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DEVELOPMENT AND PERFORMANCE EVALUATION OF A MODEL CUTTING FLUID DEVELOPED FROM SHEA BUTTER OIL

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Abstract

This research was carried out to develop a model cutting fluid from Shea Butter oil and evaluate its performance in relation to temperature and surface roughness when compared to a commercial cutting fluid. The effectiveness of the cutting fluid was evaluated on a mild steel using a turning operation on the lathe machine. Temperature variations during the turning operation were measured using an infra-red gun thermometer while surface roughness was evaluated by employing a surface roughness tester. In this work Taguchi method was used to guide the selection of machine parameters such as cutting speed (rev/min), feed rate (mm/rev), and depth of cut (mm). Using Minitab, the cutting temperature and resulting surface roughness were measured for both the developed cutting and commercial fluids. The results obtained for the average cutting temperature of ~ 30^oC and overall surface roughness value of 0.32µm for shea butter oil show a significant difference from that of ~ 35^oC and 0.47 µm respectively for commercial grade cutting fluids. These results show that the shea butter oil-based cutting fluid not only exhibits great potential but also surpasses the current capabilities of commercial cutting fluids in terms of its cooling and surface finishing performances.

Keywords: *Cutting fluid, shea butter, oil, surface roughness.*

1.0 Introduction

Cutting fluid, also known as lubricant or coolant, is a substance that reduces friction and heat generation between surfaces in mutual contact during machining processes. It has cooling and lubricating effects that improve the quality and durability of the workpiece and the cutting tool as well as having the ability to wash away chips from the cutting zones. However, cutting fluid can also harm the environment and workers' health if not disposed of properly [1]. The cooling effect of the fluids is essential to mitigate the effects of rising temperature on the cutting tool and the workpiece being machined, while the lubricating effect reduces the friction coefficient between the workpiece and the cutting tool.

Cutting fluids have significant roles during machining processes, hence the correct selection and application of cutting fluids are crucial, which usually results in improved process performance, enhanced workpiece quality, and extended tool life. Cutting fluids have three positive effects on the machining operations which are heat removal, lubrication of the chip–tool interface, and chip removal [1]. However, the benefits of cutting fluids have been challenged recently, due to the several adverse effects they cause the environment and worker's health. When improperly disposed of, cutting fluids may contaminate soil and water resources, causing severe environmental impact. Moreover, on the shop floor, machine operators may be exposed to negative effects of cutting fluids, such as skin and respiratory diseases [1].

With the increasing concerns and awareness over health, contamination, and environmental hazards, while in use or disposed after use coupled with the diminishing world oil reserves, it has become paramount to develop an alternative cutting fluid from green plants that could be eco - friendly. Using vegetable oils will enable the development of a new generation of cutting fluids that could be both eco-friendly and of higher performance.

Furthermore, it is the belief of the authors of this work that the use of vegetable oil-based lubricants is also expected to decrease petroleum consumption, increase the use of renewable resources, better manage the carbon sequestration, and contribute to reducing negative environmental and health impacts. In addition, compared with commercial or mineral oil, vegetable oil should improve the cutting performance, prolong tool life, and enhance surface finishing according to industrial studies [2].

This research work is aimed at developing a model cutting fluid from shea butter oil, and evaluating the performance of the developed fluid by comparing it with the commercial mineral oil cutting fluid. The lubricant to be developed from shea butter oil is proposed to serve as a locally sourced alternative cutting fluid.

2.0 Materials and Methods

2.1 Materials

2.1.1 Additives

They are substances that add special qualities to cutting fluids, i.e. they increase the performance of the fluid, as well as that of the machined products. The recommended range of additives in any cutting fluid may be between 25 to 30% [2, 3]. They are emulsifiers, corrosion inhibitors, biocide, friction modifiers, antioxidants, and extreme pressure modifiers (EP).

2.1.2 Workpiece

Mild steel was chosen as the workpiece because it is used for a variety of engineering systems/devices which require machining processes often than other forms of steels. A Ø25mm mild steel was machined to Ø16mm as shown in Fig 1 during the machining operation.

