Influence of Mango Seed Oil on Surface Roughness and Cutting Temperature During Sustainable Turning of AISI 1525 Steel Under Minimum Quantity Lubrication Environment

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Abstract. Mineral oil-based cutting fluids have several mechanical advantages. The use of mineral oil has been questioned due to its adverse effect on machinists and the environment. There is need for a sustainable and biodegradable cutting fluid that can perform the task of problematic mineral oil. This study considered a non-edible vegetable oil, mango oil, as a lubricant in the turning operation of AISI 1525 steel using an MQL mode of fluid application. The performance of mango oil was compared with commercial mineral oil using SR and CT as performance metrics. Experiments were conducted under three levels of SS (355, 500, and 710 rev/min), FR (0.10, 0.15, and 0.20 mm/rev), and DOC (0.75, 1.00, and 1.25 mm). Taguchi L9 orthogonal array was adopted for the experimental settings. Afterward, TOPSIS, a multi-optimization tool was employed to determine the best cutting parameters for machining the workpiece with the tungsten carbide tool. The finding showed that mineral oil outperformed mango oil lubricant in terms of both SR and CT. The optimum CT and SR can be achieved using an SS of 355 rev/min, FR of 0.15 mm/rev, and DOC of 1.00 mm for both mango and mineral oil lubricants.

Keywords: ANOVA, Cutting fluids. Lubricants, Mango oil, Mineral Oil.

1 Introduction

Machining is a vital aspect of manufacturing. During machining processes, a huge amount of heat is concentrated at the cutting region as a result of sliding between the tool and workpiece. Lubrication is required to reduce the heat to a substantial level [1]. Total elimination of heat during machining is inevitable [2]. Lubrication and cooling help to drive

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away some amount of heat to the atmosphere. The most common commercial lubricant, mineral oil is problematic and needs a substitute [3]. Several alternative coolants and lubricants have been explored. One of which is vegetable oil which is biodegradable, less toxic, and sustainable [4]. A good lubricant is necessary during machining operations for AISI 1525 steel because of its superior mechanical, tribological, and reduced thermal qualities. Because it uses less energy to remove heat generated during turning, the MQL process has emerged as the most dependable method for reducing CO2 emissions compared to dry lubrication and floods. Vegetable oil-aided MQL has been used in numerous research. To create a novel, environmentally friendly coolant fluid based on vegetable oil, Yuan *et al* [5] set out to optimally balance the amounts of castor oil (CO) and ethanol (E). Three distinct lubricating conditions (flood machining, dry machining, and CO-E blended coolant-based MQL environments) were used to measure the flank wear and SR to assess the coolant's effectiveness. SR was decreased by 36% and 15%, respectively, under the blended coolant-based MQL settings, while tool wear was decreased by 53% and 38%, in comparison to flood machining and dry machining, respectively. In their study, Singh *et al.* [6] assessed the machining effectiveness and long-term feasibility of turning Hastelloy C-276 under dry, MQL, and flood circumstances. Sustainability was evaluated and the experimental output was conducted using the Taguchi L9 array and the TOPSIS approach. According to the results of the experiments, MQL has reduced SR, temperature, and cutting forces by a range of 20–38%. Likewise, energy expenses and carbon emissions dropped by 9–27%, respectively, in comparison to other environments. Abas *et al.* [7] analyzed and multi-response optimized the cutting variables for aluminum alloy 6026-T9 in MQL and dry conditions using a combined approach of composite desirability function and Criteria Importance Through Intercriteria Correlation (CRITIC). The chiller was filled with 150 mL of MQL olive oil every hour. The optimal levels attained under dry conditions are 500 m/min cutting speed, 2 mm cut depth, 0.3 mm/rev FR, and 15° positive rake angle. On the other hand, 0.4 mm/rev FR, 500 m/min cutting speed, 2 mm cut depth, and a 15° positive rake angle are required for MQL conditions. To determine the ideal process parameters utilizing DFA and TOPSIS, Suresh *et al.* [8] performed an experimental examination to explore the machinability of AISI D3 steel when used with CVD-coated cemented carbide inserts of various kinds.

The usage of mango oil emulsion in the turning of AISI 1525 steel was investigated by Kazeem *et al.* [9]. A Taguchi L9 orthogonal array was utilized to mechanically assess the vegetable oil. The input parameters were DOC, FR, and SS; the outputs were SR, machine vibration rate, cutting machine sound level, and temperature. Multi-objective optimization was carried out using Taguchi-based GRA. In the majority of machining circumstances, mineral oil performed better than mango oil emulsion. Mango oil derived chemically was studied by Naik and Sharma [10] and contrasted with edible oils. Tribology tests and thermophysical characterization were carried out to confirm the efficacy of the extracted oil. The results were compared to inedible and edible oils, including sunflower oil and mahua seed oil. These findings revealed that mango oil had the lowest wear volume and coefficient of friction, followed by dry oil, mahua seed oil, and sunflower oil, in that order. SEM research revealed that there was no plowing, but there were tiny pits and cracks on the wear track beneath the mango oil. Mahogany seeds were used to extract oil, which Abutu *et al.* [11] then analyzed for viscosities, pH, and flash points. AISI 304 austenitic stainless steel was turned to examine the effects of mahogany oil on CT, MRR, and surface finish. The experiment was designed using the CCD approach via RSM. The formulated mahogany oil contrasted favorably with mineral oil, according to experimental data derived from machining procedures. Using a multi-objective optimization technique, Chinchanikar *et al.* [12] assessed the SR, cutting force, and MRR of titanium grade-1 alloy to determine its machining capability. Under MQL, turning tests were conducted using a nanofluid based on coconut oil. To maximize the machining efficiency, the DFA, GRA, TOPSIS, and (Non-Dominated Sorting Genetic Algorithm) NSGA-II were employed. The results indicated that the highest cutting speed, highest DOC, lowest feed, and lowest nanoparticle concentration were associated with optimal performance. Maximum MRR was 9375 mm^3/min, whereas the lowest values of SR and forces were 0.47 µm and 387 N respectively.

