% respectively and therefore, it can be concluded that the rubber seed oil based cutting fluid performed better than the mineral oil in turning of mild steel.

Keywords: Rubber oil, Turning, Surface roughness, Temperature

1.0 INTRODUCTION

Cutting fluids which are also known as metal working fluids play a vital role in metal removal processes. Conventionally, cutting fluids are used to reduce friction and heat in the cutting zone and thus improve the surface finish of the workpiece and prolong tool life. Basically, cutting fluids perform the functions of lubricating, cooling and flushing out of chips formed during machining operation. During cutting operation, friction and heat are generated between the cutting tool and workpiece and as well as between the cutting tool and chips which lead to increase in temperature at the cutting zone. [1] noted that almost all of the work done in cutting processes is converted to heat that caused high temperature in cutting tool and workpiece surface. [2] observed that the large area of intimate contact between the cutting tool and workpiece results in substantial friction between them, causing the temperature to rise rapidly which facilitates cutting tool failure. High temperature does not only affect the tool wear and tool life it also leads to increase in the surface roughness of the workpiece, the dimensional accuracy and the overall quality of the product. Longer time duration and higher cutting speed results in higher cutting temperature in the

cutting zone [3]. The effect is more severe when machining the difficult-to-cut materials [4] and [5].

Most of the cutting fluids being used worldwide are mineral oils based types. They are widely used in machining operations because of their excellent performance and cost effectiveness [6]. Despite their extensive use, they pose substantial environmental and health hazards during their life cycle. Basically, the type of oil and additives used in the formulation of cutting fluids determine their effects on the environment. Mineral oil based cutting fluids are poor degradable and they contain several chemical additives to enhance their performance and unfortunately, some of these additives are harmful to the operator and the environment [7].

In view of the foregoing, there is global interest for eco - friendly cutting fluids that will not only meet the characteristics of cutting fluids, but to have better performance and cost effectiveness than mineral oil. From literature a lot of work has been done on edible vegetable oils based cutting fluids and proved to be viable potential alternatives to conventional oil because they are readily biodegradable, low toxicity, eco - friendly and renewable sources. Besides, vegetable oils possess potential properties such as higher viscosity index, higher lubricity, higher load carrying capacity, higher shear stability and lower volatility [8]. However, the sustainability of edible vegetable oils for industrial purposes is now a concern in the cutting fluid industry because they compete with food stuffs especially in developing countries that depend on

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importation to meet their domestic need of the growing population [9] and [10]. In other words, there is a huge of production. Nigeria is heavily dependent on importation of edible oils for domestic consumption and therefore, the sustainability of edible oils for industrial purposes is not feasible in the present-day challenges [11]. With this development, it becomes imperative for researchers to pay more attention to non - edible vegetable oils such as rubber seed oil, jatropha, neem and castor oils as raw materials for industrial purposes like cutting fluids that are not competing with food because they are not edible by human beings. Non-edible vegetable oils derived from plant sources, seem to be more promising for industrial raw materials because they are viable potentials that have not been completely exploited but are being wasted [12]. Rubber seed oil (RSO) has useful properties like soya bean and linseed [13]. The seed oils have several industrial applications such as paint, alkyl resin, soap making, surface coating, biodiesel and bio-lubricant [14], [15] and 16]. Drilling mud and automobile lubricant have been developed from RSO by [17] and [18] respectively. In this study, the main focus was to utilize rubber seed oil to formulate oil -in-water emulsion cutting fluid that is eco-friendly and compare the performance with the mineral oil in turning mild steel. Oil-in-water emulsion (water soluble) cutting fluid is one of the methods being used in machining industry in the world generally and in developing countries particularly because of its inherent combination of excellent cooling and lubricating properties, availability and cost effectiveness [19].

2.0   MATERIALS AND METHODS
2.1   *Materials*
2.1.1   *Cutting Fluid Materials*
The materials for formulation of the cutting fluid in this study include rubber seed oil, distilled water and additives (emulsifier, antioxidant, anti-corrosive agent (banana sap) and biocide) and mineral oil.

2.1.2   *Turning Process Materials and Equipment*
The material for the turning operations is mild steel rod of 600 mm length and 32 mm diameter. The equipment used include: Sumore lathe (Model- SP 21100 -11 Shanghai China), cutting tool holder (PCLNR 2020K12, Wodex), tungsten coated carbide tool inserts (SNMG120408), infrared thermometer (Model-ST600, Range: -32°C – 600°C +2%, Shangai, China) and surface roughness tester (Model- SRT-62105, +10%, Guang Zhoul Landtek).

2.2   *Methods*
2.2.1   *Physicochemical Properties and Fatty Acid Composition of Rubber Seed Oil*
In this study, the physicochemical properties determined include kinematics viscosity (ASTM D 445), acid value (ASTM D664), flash point (ASTM D 92), pour

gap in demand and supply of edible vegetable oils in the market which could lead to increase in price and high cost point (ASTM D 97). The specific gravity, saponification value and iodine value were determined using the expressions by [20]. The pH value was determined using pH digital meter and the fatty acid composition was carried out using the Gas Chromatograph (GC).

2.2.2   *Formulation of Rubber Seed Oil Cutting Fluid*
The method used by an earlier researcher [5] was adopted. That is, full factorial design was used for the formulation of the oil-in-water emulsion cutting fluids. A total of 16 runs were designed with variation of input parameters (additives) as follows: emulsifier (10,130); anticorrosion agent (10, 12); antioxidant (0.5, 1.0) and biocide (0.5, 1.0) percentage per weight respectively. The optimal process parameters obtained (11.50% of emulsifier (A), 11.00% of anticorrosion (B), 0.90% of antioxidant (C) and 0.95% of biocide (D) were used for formulation of the cutting fluid.

Oil - water ratio of 1:9 was used and the additives that were used are not banned products in composition such as nitrosamines and chlorine for facilitating treatment and disposal process of cutting fluid [5]. Oil and additives were mixed and poured into the water in the measuring cylinder and mechanical stirrer was used for mixing the mixture within 15 minutes. The same ratio of oil-water that was used for the formulation of the rubber seed oil based cutting fluid was used to mix the mineral oil cutting fluid.

2.2.3   *Characterization of the formulated Cutting Fluid*
Characterization of the novel formulated rubber seed oil based cutting fluid such as stability, viscosity; corrosion and pH were carried out in accordance to ASTM standards. The stability of the rubber seed oil cutting fluid was evaluated based on visual transparency. The cutting fluid was filled into 100 ml measuring cylinder and remained within three days at room temperature to determine the appearance and possible oil and water separation.