Fig. 1 Workpiece

2.1.3 Lathe Machine

A 4-jaw lathe machinelocated at the central workshop of the Department of Mechanical Engineering, Kaduna Polytechnic, Kaduna, was used for the machining operation used to validate the effectiveness of the developed cutting fluid.

2.1.4 Cutting Tools and Holder

The cutting tool was a TNMG 1604 tungsten carbide insert (indexable) by Canela Tools, S.A. (Société Anoyme). It was a right-hand cutting tool.

2.1.5 Test Equipment

The equipment used to carry out tests on the samples includes digital Separate Surface Roughness Tester (Model SRT-621 0S) with ±10% accuracy and not more than 6% fluctuation display value; hand-held Digital Thermometer, (Model TP3001) with a temperature range of -50 to 300 °C having a resolution of 0.1 °C having a response time of less than 1 min; Casio Stop Watch (Model G-Shock), and pH Meter (Model pHS – 25).

2.2 Methodology

The cutting fluid was formulated by mixing the base oil which consists of 66.77% shea butter oil, 11.11% additives, 22.22% antioxidant and water. The formulated cutting fluid was then characterized to determine its properties. The schematic diagram of the experimental methods is presented in Fig. 2.

The Experimental design adopted in this research work is the Taguchi method [4]. The full factorial method has proved successful in performing cutting force trend analysis and material removal rate in metal cutting involving turning and milling processes.

In designing the experiment for this work, the main machine parameters of concern were cutting speed, feed rate, and depth of cut which are of paramount importance and are therefore part of the input factors. Furthermore, the cutting fluids being investigated may have some influence on the cutting temperature, the work piece, and surface roughness which are considered part of the output factors.

Table 2: Cutting Parameters and Levels

Factor	**Unit**	**Level I Low (-)**	**Level 2 Medium (0)**	**Level 3 High (+)**
Cutting speed (A)	rev/min	-	0	+
Feed rate (B)	mm/rev	-	0	+
Depth of cut (C)	Mm	-	0	+

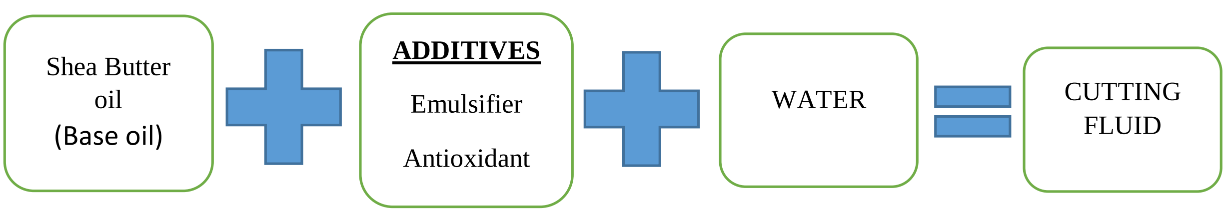

Fig. 2: Formulation of shea butter Oil Cutting Fluids

Table 2: Experimentation Layout using an L_{8i} Orthogonal Array (Minitab)

Std Order	Run Order	Pt Type	Blocks	Speed	Feed Rate	Depth of Cut
8	1	1	1	159	0.9	1.2
20	2	0	1	126	0.7	1
17	3	0	1	126	0.7	1
19	4	0	1	126	0.7	1
11	5	-1	1	126	0.36364	1
9	6	-1	1	70.501	0.7	1
7	7	1	1	93	0.9	1.2
16	8	0	1	126	0.7	1
14	9	-1	1	126	0.7	1.33636
12	10	-1	1	126	1.03636	1
1	11	1	1	93	0.5	0.8
15	12	0	1	126	0.7	1
5	13	1	1	93	0.5	1.2
13	14	-1	1	126	0.7	0.66364
4	15	1	1	159	0.9	0.8
3	16	1	1	93	0.9	0.8
18	17	0	1	126	0.7	1
6	18	1	1	159	0.5	1.2
2	19	1	1	159	0.5	0.8
10	20	-1	1	181.499	0.7	1

Table 3. Experimental process parameters and response for shea butter cutting fluid.