On top of that, During the MQL turning of Ti–6Al–7Nb, Gupta *et al*. [13] improved the machining parameters using a combined Taguchi and TOPSIS technique. To concurrently maximize surface quality and flank wear, the effects of several input process variables—namely, the type of oil, the rate at which it flows, and the cutting speed—were examined. It was discovered that the kind of oil contributes 74.81% of the overall variability and has the greatest impact on the proximity coefficient. Compared to synthetic oil and mineral oil, vegetable oils turned out to be a good substitute. Sen *et al*. [14] used castor oil as a lubricant to ascertain the optimal sequence of MQL milling variables for Inconel 690. To establish a relationship between input and machining outputs, RSM was utilized. A two-stage computational approach, TOPSIS and NSGA-II, was used to address the optimization challenge to determine which compromise functions best. Also, an investigation on the impact of soybean oil on the MQL turning of Ti6Al-4V alloy was conducted by Sharma *et al*. [15]. SR, TWR, and MRR were examined as a function of the machining settings. Additionally, a gray correlation-based strategy for order of preference by similarity to the ideal solution (GC-TOPSIS) approach was used in conjunction with fuzzy weights to discover the ideal parameter combination, hence improving the standard of machining performance indicators. A speed of 575 rpm, a DOC of 0.1 mm, and a FR of 0.02 mm/rev were the ideal sets of parameters. In comparison with dry cutting, MQL showed a substantial improvement of 46.39%, 18.18%, and 11% for SR, TWR and MRR, respectively. To better understand the machinability of Inconel 718, Zahoor *et al*. [16] replaced standard fluids with synthetic vegetable ester-based biodegradable oil (Mecagreen 450) to provide an ecologically conscious flood-cooling substitute. Sen *et al*. [17] used an MQL milling of Inconel 690 to examine six castor-palm mixes (ranging from 1:0.5 to 1:3) to improve the lubricating behavior of vegetable oil. Comparing the best castor-palm volume proportion to that of palm oil and castor oil medium, respectively, showed that there was a decrease in SR of 16.146 and 8.262%, in specific cutting energy of 7.971 and 5.459%, and tool wear of 3.155 and 2.445%.

According to a survey of the literature, non-edible oil is rarely used as a lubricant. The majority of vegetable oils utilized are edible and will eventually compete with consumable oils. This study looks into the usage of mango oil as a lubricant during the MQL turning of AISI 1525 steel using a tungsten carbide tool.

2 Materials and Methods

2.1 Cutting Parameters, Measuring Equipment, Workpiece and Cutting Tool

In this work, AISI 1525 steel was taken as workpiece material to carry out the cylindrical turning operations. The dimension of the workpiece is 80 mm by 150 mm. Kazeem *et al*. [9] provided information on the workpiece's chemical and physical characteristics. The study considered tungsten carbide tool holders and inserts for the machining experiment. Fig. 1 displays the photographic view of the workpiece and tool holder. to assess how CT and SR are affected by changing input parameters, such as feed, DOC, and SS. Using an infrared thermometer and an SRT-620 roughness meter, the temperature of the cutting surface and its roughness were measured, respectively. AJAX machine tool was utilized in the experimentation process. Nine tests were carried out using the Taguchi L9 Design of experiments, with each turning parameter (i.e., DOC (0.75, 1.00, and 1.25 mm), FR (0.10, 0.15, and 0.20 mm/rev), and SS (355, 500, and 710 rev/min) varied at three different levels. Table 2 presents the cutting parameters together with the DOE. 2.3 ml/hr is the operating speed for the MQL cutting fluid application technique. Pre-processing is carried out using Equation (1) for the data sequences for SR and CT, which are characteristics of performance that are better when smaller.

$$SNR = -10\log\frac{1}{n}\left(\sum y_i^{\,2}\right) \tag{1}$$

Fig. 1. (a) Photographic View of AISI 1525 Steel (b) Tungsten Carbide Tool holder

2.2 Multi-Optimization Technique (TOPSIS Method)

A straightforward multiple-criteria decision-aid method is TOPSIS. As the name implies, the method's foundation is calculating the separation between each option and the ideal and anti-ideal solutions. To provide readers with a broad understanding of the methods used, we provide a few options for the operations, such as mean operators, distance evaluations, and normalization, for each of the relevant TOPSIS phases [18]. The procedures that need to be performed to properly optimize utilizing TOPSIS are listed below.

1. Apply Equation (2) to compute the normalized decision matrix.
2. Selecting the weights and using Eq. (3) to calculate the normalized weights of the criteria.
3. Use Equation (4) to calculate the weighted normalized decision matrix.
4. Use Equations (5) and (6) to determine which choice is the best and which is the worst.
5. Use Eq. (7) to calculate the n-dimensional Euclidean distance between each conceivable outcome and the desired outcome.
6. Using Eq. (8), get the n-dimensional distance between each potential solution and the negative ideal solution.
7. Using Eq. (9), calculate the rating score, which is a measure of the extent to which the solution is closer to the ideal.

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^{2}}} \tag{2}$$

$$w_i = \frac{W_i}{\sum_{i=1}^{k} W_i} \tag{3}$$

Where $i = \frac{1}{k}$ and $\sum_{i=1}^{k} w_i = 1$

$$U_{ij} = w_i Z_{ij} \tag{4}$$

$$B^{+} = \left\{ u_1^{+}, u_2^{-}, \ldots u_i^{+}, \ldots u_n^{+} \right\} \tag{5}$$

$$B^{-} = \left\{ u_1^{-}, u_2^{-}, \ldots u_i^{-}, \ldots u_n^{-} \right\} \tag{6}$$

where u_i^{+} and u_i^{-} are the best and worst values for the criterion across all possibilities.

$$P_j^{+} = \sqrt{\sum_{i=1}^{k} \left(u_{ij} - u_i^{+} \right)^2}, \qquad j = \frac{1}{n} \tag{7}$$

$$P_j^{-} = \sqrt{\sum_{i=1}^{k} \left(u_{ij} - u_i^{-} \right)^2}, \qquad j = \frac{1}{n} \tag{8}$$

$$Q_j = \frac{P_j^{-}}{P_j^{+} + P_j^{-}}, \qquad j = \frac{1}{n} \tag{9}$$

The closeness coefficient *(Q_j)* represents a single response by converting the multiple responses (i. e. SR and CT) into a single response.