The kinematic viscosity of the cutting fluid was carried out by ASTM D 445. Corrosion test of the formulated cutting fluid was done by ASTM D 4627. The corrosion test was done by using electric weighing scale to measure 2 g of dry - cut and clean cast iron chips and placed in a glass cylinder. About 10 ml of the formulated cutting fluid was taken and added to the cast iron chips and shaken for about 60s and allowed to soak for few minutes. The cast iron chips were drained and piled on the filter paper and left for about 2 hours. Thereafter, the chips were removed from the filter paper and the filter paper was examined for staining by the damp chips. The pH value of the cutting fluid was measured by using pH digital meter.

2.2.4 Design of Experiment for Turning Process

Box-Behnken design was used for the turning process. It is a design for multivariate optimization class of rotatable or nearly rotatable of three level incomplete factorial designs. A total of 15 runs were designed with variation of input parameters. Minitab Statistical Software (2020) was used to carry out the design matrix. The tuning process parameters, their levels and the design matrix are shown in Table 1 and Table 2.

2.2.5 Turning Process

A 3-jaw conventional lathe (with speed range of 75 - 1050 rpm and 3.8 kW) was used to carry out the turning process using coated carbide inserts and new cutting edge was used for each experiment.

2.2.6 Determination of Surface Roughness

The surface roughness (Ra μm) of the machined workpiece was measured with the aid of surface roughness tester (SRT- 6210S). A new cutting edge of the cutting tool inserts was used for each turning operation of the workpiece and thereafter, three measurements were taken at different points along the workpiece surface and the average value was recorded for the analysis.

2.2.7 Determination of Cutting Temperature

The temperature of the cutting zone was measured using ST 600 infrared thermometer. The ray is beamed at the cutting zone (point of interface between the cutting tool and the workpiece for about 2 seconds within which the value of the temperature measured is displayed on the screen. Three measurements were taken at different points along the workpiece during machining operation of each run and the average temperature was used for the analysis.

Table 1: Turning Process Parameters and their Levels

Parameter	Symbol	Level		
		Minimum	Medium	Maximum
Cutting speed (m/min)	(cs)	200	220	270
Feed rate (mm/rev)	(fr)	0.092	0.104	0.115
Depth of cut (mm)	(doc)	0.7	1.0	1.5

Table 2: Box-Behnken Design Matrix for Turning Process

Experiment No	Cs	Fr	doc
1	200	0.092	1.1
2	270	0.092	1.1
3	200	0.115	1.1
4	270	0.115	1.1
5	200	0.104	0.7
6	270	0.104	0.7
7	200	0.104	1.5
8	270	0.104	1.5
9	220	0.092	0.7
10	220	0.115	0.7
11	220	0.092	1.5
12	220	0.115	1.5
13	220	0.104	1.1
14	220	0.104	1.1
15	220	0.104	1.1

3.0   RESULTS AND DISCUSSION

3.1   Characterization of Rubber Seed Oil

The physicochemical properties and fatty acid composition analysis of the rubber seed oil are shown in Table 3 and Table 4, while the GC-MS of the RSO is shown in Figure 1. The specific gravity of rubber oil (0.920) is in agreement with that of rubber seed (0.91) [21] and the low value indicates good property because the lighter the better for cutting fluid formulation as heavier oil will not easily flow in between the chips and the cutting tool for effective cooling. The viscosity of rubber seed (68.37 mm²/s) at 40°C is comparable to those of neem oi (68.04mm²/s) [22] and rubber seed (66 mm²/s) [21]. This indicates that the lubricating property of the oil is high. The acid value of rubber seed oil (7.29 mg KOH/g) is comparable to that of melon oil (9.39) [23]. The saponification value of rubber seed (163.60 mg KOH/g) is comparable to that of neem (166 mgKOH/g) [22]. The rubber seed oil has iodine value (53.29 mg/g) and is comparable to palm oil (54.24) [24]. The pH value of rubber seed (5.42) is comparable with beniseed (5.28)

[23]. Though the pH value shows that the oil is acidic, however, blending with water and other additives will normalise it for safe use. The flash point value of rubber seed (245°C) is within that of *quassia undulated* seed (255°C) [25]. The high flash point of the rubber seed oil shows that it is safe for handling.
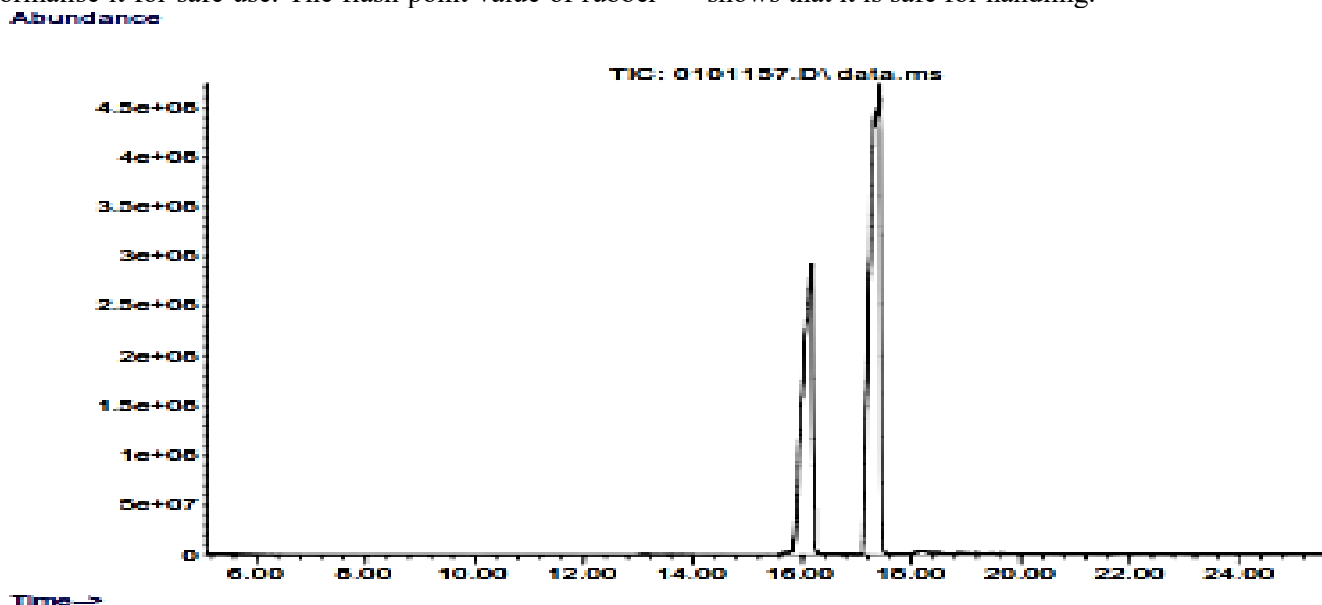