Run order	Speed (rev/min)	Feed rate (mm/rev)	Depth of cut (mm)	Temperature (^{O}C)	Surface roughness (um)	S/N Ratio for temp (db)	S/N Ratio for S (db)
1.	159.00	0.90	1.20	33.40	0.30	-30.47	10.37
2.	126.00	0.70	1.00	29.40	0.33	-29.37	9.76
3.	126.00	0.70	1.00	29.60	0.33	-29.43	9.58
4.	126.00	0.70	1.00	29.30	0.32	-29.34	9.82
5.	126.00	0.36	1.00	28.30	0.33	-29.04	9.66
6.	70.50	0.70	1.00	29.50	0.34	-29.40	9.50
7.	93.00	0.90	1.20	28.35	0.33	-29.05	9.68
8.	126.00	0.70	1.00	29.05	0.32	-29.26	9.98
9.	126.00	0.70	1.34	29.90	0.32	-29.51	9.90
10.	126.00	1.04	1.00	29.00	0.32	-29.25	9.90
11.	93.00	0.50	0.80	27.00	0.33	-28.63	9.63
12.	126.00	0.70	1.00	29.30	0.32	-29.34	9.82
13.	93.00	0.50	1.20	28.20	0.33	-29.00	9.66
14.	126.00	0.70	0.66	29.40	0.33	-29.37	9.76
15.	159.00	0.90	0.80	32.20	0.31	-30.16	10.29
16.	93.00	0.90	0.80	27.40	0.31	-28.76	10.17
17.	126.00	0.70	1.00	29.30	0.32	-29.34	9.82
18.	159.00	0.50	1.20	32.90	0.31	-30.34	10.29
19.	159.00	0.50	0.80	31.30	0.31	-29.91	10.14
20.	181.50	0.70	1.00	32.50	0.30	-30.24	10.34

3.0 Results and Discussion

3.1 Developed shea butter oil cutting fluid results

Table 3.1 presents the experimental result based on the design of experiment using the formulated shea butter oil.

From Table 3.1, it can be observed that the value of the responses (temperature and surface roughness) changes sign with variation in the experimental factors. From the data, the maximum, minimum, and average temperatures recorded were ~ 33^{o}C, 27^{o}C, and 30 ^{o}C respectively, while the maximum, minimum, and average surface roughness recorded were 0.34μm, 0.30μm,, and 0.32μm respectively.

3.2 Main effect plot

Main effect plots are graphical tools used to determine the relative impact of a variety of inputs on the output of interest. Mean effect plots for the SN (smaller is better) for Temperature and Surface roughness from Shea butter oil-based cutting fluid are shown in Figs. 3.1 and 3.2 respectively.

Fig. 3.1 shows that the optimum cutting temperature can be achieved using a cutting speed of 93 rev/min, feed rate of 0.36 min/rev, and 0.66 – 1 mm depth of cut for shea butter oil cutting fluid. Therefore, any alteration in the optimal process parameter will affect the value of the cutting temperature of the mild steel.

Fig. 4 shows that the best surface finish while machining the mild steel was obtained from a cutting speed of 181.5 rev/min, feed rate of 0.9 min/rev, and a depth of cut of 0.8 mm for shea butter oil-based cutting fluid.