3 Results and Discussion

A set of experiments was conducted to investigate how SR and CT were affected by changes in SS, FR, and DOC. Table 1 displays the measured SR and CT data. In Figs. 2 and 3, the SR and CT variation charts are displayed, respectively, for enhanced observation.

3.1 The Impact of Turning Variables on SR

The tribological actions of surfaces, such as deformation or asperity interlocking that might enhance friction, are significantly influenced by SR. The SR was determined by calculating the *Ra* which gives the average roughness. Three measurements were averaged to give the results shown in Table 1. The measured values range from 5.29 to 20.71 µm and 3.20 to 17.47 µm for mango and mineral oil lubricants, respectively. The average and standard deviation of mango and mineral oil lubricants are 12.134±4.617 and 8.75±4.075 µm. The total roughness recorded for mineral oil was 78.75 µm which is about 27.89% better than mango oil. Mineral oil outperformed mango oil lubricant in most machining trials as shown in Table

1 and Fig. 2. The fluid outperformed the vegetable oil in terms of lubrication. However, mango oil with a very close average value should be avoided due to its poor biodegradability and negative environmental effects, such as groundwater and surface contamination, soil contamination, air pollution, and, ultimately, food and agricultural product contamination, as well as operator health. Mango oil surpassed mineral oil lubricant in three experimental trials, experiments 1, 3, and 8. The roughness of mineral oil was hardly up to 10 µm. Mango oil gave higher SR values as a result of irregularities of the surface which can cause quicker wear and tear, breaks, and corrosion [19]. Mango oil may have a rough surface since there is more friction between the cutting tool and the workpiece. Because of the high friction coefficient, sliding requires more force than a surface with a smooth finish. Vegetable oil derived from mango could perform better, if necessary, lubricant additives are added to its production. The mango oil utilized in this study was raw, with no enhancements. Similar results were reported by Kazeem *et al.,*[20] and Kolawole and Odusote [21].

3.2 The Impact of Turning Variables on CT

The variation of cutting parameters on CT are shown in Table 1 and Fig. 3. CT varies from 68.5°C to 137.3°C and 69.4°C to 152.1°C for mango oil and mineral oil, respectively. The average and standard deviation of mango and mineral oil are presented in Table 1 as 118.089±23.32 and 110.244±18.645, respectively. The lowest machining temperature (68.5°C) was obtained with mango oil at the highest SS (710 rev/min), higher FR (0.15 mm/rev), and lowest DOC (0.75 mm). Mineral oil also outsmarted mango oil by 6.6%. The percentage difference is encouraging for a crude lubricant like mango oil. Mango oil completely strongly with mineral oil in lubricating AISI 1525 steel during MQL turning operations. In experiments 4, 7, and 8, mango oil had a superior performance than the mineral oil and was almost equal to mineral oil in experiment 9. Given their intriguing inherent qualities—such as sufficient lubrication, high flashpoints, high viscosity indices, and environmental friendliness—vegetable oils are a good substitute, as demonstrated by the study's findings. At high temperatures, they are less stable against oxidation [22].

Table 1. Experimental Matrix and Results of Response Variables

Exp. No.	**SS (rev/min)**	**FR (mm/rev)**	**DOC (mm)**	**Mango Oil**		**Mineral Oil**	
				SR (µm)	**CT (°C)**	**SR (µm)**	**CT (°C)**
1	355	0.10	0.75	9.32	130.4	9.72	69.4
2	355	0.15	1.00	6.96	113.4	3.90	100.6
3	355	0.20	1.25	5.29	124.6	9.89	109.7
4	500	0.10	1.00	12.91	108.1	8.32	116.8
5	500	0.15	1.25	20.71	137.3	8.80	124.9
6	500	0.20	0.75	14.69	152.1	8.60	102.8
7	710	0.10	1.25	11.39	111.1	3.20	135.4
8	710	0.15	0.75	14.69	68.5	17.47	116.6
9	710	0.20	1.00	13.25	117.3	8.85	116.0
Total response value				**109.21**	**1062.8**	**78.75**	**992.2**
Mean average value				**12.134**	**118.0889**	**8.75**	**110.2444**
Standard deviation				**4.617**	**23.31863**	**4.075**	**18.64498**

Table 2. S/N Ratio for Response Variables (SR and CT)

Experiment No.	S/N Ratio for SR	S/N Ratio for CT	S/N Ratio for SR	S/N Ratio for CT
1	-19.38831825	-42.30555183	-19.7533253	-36.82718941
2	-16.85218479	-41.09226109	-11.82129214	-40.05195961
3	-14.46911344	-41.91036085	-19.90392583	-40.80413255
4	-22.21852485	-40.67651388	-18.40246653	-41.34885686
5	-26.32360198	-42.75341074	-18.88965344	-41.93124877
6	-23.34043592	-43.64258428	-18.68996902	-40.23986229
7	-21.13047448	-40.91428118	-10.10299957	-42.63237329
8	-23.34043592	-36.71381143	-24.84585810	-41.33397101
9	-22.44431757	-41.38596024	-18.93886541	-41.28915978