Figure 1: Gas chromatograph of rubber seed oil

Table 3: Physicochemical properties of rubber seed oil

Property	Rubber Seed Oil
Specific Gravity	0.920
Kinematic Viscosity @ 40^{0}C (mm^2/s)	68.37
Acid Value (mgKOH/g)	7.29
Saponification Value (mgKOH/g)	163.37
Iodine Value (mgl/g)	53.29
pH Value	5.42
Flash Point ^{0}C	245
Pour Point ^{0}C	-12

The specific gravity of rubber oil (0.920) is in agreement with that of rubber seed (0.91) (21] and the low value indicates good property because the lighter the better for cutting fluid formulation as heavier oil will not easily flow in between the chips and the cutting tool for effective cooling. The viscosity of rubber seed (68.37 mm^2/s) at 40°C is comparable to those of neem oi (68.04mm^2/s) [22] and rubber seed (66 mm^2/s) [21]. This indicates that the lubricating property of the oil is high. The acid value of rubber seed oil (7.29 mg KOH/g) is comparable to that of melon oil (9.39) [23]. The saponification value of rubber seed (163.60 mg KOH/g) is comparable to that of neem (166 mgKOH/g) [22]. The rubber seed oil has iodine value (53.29 mg/g) and is comparable to palm oil (54.24) [24]. The pH value of rubber seed (5.42) is comparable with beniseed (5.28) [23]. Though the pH value shows that the oil is acidic, however, blending with water and other additives will normalise it for safe use. The flash point value of rubber seed (245°C) is within that of *quassia undulated* seed (255°C) [25]. The high flash point of the rubber seed oil shows that it is safe for handling.

Table 4: Fatty acid compositions of rubber seed oil

Name of Acid	Form	Rubber seed oil Value (%)
Hexadecanoic acid	C17H32O2	18.02
Pentadecanoic acid	C19H34O2	5.43
9-octadecenoic acid	C21H40O2	50.47
Trans-13-octadecenoic acid	C19H36O2	14.82
11-octadecenoic acid	C18H34O2	9.18
Others		2.08
Total Saturated		23.45
Total Unsaturated		74.47

The fatty acid composition of the rubber seed oil shows five main fatty acids which are: hexadecanoic acid (18.02%), pentadecanoic acid (5.43%), 9-octadecanoic acid (50.47%), trans -13-octadecanoic acid (14.82%) and 11-octadecanoic acid (9.18%). Table 4 shows that the rubber seed oil contains approximately 23.45% saturated acids and 74.47% unsaturated acids and is high oleic unsaturated vegetable oil which can be used as feedstock for eco-friendly cutting fluid.

3.2 Characterization of the Formulated Cutting Fluid
The results of the characterization of the formulated rubber seed oil cutting fluid are shown in Table 5.
From Table 5, it could be observed that the viscosity of the formulated rubber seed oil based cutting fluid is 4.25

mm^2/s and is in agreement with the viscosity 4.39 mm^2/s of castor oil emulsion cutting fluid [26]. The rubber seed oil based cutting fluid with pH value of 8.3 compares favourably with the pH value 8.2 of melon seed oil cutting fluid [23]. The stability test of the cutting fluids as described in section 2.2.3, showed that there was no phase separation of oil and water which indicates that the cutting fluid is stable.

3.3 Experimental Results and S/N Ratios
Surface roughness and cutting temperature were the responses evaluated during the turning processes for the rubber seed oil and mineral oil cutting fluids. The data and their corresponding S/N ratios of the surface roughness and temperature of each cutting fluid are shown in Table 6.

Table 5: Characteristics of rubber oil and mineral oil cutting fluids

S/N	Property	Value Rubber Seed oil	Mineral oil
1	Viscosity (mm^2/s)	4.25	0.75
2	pH value	8.3	8.04
3	Stability	stable	stable
4	Corrosion level	corrosion resistant	corrosion resistant
5	Colour	Milky	Milky

Table 6: Experimental results and their corresponding S/N ratios

Exp. Run	Ra (µm) Rubber oil	Mineral oil	S/N Rubber oil	Mineral oil	Temp. (ºC) Rubber oil	Mineral oil	S/N Rubber Oil	Mineral oil
1	0.72	0.86	2.8534	1.3100	35.2	35.4	-30.9309	-30.9800
2	0.55	0.62	5.1927	4.1522	36.7	38.2	-31.2933	-31.6413
3	0.93	1.06	0.6303	0.5061	39.1	39.7	-31.8435	-31.9758
4	0.84	0.94	1.5144	0.5374	42.0	42.5	-32.4650	-32.5678
5	0.71	0.74	2.9748	2.6154	38.9	39.4	-31.7990	-31.9099
6	0.60	0.66	4.4370	3.6091	39.0	40.5	-31.8213	-32.1491
7	0.74	0.77	2.6154	2.2702	38.0	39.6	-31.5957	-31.9539
8	0.61	0.68	4.2934	3.3498	40.0	40.1	-32.0412	-32.0629
9	0.57	0.61	4.8825	4.2934	35.9	36.0	-31.1019	-31.0777
10	0.80	0.90	1.9382	0.9151	39.7	40.6	-31.9758	-32.1705
11	0.69	0.77	3.2230	2.2702	36.2	36.8	-31.1742	-31.3170
12	0.81	0.99	1.8303	0.0873	40.2	40.6	-32.0845	-32.1705
13	0.68	0.70	3.3498	3.0980	39.5	39.8	-31.9319	-31.9977
14	0.67	0.72	3.4785	2.8534	39.2	39.9	-31.8657	-32.0195
15	0.68	0.70	3.3498	0.2491	39.4	39.7	-31.9099	-31.9758

3.4 Signal-to Noise Ratio of Responses
3.4.1 Surface Roughness
The main effect plots for surface roughness of rubber oil and mineral oil cutting fluids are shown in Figure 2 and Figure 3.
Figure 2 shows the main effects plot of S/N ratio for surface roughness using rubber oil based cutting fluid.