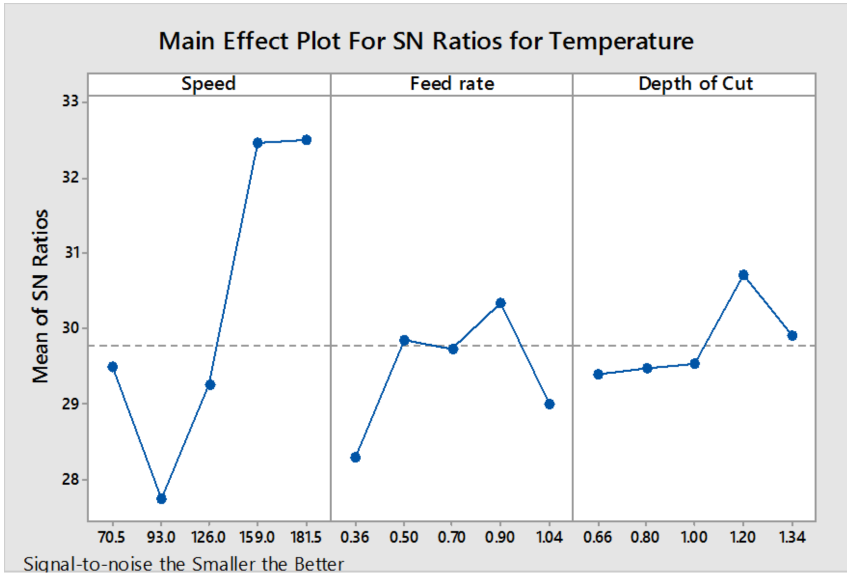

Fig. 3.: Main effects plot S/N ratio for temperature -shea butter cutting fluid

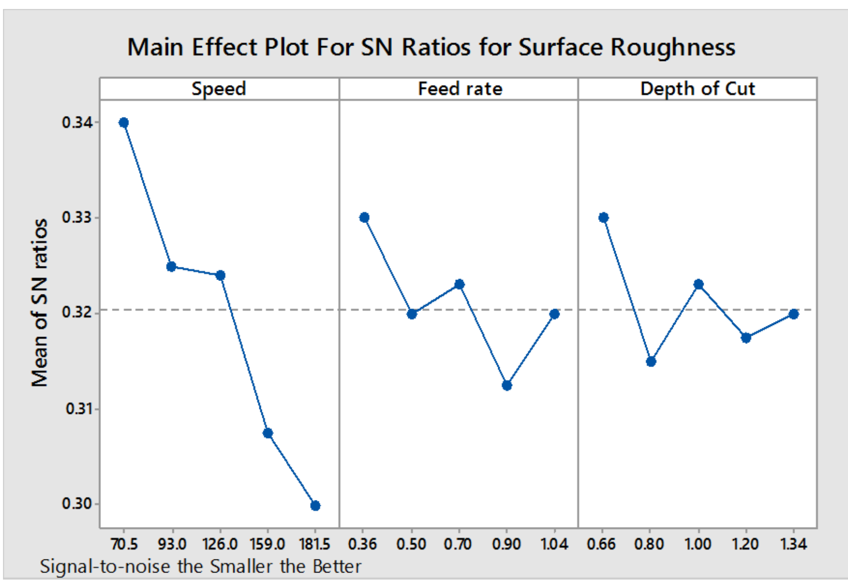

Figure 4 Main effects plot S/N ratio for surface roughness-shea butter cutting fluid.

3.3 Interaction Plots for Shear Butter Cutting Fluid

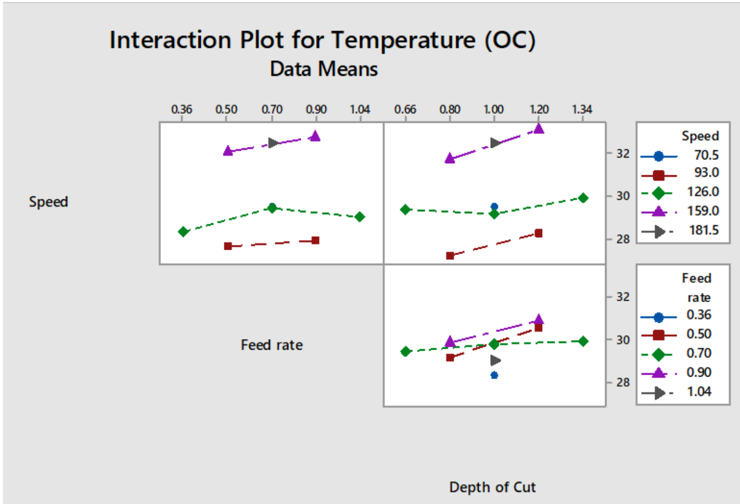

Fig. 5: Interaction plot for temperature.