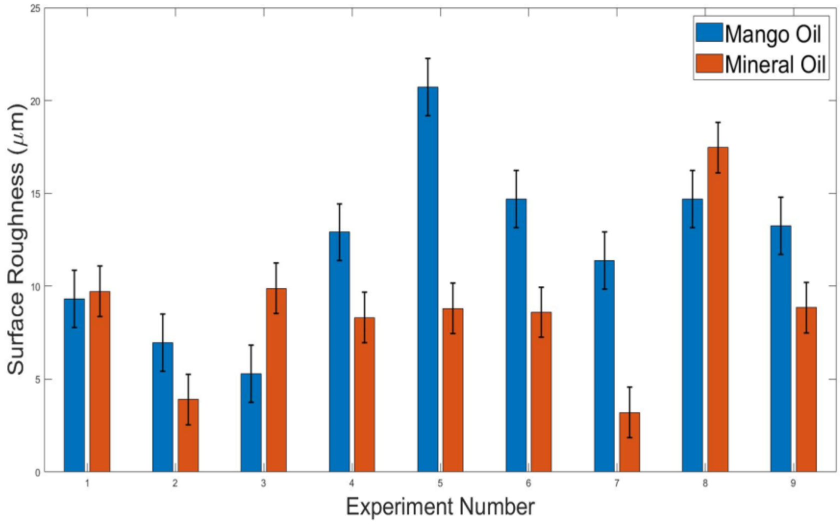


Fig. 2. The Impact of Cutting Variables on the SR of AISI 1525 Steel.

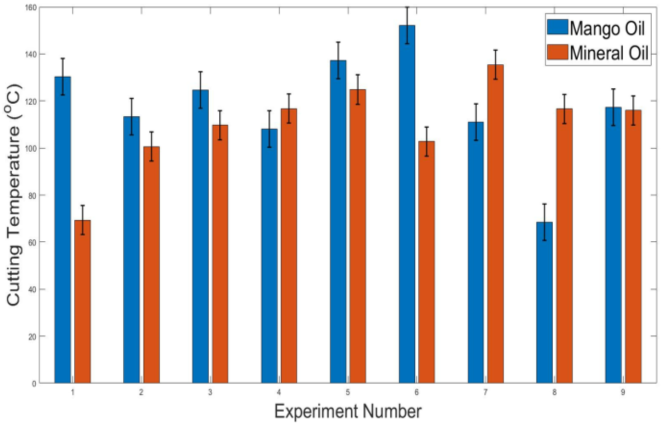
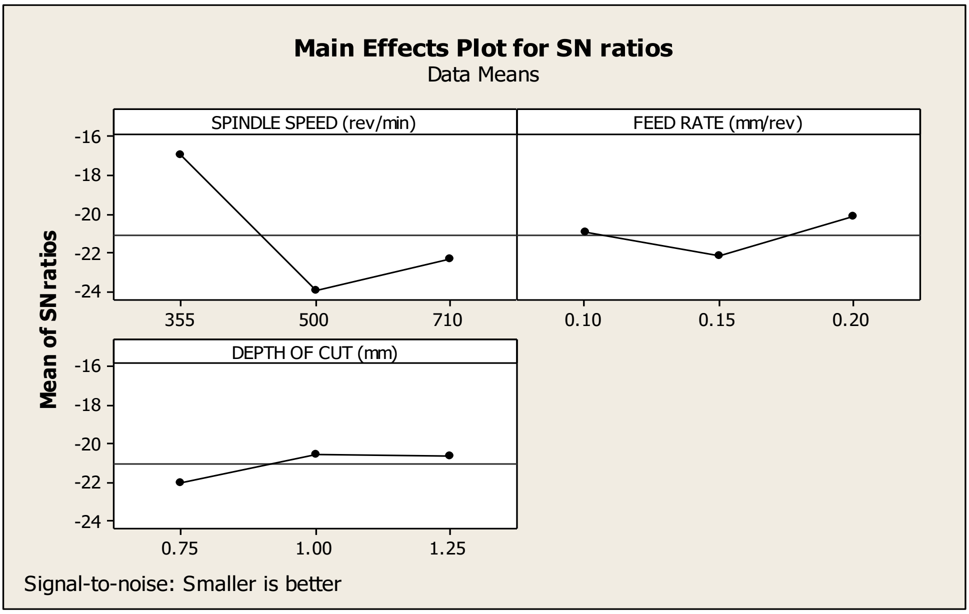


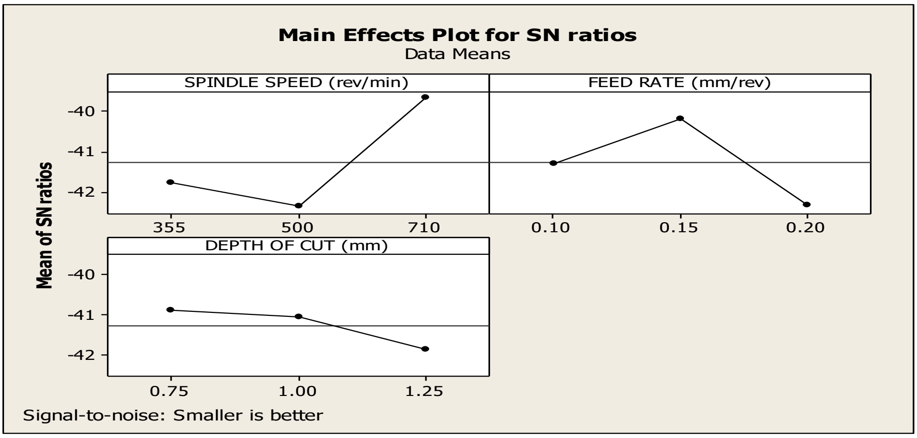
Fig. 3. The Impact of Cutting Variables on the CT of AISI 1525 Steel