It can be observed that the optimal turning parameters for minimum surface roughness are 270 m/min of cutting speed (level 3), 0.092 mm/rev of feed rate (level 1) and 0.7 mm of depth of cut (level 1). From the result, it can be deduced that high speed, low feed rate and low depth of cut reduce the surface roughness in machining and this is in agreement with the work by [2].
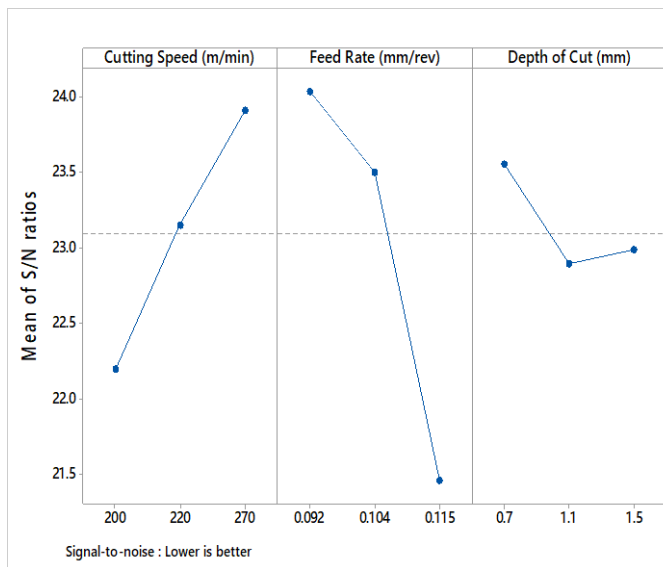
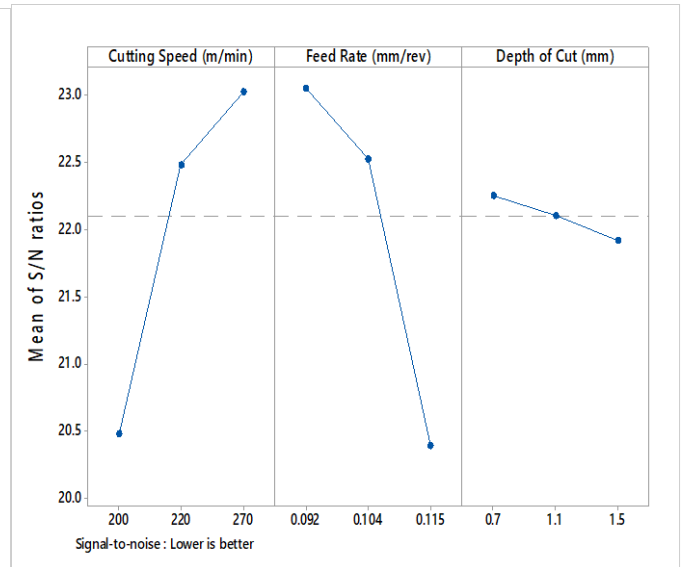**Figure 2:** Main effect plot for rubber seed oil

Figure 3: Main effect plot for mineral oil

The predicted surface roughness, Ra (μm) value for rubber seed oil based cutting fluid is expressed by the regression model:

$$Ra = 0.071417 - 0.00014cs - 0.00836fr + 0.03020 \text{ doc} \quad (1)$$

$R2 = 94.42\%$, $R2 = 90.24\%$

The model equation for surface roughness, Ra (μm) for conventional cutting fluid is:

$$Ra = 0.08000 - 0.00014cs - 0.00840fr + 0.02530 \text{ doc} \quad (2)$$

$R2 = 94.50\%$, $R2 = 90.37\%$.

Figure 3 shows the main effect plots of S/N ratio for surface roughness using mineral oil. It can be observed that the optimal turning parameters for minimum surface roughness are 270 m/min of cutting speed (level 3), 0.092 mm/rev of feed rate (level 1) and 0.7 mm of depth of cut (level 1) respectively. The effect of the different cutting fluids on surface roughness at various cutting speeds is as shown in Figure 4.
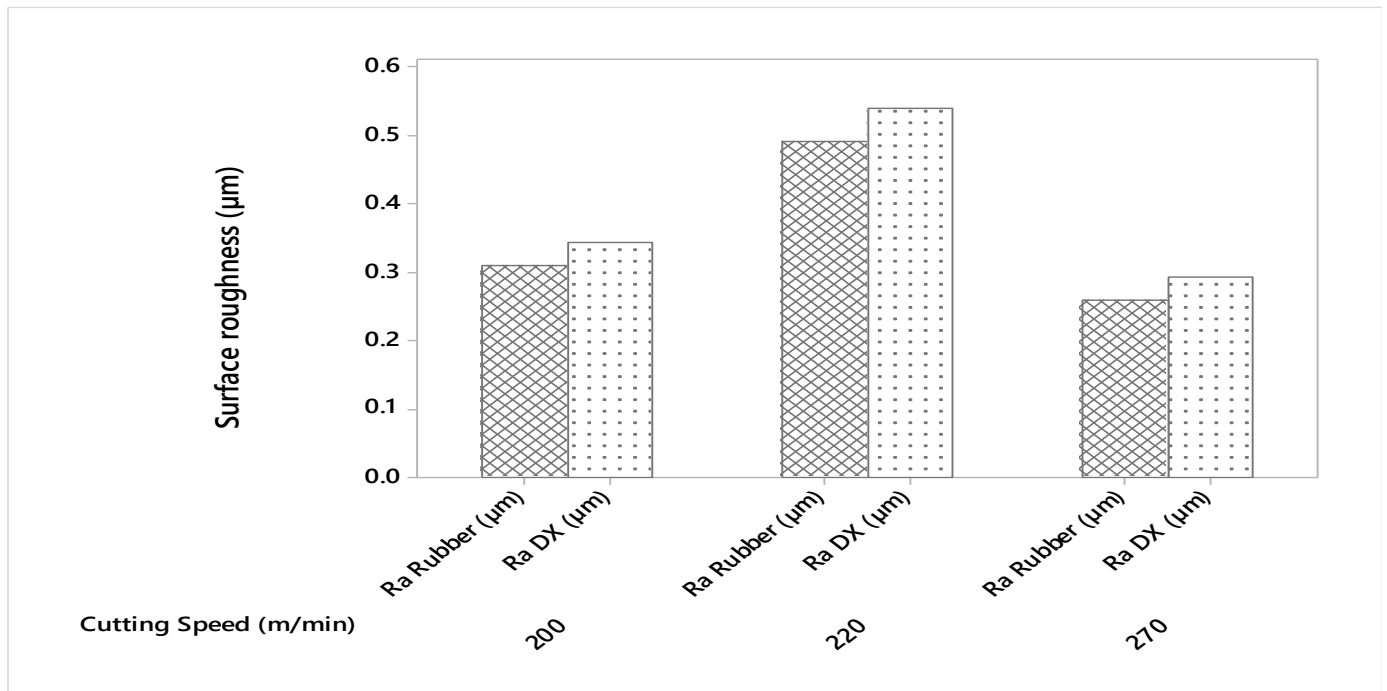

Figure 4: Effect of the different cutting fluids on surface roughness at various speeds

Figure 4 shows the effects of the different cutting fluids on surface roughness at various cutting speeds in the following: At lower cutting speed of 200 m/min,

rubber seed cutting fluid reduced the surface roughness by 9.62% as compared to the mineral oil and at 220 m/min cutting speed, the rubber cutting fluid reduced the surface

roughness by 9.09%. At 270 m/min speed, the percentage reduction for rubber oil was 11.26% respectively. It can be observed that the rubber seed oil based cutting fluid with higher viscosity 4.25 mm^2/s showed more influence on the surface roughness than the mineral oil cutting fluid with viscosity 0.75 mm^2/s at the various cutting speed conditions. Therefore, it can be concluded that the rubber seed oil based cutting fluid performed better as compared to the mineral oil with respect to the surface roughness. The different behaviour of the rubber seed oil based cutting fluid can be attributed to higher viscosity, lubricity and exceptionality of their structure and fatty acid compositions. This is in agreement with the work by [5].

3.4.2   Cutting Temperature

The main effect plots for cutting temperature of rubber oil and mineral oil cutting fluids are shown in Figure 5 and Figure 6.

From the main effect plots, in Figure 5 and Figure 6, it can be observed that the optimal input parameters for temperature are: 200 m/min (level 1), feed rate of 0.092 mm/rev (level 1) and depth of cut of 0.7 mm (level 1) for both cutting fluids during turning operations. From the results, it can be deduced that the cutting temperature decreases with decreased in cutting speed and feed rate and verse versa.

The model equation for cutting temperature (^{o}C) for rubber seed oil based cutting fluid is:

Cutting temperature (Tp) = 39.6500 – 0.0221cs – 2.4740fr – 0.2450 doc   (3)

R^2 = 94.98%, R^2 adjusted = 91.22%.

The model equation for cutting temperature (^{o}C) for conventional seed oil is:

Cutting temperature (Tp) = 39.1170 – 0.0144cs – 2.5000fr – 0.1990 doc   (4)

R2 = 95.22%, R2 adjusted = 91.64%

The effect of the different cutting fluids on cutting temperature at various speeds is as shown in figure 7
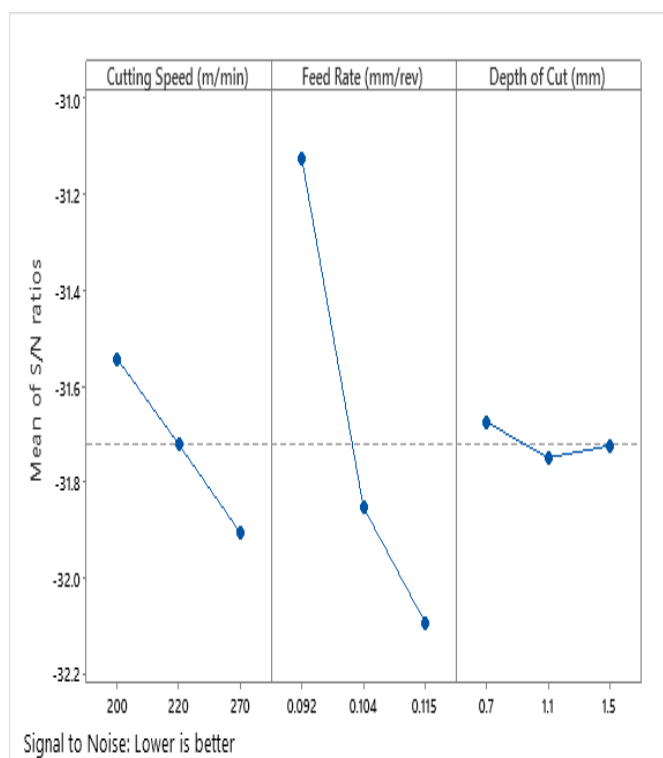

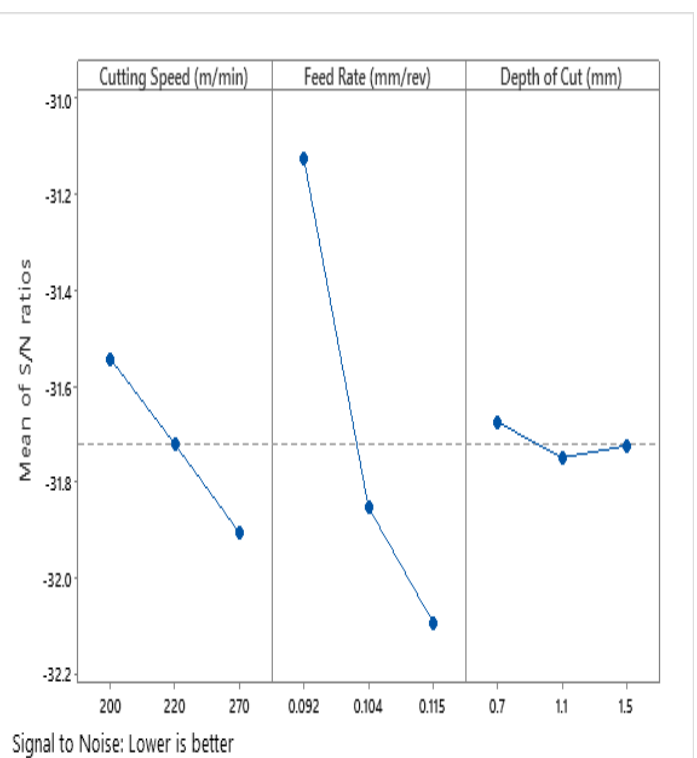**Figure 5:** Main effect plot for rubber seed oil

Figure 6: Main effect plot for mineral oil

Figure 7 shows the effect of the different cutting fluids on cutting temperature at various cutting speeds in the following: At lower cutting speed of 200 m/min, rubber seed oil cutting fluid reduced the cutting temperature by 1.88% compared to mineral oil and at 220 m/min cutting speed, the rubber oil cutting fluid reduced the cutting temperature by 1.21 %. At 270 m/min speed, the percentage reduction for rubber oil was 2.23% respectively.