3.3 Main Effect Plots and Analysis of Variance of Response Variables

The values of the SR and CT S/N ratios for the two lubricants are shown in Table 2. For process optimization, the better characteristic was chosen when the S/N (dB) ratio was smaller. The main effect plot of the S/N ratio for both CT and SR is shown in Fig. 4 (a-d). The appropriate cutting parameters for SR are shown in Fig. 4(a) for mango oil. These are 0.20 mm/rev FR (level 3), 355 rev/min SS (level 1), and 1.00 mm DOC (level 2). The optimal CT cutting parameters are 0.15 mm/rev FR (level 2), 710 rev/min SS (level 3), and 0.75 mm DOC (level 1). These are shown in Fig. 4(b). The ANOVA findings for the SR of mango oil are shown in Table 3. The following input parameters are involved: SS (72.39%), FR (10.42%), and DOC (3.33%). It illustrates how SS (72.39%) and FR (10.42%) significantly affect the SR during the turning process. Cut depth has less of an effect on SR. In a similar vein, Table 3 shows the CT (mango oil) ANOVA. Each input parameter's contribution is given as follows: FR (21.69%), DOC (4.60%), and SS (64.07%). It reveals that during the turning process, the CT is greatly influenced by FR (21.69%) and SS (64.07%). There is less of a bond between DOC and CT. The S/N ratio main effect plots for the mineral oil CT and SR are shown in Figs 4(c) and (d), respectively. For mineral oil, the ideal cutting parameters are 355 rev/min SS (level 1), 0.10 mm/rev FR (level 1), and 1.25 mm DOC (level 3). For CT, the optimal cutting parameters are 355 rev/min SS (level 1), 0.10 mm/rev FR (level 1), and 0.75 mm DOC (level 1). The ANOVA of SR for mineral oil in Table 4 shows the relative contributions of each input parameter, which are DOC (75.0%), SS (4.64%), and FR (10.45%). The data indicates that throughout the turning process, FRs (10.45%) and DOC (75.0%) significantly affect SR. SS barely affects SR at all. Moreover, Table 4 shows the contributions of each input parameter to the ANOVA of CT for mineral oil: SS (50.12%), FR (2.61%), and DOC (39.62%). The data shows that both FR (39.62%) and SS (50.12%) have a considerable impact on the CT during the turning process. The relationship between FR and CT is less pronounced. The required degree of confidence for these analyses is 95%.



(a)



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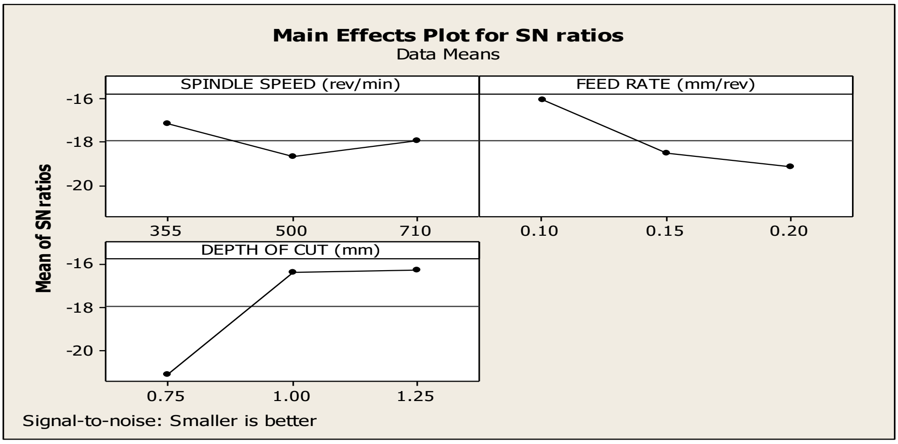

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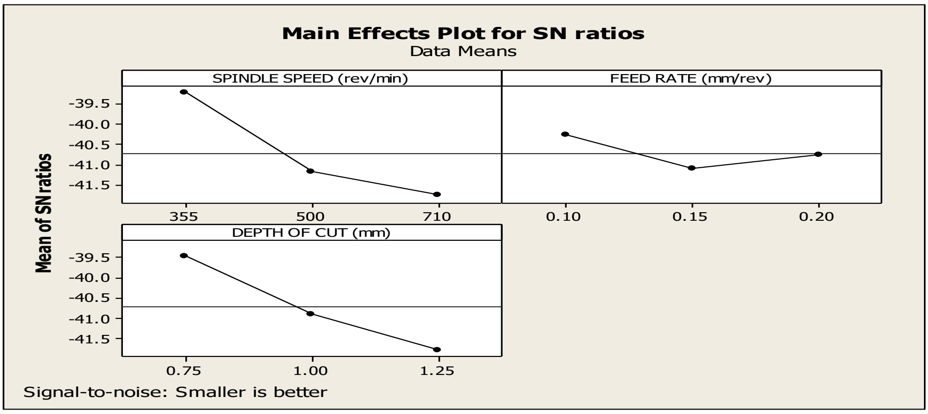


(d)

Fig. 4: Main Effect Plot of S/N Ratio (a) For Mango Oil (SR) (b) For Mango Oil (CT) (c) Mineral Oil (SR) (d) For Mineral Oil (CT)

Table 3: ANOVA for SR and CT (Mango Oil)

Process Parameter	**Factor**	**DOF**	**SOS**	**MS**	**F**	**P%**
SR (µm)	SS (rev/min)	2	123.45	61.725	5.220226	72.38584
	FR (mm/rev)	2	17.77	8.885	0.751425	10.41957
	DOC (mm)	2	5.676	2.838	0.240016	3.328166
	Error	2	23.6484	11.8242		13.86642
	Total	8	170.5444	21.31805		100
CT (℃)	SS (rev/min)	2	2787	1393.5	6.645699	64.06795
	FR (mm/rev)	2	943.4	471.7	2.24957	21.68701
	DOC (mm)	2	200.3	100.15	0.477622	4.604525
	Error	2	419.369	209.6845		9.640514
	Total	8	4350.069	543.7586		100

Table 4. ANOVA for SR and CT (Mineral Oil)

Process Parameter	**Factor**	**DOF**	**SOS**	**MS**	**F**	**P%**
SR (µm)	SS (rev/min)	2	6.16	3.08	0.46795	4.637723
	FR (mm/rev)	2	13.88	6.94	1.054407	10.44993
	DOC (mm)	2	99.62	49.81	7.567724	75.00162
	Error	2	13.1638	6.5819		9.910724
	Total	8	132.8238	16.60298		100
CT (℃)	SS (rev/min)	2	1394	697	6.558704	50.12438
	FR (mm/rev)	2	72.54	36.27	0.341297	2.608337
	DOC (mm)	2	1102	551	5.184858	39.62487
	Error	2	212.542	106.271		7.642421
	Total	8	2781.082	347.6353		100

3.4 Evaluation of Contour Plots for Response Variables vs. Pairwise Factors (Mango Oil)

SS and FR are the main factors influencing the SR of mango oil, as Fig. 5(a) shows. The results showed that although SR increases in tandem with SS and FR, SS and FR seem to have the greatest impact on SR at the halfway points of the plot, after which SR's return on investment decreases as SS and FR decrease. The SR peak was found to measure more than 18 µm. The horizontal area at the peak region of the plot covers the interaction between 0.1198 mm/rev FR and 558.29 rev/min SS, as well as 0.1899 mm/rev FR and 558.29 rev/min SS, while the vertical area covers the interaction between 0.1548 mm/rev FR and 454.57 rev/min SS, and 0.1548 mm/rev FR and 663.85 rev/min. Fig. 5(b) depicts how FR and SS affect the CT of mango oil. It was discovered that as the FR (mm/rev) increased, the CT rose but the SS decreased. A thorough examination found that the CT peaked at temperatures greater than 140°C. Within the plot, the horizontal area at the peak region covers the interaction between 0.155 mm/rev FR and 477.51 rev/min SS and 0.1989 mm/rev FR and 477.51 rev/min SS; the vertical area covers the interaction between 0.197 mm/rev FR and 414.18 rev/min SS and 0.197 rev/min FR and 604.19 rev/min SS.

3.5 Evaluation of Contour Plots for Response Variables vs. Pairwise Factors (Mineral Oil)

The graphic depiction presented in Fig. 5(c) demonstrates how mineral oil SR is entirely dependent on FR and DOC during the fluid formulation process. It was discovered that SR rises when FR rises with a decreasing DOC. Further analysis showed that the SR peak had a measurement of more than 15 µm. When the figure reaches its maximum in the middle, an interaction between the DOC of 0.7594 mm and the FR of 0.1475 mm/rev is covered. Fig. 5(d) provides a graphic representation of how SS and DOC impact mineral oil CT during the formulated oil-turning process. It was discovered that the CT and SS both climb as the DOC does. According to additional measurements, the CT peaked at a temperature of more than 130°C. The region at the top of the plot covers the interaction between 1.21 mm of cut depth and 659.26 rev/min SS and 1.25 mm of cut depth and 659.26 rev/min SS; the vertical area covers the interaction between 1.24 mm of cut depth and 597.76 rev/min SS and 1.23 mm of cut depth and 706.99 rev/min SS.

3.6 Regression Evaluation and Analysis

Finding the relationships between a dependent variable and one or more independent variables is accomplished using a set of statistical methods called regression analysis [23]. FR, DC, and SS are the independent variables, and CT and SR are the factors of dependence. Regression analysis is used to make predictions about CT and SR. Eqs. 10 through 13 display the regression models.

For Mango Oil Lubricant

$$SR(\mu m) = 6.12 + 0.0201(SS) - 1.293(FR) - 0.94(DOC) \tag{10}$$

$$R^2 = 75.0\%;\ R^2(adj) = 66.4\%;\ R^2(pred) = 42.04\%$$

When SS = 355 rev/min, FR = 0.20 mm/rev, DOC = 1.00 mm
Ra = 12.06 µm

$$CT(^{\circ}C) = 118.59 - 0.07838(SS) + 150.03(FR) + 15.28(DOC) \tag{11}$$

$$R^2 = 70.78\%;\ R^2(adj) = 63.12\%;\ R^2(pred) = 48.19\%$$

When SS = 710 rev/min, FR = 0.15 mm/rev, DOC = 0.75 mm
CT (°C) = 96.9 °C

For Mineral Oil Lubricant

$$SR(\mu m) = 11.73 + 0.01033(SS) + 19.89(FR) - 10.21(DOC) \tag{12}$$

$$R^2 = 78.0\%;\ R^2(adj) = 69.34\%;\ \mathrm{R}^2(pred) = 48.11\%$$

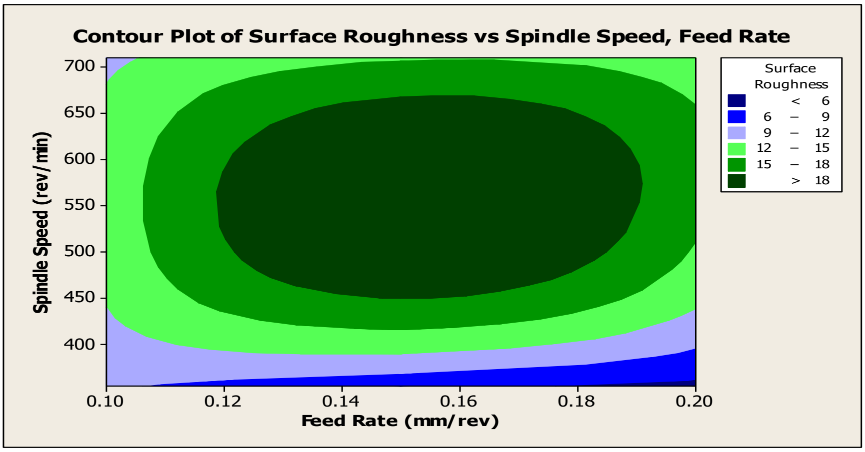
When SS = 355 rev/min, FR = 0.10 mm/rev, DOC = 1.25 mm
Ra = 4.62 µm

$$CT\left(°C\right) = 11.1 + 0.0797\left(SS\right) + 23.0\left(FR\right) + 54.1\left(DOC\right) \tag{13}$$