From the result, it can be observed that the rubber seed oil cutting fluid with viscosity 4.25 mm^2/s had lower cutting temperature than the mineral oil cutting fluid with viscosity of 0.75 mm^2/s at various speeds. This may be attributed to higher viscosity and the combination of

cooling and lubrication properties of rubber seed oil because the viscosity significantly affects the thickness of

the lubricating film formed from cutting fluid during machining. This is in agreement with the studies by [28].
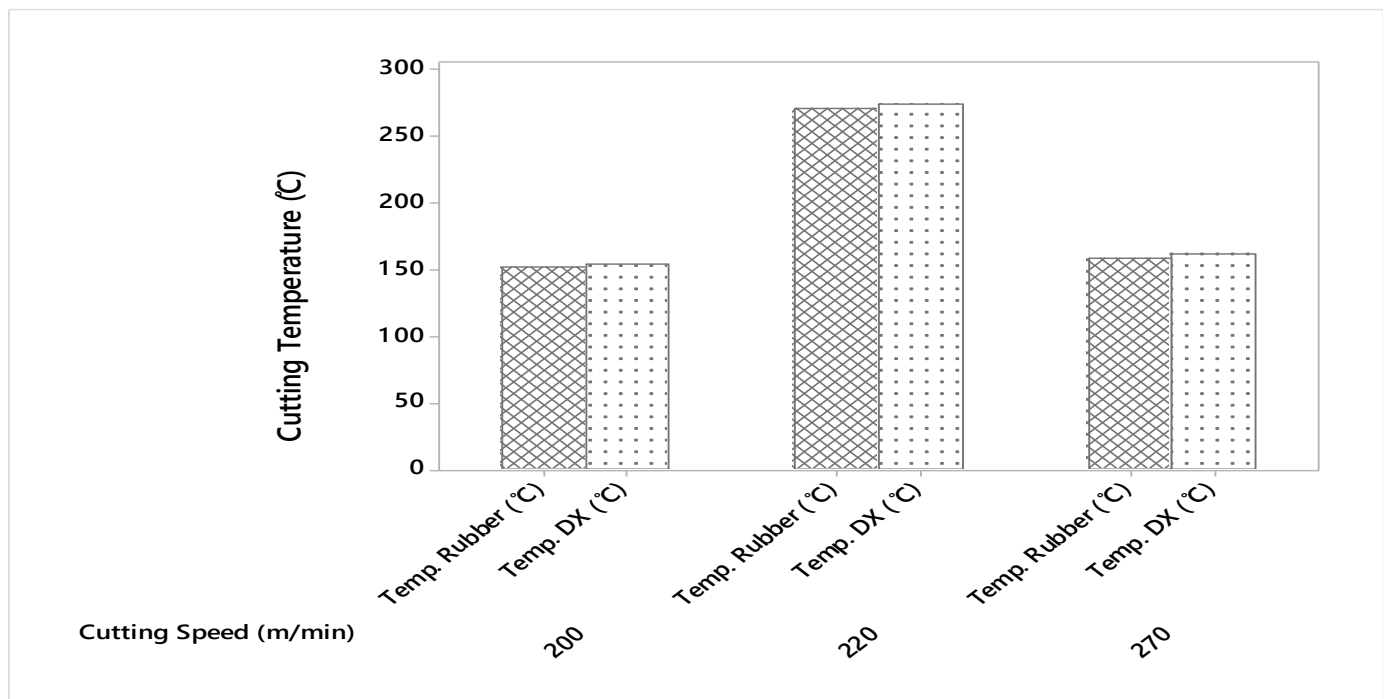

Figure 7: Effect of the different cutting fluids on cutting temperature at various speeds.

3.5　　Analysis of Variance

Minitab Statistical Software was used to carry out the ANOVA analysis for surface roughness and cutting temperature and the results are shown in Table 3.5 and Table 3.6.

It can be observed that the percentage contribution of each input parameters to the surface roughness are: cutting speed (20.79 %), feed rate (69.50%) and depth of cut (4.08%) respectively. The results show that the feed rate has the most significant effect on the surface roughness, followed by the cutting speed and depth of cut respectively. Therefore, it can be concluded that the

cutting speed and feed rate have more significant effect on the surface roughness in the turning operation. This is in agreement with the work by [27].

From Table 7, the ANOVA of surface roughness using mineral oil, it can be observed that the percentage contributions of input parameters to the surface roughness are: cutting speed (14.44%), feed rate (75.05%) and depth of cut (5.01%) respectively. The results show that the feed rate has the most significant effect on the surface roughness, followed by the cutting speed and depth of cut respectively. This is in agreement with the work by [27].

Table 7: ANOVA for surface roughness for rubber seed oil and mineral oil cutting fluids

Variable	Rubber seed oil					Mineral oil				
	DOF	SS	MS	F	P(%)	DOF	SS	MS	F	P(%)
CS (m/min)	2	0.0321	0.0161	14.8	20.79	2	0.0383	0.0191	10.45	14.44
FR (mm/rev)	2	0.1073	0.0537	3	69.50	2	0.1991	0.0995	54.39	75.05
DOC (mm)	2	0.0063	0.0032	49.5	4.08	2	0.0133	0.0066	3.62	5.01
Error	8	0.0087	0.0011	4	5.63	8	0.0146	0.0018		5.5
Total	14	0.1544		2.92	100	14	0.2653			100

Table 8: ANOVA for cutting temperature of rubber seed oil and mineral oil cutting fluids

Variable	Rubber seed oil					Mineral oil				
	DOF	SS	MS	F	P(%)	DOF	SS	MS	F	P(%)
CS (m/min)	2	5.2998	2.6499	8.77	10.97	2	6.7592	3.3796	11.27	13.49
FR (mm/rev)	2	40.1635	20.0818	66.48	83.13	2	40.7981	20.3990	68.00	81.41
DOC (mm)	2	0.4813	0.2407	0.80	1.00	2	0.1581	0.0790	0.26	0.31
Error	8	2.4167	0.3021		5.00	8	2.4000	0.3000		4.79
Total	14	48.3146				14	50.1154			

From Table 7, the ANOVA of cutting temperature for rubber seed oil cutting fluid, it can be observed that the percentage contributions of input parameters to the cutting temperature are: cutting speed (10.97%), feed rate (83.13%) and depth of cut (1.00%) respectively. It indicates that feed rate is the most significant parameter that influences the cutting temperature in this study. This is in agreement to the work by [23].