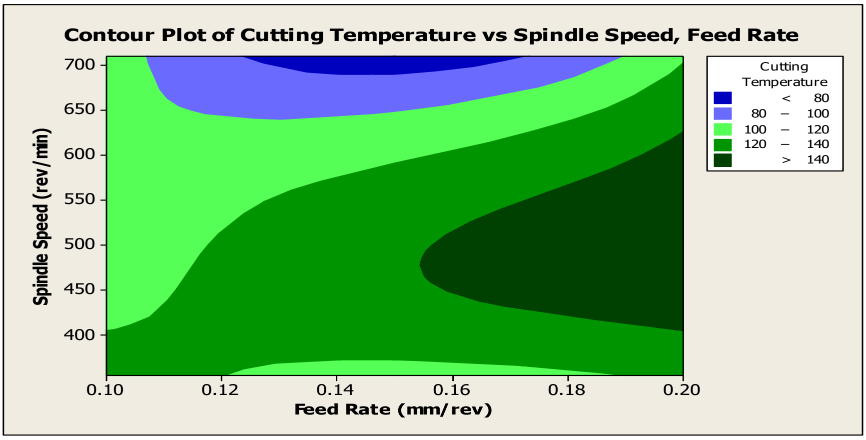
$$R^2 = 83.41\%;\ \ R^2\left(adj\right) = \ 73.45\%;\ \ R^2\left(pred\right) = 33.12\%$$

When SS = 355 rev/min, FR = 0.10 mm/rev, DOC = 0.75 mm
CT (°C) = 82.27°C

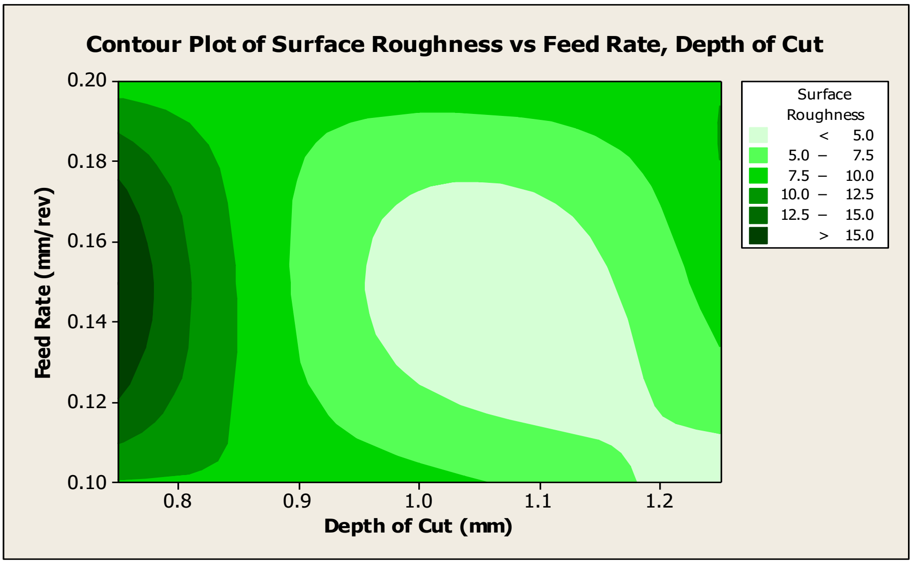
The first model, which used SR as the only predictor, produced an R-squared value of 75.0%, which explained a significant amount of the variation in overall accuracy. However, the adjusted and predicted R-squared values were lower, indicating potential applicability restrictions. Only CT was included as a predictor in the second model, which was predictive and had a high correlation (70.78%) with R-square. With an R-squared value of 78%, the third model had a significant explanatory influence when linked. With an extraordinarily strong R-squared of 83.41%, the fourth model explains a sizable amount of overall performance. The R-squared in multiple linear regression analysis should be in the range of 70% to 100% [24]. The re is a correlation between the experiment's results and the predictions. The obtained R-squared values are within an acceptable range.



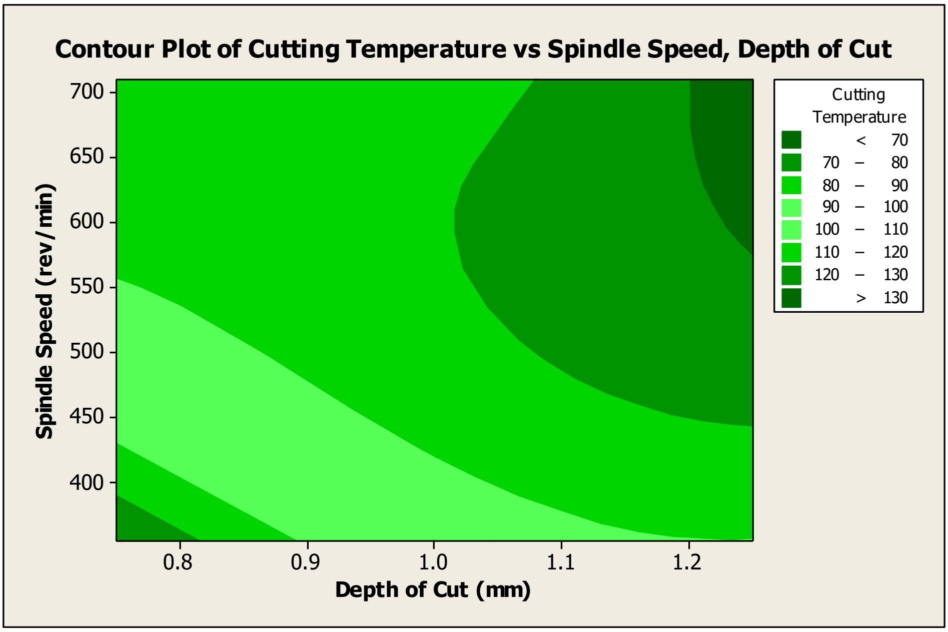
(a)



(b)



(c)



(d)

Fig. 5. Contour Plots of Some Selected Relationships (a) SR vs SS and FR for Mango Oil (b) CT vs SS and FR for Mango Oil (c) SR vs FR and DOC for Mineral Oil (d) Cutting Speed vs SS and DOC for Mineral Oil.

3.7 Computation of Multiple Response Parametric Optimizations Using TOPSIS

Tables 5-8 present the results of many studies conducted using the TOPSIS technique, as well as the rank order and preference value for mineral and mango oils, respectively. Equations

(2) need the values of the input parameters to be substituted, and the resulting preference values (Qj) with the ranking system, rk (A), are then derived into additional equations (Eqs 3-9). The Qj for each choice can be determined by taking into account and displaying the proximity to the best alternative. When machined under ideal conditions, all of the output reactions are weighed equally concerning the performance criteria. SR and CT, the two research variables, were each given a weight of 0.5. The degree to which the perfect solution is closest to the optimal performance measure establishes the performance measure's proper value [25]. In terms of preferred value and rank, this distance is the highest. It's obvious that experiment run 2 is the best arrangement; runs 3 and 1 come next. Mango oil preference order is highest in this setup, which offers the best numerous performance benefits. Experiment 2 for mineral oil is also the most successful of the nine trials that were carried out. Examining the higher values of the desired order can help find the best parametric mixture. The best parameters were found to be FR (0.15 mm/rev), SS (355 rev/min), and DOC (1.00 mm) for both mineral oil and mango oil.

Table 5: Decision Matrix, Weighted and Normalized (Mango Oil)

$Exp-No.$	**Decision Matrix Normalized**			**Decision Matrix with Weighted Normalization**	
	$CT\left({}^{\circ}C\right)$	$SR\left(\mu m\right)$		$CT\left({}^{\circ}C\right)$	$SR\left(\mu m\right)$
1	0.36187	0.24098		0.180933	0.120492
2	0.31469	0.17996		0.157345	0.089981
3	0.34577	0.13678		0.172886	0.068391
4	0.29998	0.33381		0.149991	0.166904
5	0.38101	0.53549		0.190507	0.267745
6	0.42209	0.37983		0.211043	0.189917
7	0.30831	0.29451		0.154154	0.147253
8	0.19009	0.37983		0.095045	0.189917
9	0.32551	0.34260		0.162757	0.1713
			B^{+}	0.095045	0.068391
			B^{-}	0.211043	0.267745

Table 6: Effectiveness Measure of Various Machining Setups Employing TOPSIS (Mango Oil)

$Exp-No.$	P_j^{+}	P_j^{-}	Q_j	$rk\left(A\right)$
1	0.10046	0.15030	0.599389	3
2	0.06593	0.18570	0.737971	1
3	0.07784	0.20297	0.722804	2
4	0.11280	0.11788	0.511013	6
5	0.22103	0.02054	0.085009	9
6	0.16800	0.07783	0.316597	8
7	0.09856	0.13325	0.574829	4
8	0.12153	0.13969	0.534764	5
9	0.12319	0.10786	0.466824	7

Table 7: Decision Matrix, Weighted and Normalized (Mineral Oil)

$Exp-No.$	**Decision Matrix Normalized**			**Decision Matrix with Weighted Normalization**	
	$CT(^{\circ}C)$	$SR(\mu m)$		$CT(^{\circ}C)$	$SR(\mu m)$
1	0.20722	0.33905		0.10361	0.169524
2	0.30038	0.13604		0.150189	0.068019
3	0.32755	0.34498		0.163775	0.172489
4	0.34875	0.29021		0.174374	0.145107
5	0.37293	0.30696		0.186467	0.153478
6	0.30695	0.29998		0.153473	0.14999
7	0.40429	0.11162		0.202143	0.05581
8	0.34815	0.60938		0.174076	0.304689
9	0.34636	0.30870		0.17318	0.15435
			B^{+}	0.10361	0.05581
			B^{-}	0.202143	0.304689

Table 8: Effectiveness Measure of Various Machining Setups Employing TOPSIS (Mineral Oil)

$Exp-No.$	P_j^{+}	P_j^{-}	Q_j	$rk(A)$
1	0.11371	0.16727	0.595299	4
2	0.04815	0.24231	0.834218	1
3	0.13128	0.13766	0.511859	8
4	0.11394	0.16198	0.587062	5
5	0.12808	0.15202	0.542737	7
6	0.10657	0.16217	0.603462	3
7	0.09853	0.24888	0.716379	2
8	0.25866	0.02807	0.097887	9
9	0.12062	0.15310	0.559327	6

4 Conclusion

The study examined the use of mango seed oil as a lubricant in AISI 1525 steel turning under the MQL approach. Taguchi L9 was adopted to carry out the experimentation.

- The performance of mineral oil lubricant surpassed that of mango oil in many machining trials.
- In terms of SR, mineral oil reduced the SR of AISI 1525 steel by 10% over the mango seed oil.
- The mineral oil reduced the CT at the tool/ workpiece interface by 15% over the mango seed oil.
- The analysis of variance showed that SS is the most significant parameter for SR and CT of mango oil while for the mineral oil, DOC and SS were the most important parameters for SR and CT, respectively.
- The optimum CT and SR can be achieved using an SS of 355 rev/min, FR of 0.15 mm/rev, and DOC of 1.00 mm for both mango and mineral oil lubricants.

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