From Table 8, the ANOVA of cutting temperature for mineral oil, it can be observed that the percentage contributions of input parameters to the cutting temperature are: cutting speed (13.49%), feed rate (81.41%) and depth of cut (0.31%) respectively. This is in agreement to the work by [23].
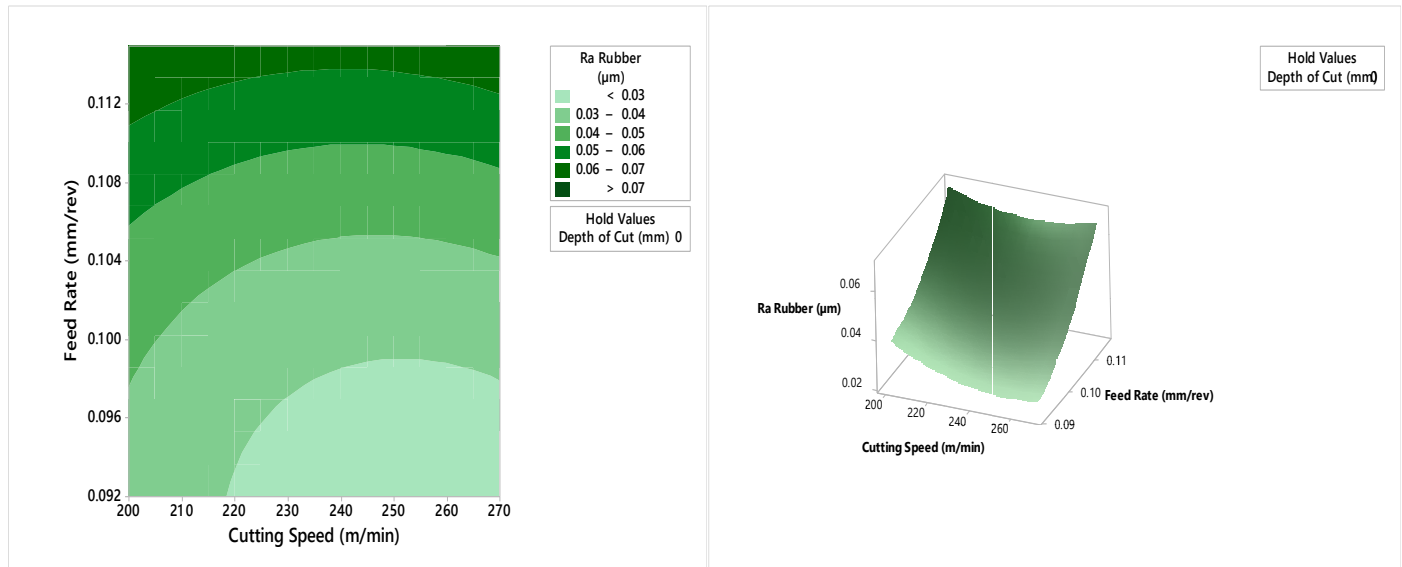

Figure 8: Contour and 3D plots for surface roughness for rubber oil

3.7   Contour Plots and 3D Surface Plots

The contour and 3D surface plots for interaction effects of surface roughness and cutting temperature for rubber seed oil and mineral oil cutting fluids are shown in Figures 8 – 11. Figures 8 - 11 show the contour and 3D surface plots for interaction effect of cutting speed and feed rate on the surface roughness and cutting temperature when depth of cut held constant. It can be deduced that the surface roughness and cutting temperature increased with increase in cutting speed and feed rate when both cutting fluids were used. The 3D surface plots show the effect of cutting speed and feed rate on the surface roughness and cutting temperature with flattened curve shapes design model. It is observed that the surface roughness and cutting temperature increased with increased in cutting speed and feed rate. This agrees with the contour plots.
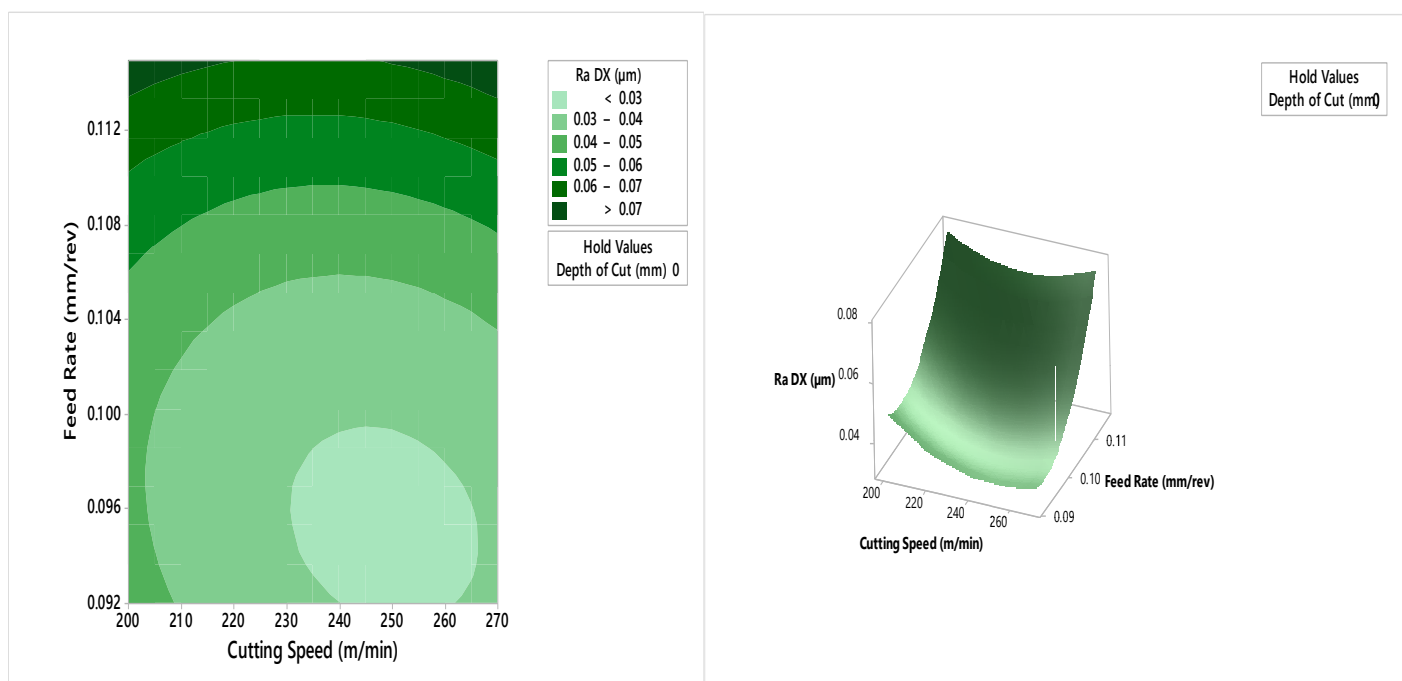

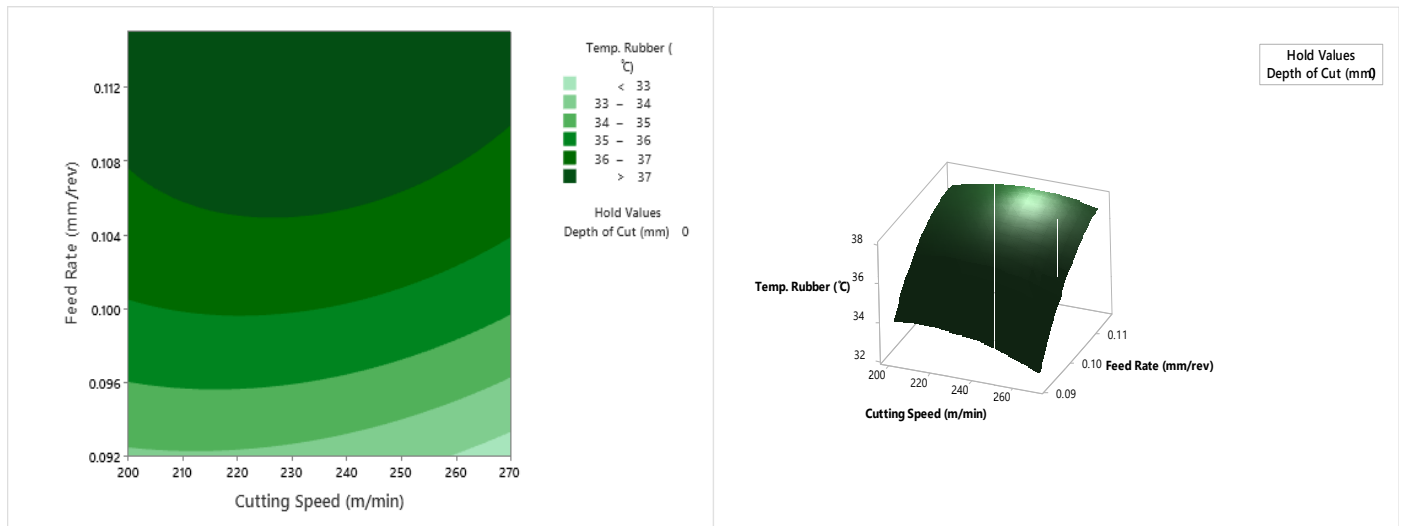**Figure 9:** Contour and 3D plots for surface roughness for mineral oil.

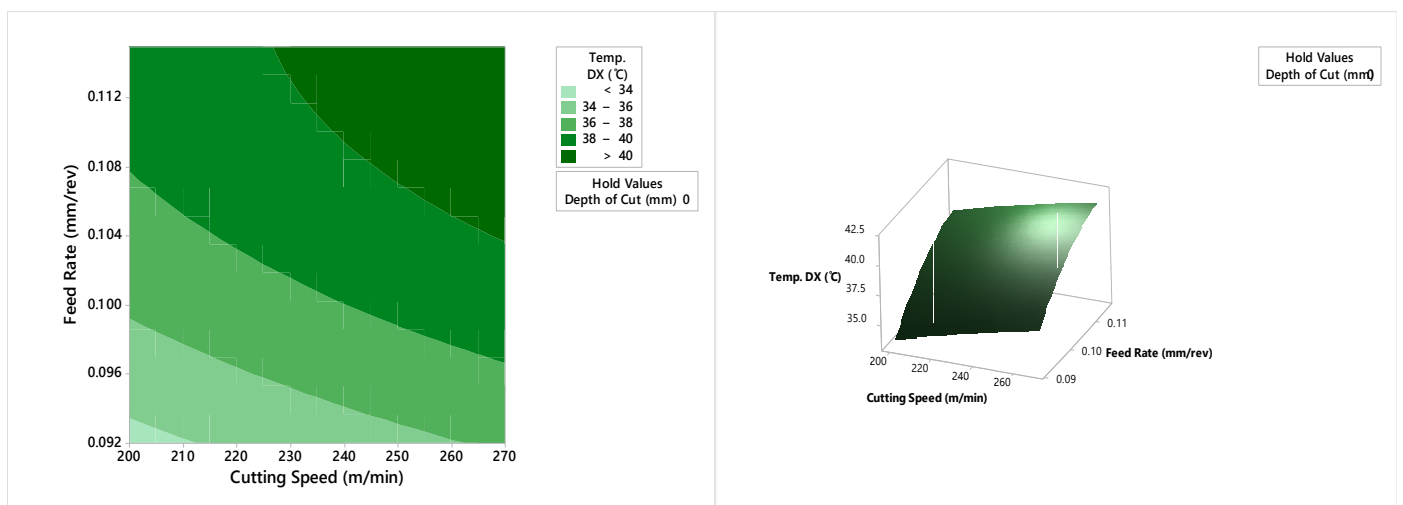**Figure 10:** Contour and surface plots cutting temperature for rubber seed oil

Figure 11: Contour and 3D surface plots for cutting temperature for mineral oil.

3.8   *Confirmation Test*

The model equations 1 - 4 obtained from the regression analysis in section 3.4.1 were used for the confirmation test. The experimental values, the calculated results from the model equations and the percentage error are shown in Table 9.

$$Percentage\ eror\ (E) = \frac{Experimental\ (EX)value - Calculated\ (Cc)value}{Experimental\ (EX)value} \times 100 \qquad (5)$$

The confirmation tests conducted using regression equations show that the results are reliable having the percentage error between 0.9% and 3.3% for the two responses.

Table 9: Confirmation test and percentage error

Response	Experimental Value		Calculated Value		Percentage Error (%)	
	Rubber oil	Mineral oil	Rubber oil	Mineral oil	Rubber oil	Mineral oil
Ra (μm)	0.055	0.061	0.054	0.059	1.8	3.3
Temp. (ºC)	35.2	35.4	34.9	35.9	0.9	1.4

4.0   CONCLUSION

(i) A novel oil-in-water cutting fluid from rubber seed oil based cutting fluid has been formulated and performance evaluation was conducted as compared to the mineral oil. From the findings, the rubber seed oil based cutting fluid performed better than the mineral oil in terms of surface roughness and cutting temperature at different cutting conditions.

(ii) The performance evaluation conducted indicates that the optimum conditions for surface roughness for both cutting fluids is $A_3B_1C_1$ which has a cutting speed of 270 m/min, feed rate of 0.092 mm/rev and depth of cut of 0.7 mm respectively and for temperature it is obtained at $A_1B_1C_1$ which has a cutting speed of 200 m/min, feed rate of 0.092 mm/rev and depth of cut of 0.7mm respectively.

(iii) That optimal surface roughness can be obtained at high cutting speed, low feed rate and depth of cut, while minimum cutting temperature can be obtained at low cutting speed, feed rate and depth of cut respectively.

(iv) The ANOVA results show that the feed rate has the most significant effects on the surface roughness and cutting temperature, followed by the cutting speed and depth of cut.

(v) The confirmation test conducted using regression equations show that the results are reliable having the percentage error between 0.9% and 3.3% for the two cutting fluids.

The new cutting fluid was formulated with a high concentration of water to oil ratio 9:1 with few additives that are not banned. Therefore, rubber seed oil is viable and suitable source for renewable eco - friendly cutting fluid. This study has exploited the potential of rubber seed oil for industrial purposes and it has also open up a new ground in cutting fluid sector since there is no report yet of using rubber seed oil as cutting fluid to the best knowledge of the authors. However, further study may focus on using the cutting fluid on other materials.

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