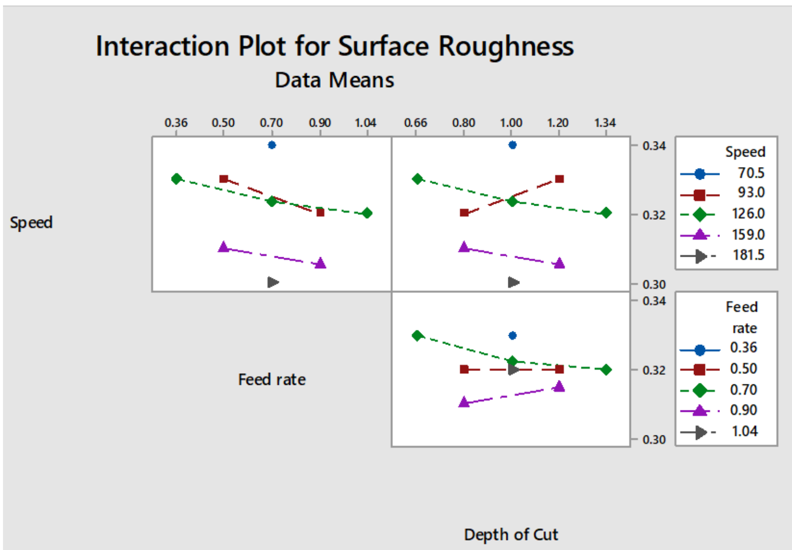

Fig. 6: Interaction plot for surface roughness.

The interaction plots show how cutting speed, feed rate and depth of cut are related to and affect the machining temperature (Fig. 5 and surface roughness (Fig. 6) of the mild steel respectively. In interaction plots, parallel lines mean no interaction or no effects, while slope lines suggest otherwise. The interaction plot for temperature is shown in Figure 5 and this shows that there is no interaction between cutting speeds, feed rates and depth of cuts. However, there is an interaction of feed rate at 0.5 mm/rev and 0.7 mm/rev at a depth of cut of 1 mm. Furthermore, the interaction plots for surface roughness are presented in Figure 6. There is an interaction of cutting speeds of 93 rev/min with 126 rev/min at a feed rate of 0.8 mm/rev. Also cutting speeds 93 rev/min and 126 rev/min has an interaction at a depth of cut of 0.95 mm.

Table 4: Experimental process parameters and response for commercial cutting fluid

Run order	Speed (rev/min)	Feed rate (mm/rev)	Depth of Cut (mm)	Temperature (^{O}C)	Surface Roughness (um)	S/N Ratio for Temp (db)	S/N Ratio for S (db)
1.	159.00	0.90	1.20	38.40	0.46	-31.69	6.69
2.	126.00	0.70	1.00	34.40	0.49	-30.73	6.29
3.	126.00	0.70	1.00	34.60	0.49	-30.78	6.16
4.	126.00	0.70	1.00	34.30	0.48	-30.71	6.32
5.	126.00	0.36	1.00	33.30	0.49	-30.45	6.21
6.	70.50	0.70	1.00	34.50	0.50	-30.76	6.11
7.	93.00	0.90	1.20	34.10	0.46	-30.66	6.74
8.	126.00	0.70	1.00	35.00	0.48	-30.88	6.43
9.	126.00	0.70	1.34	34.90	0.48	-30.86	6.38
10.	126.00	1.04	1.00	34.00	0.48	-30.63	6.38
11.	93.00	0.50	0.80	32.60	0.49	-30.26	6.20
12.	126.00	0.70	1.00	34.30	0.48	-30.71	6.32
13.	93.00	0.50	1.20	33.20	0.49	-30.42	6.21
14.	126.00	0.70	0.66	34.40	0.49	-30.73	6.29
15.	159.00	0.90	0.80	37.20	0.44	-31.41	7.13
16.	93.00	0.90	0.80	31.60	0.47	-29.99	6.56
17.	126.00	0.70	1.00	34.30	0.48	-30.71	6.32
18.	159.00	0.50	1.20	37.90	0.47	-31.57	6.63
19.	159.00	0.50	0.80	36.30	0.43	-31.20	7.33
20.	181.50	0.70	1.00	35.90	0.41	-31.10	7.74

3.4 Commercial cutting fluid experimental results

The experimental result based on the design of experiment using commercial cutting fluid is presented in Table 4.

3.5 Mean effect plots for commercial cutting Fluid

The mean effect plot of the commercial cutting fluid was plotted for signal-to-noise ratio against machining speed, feed rate, and depth of cut. Figures 7 and 8, present the mean effect plot of the machining temperature and surface roughness of the mild steel respectively against machining speed, feed rate, and depth of cut.

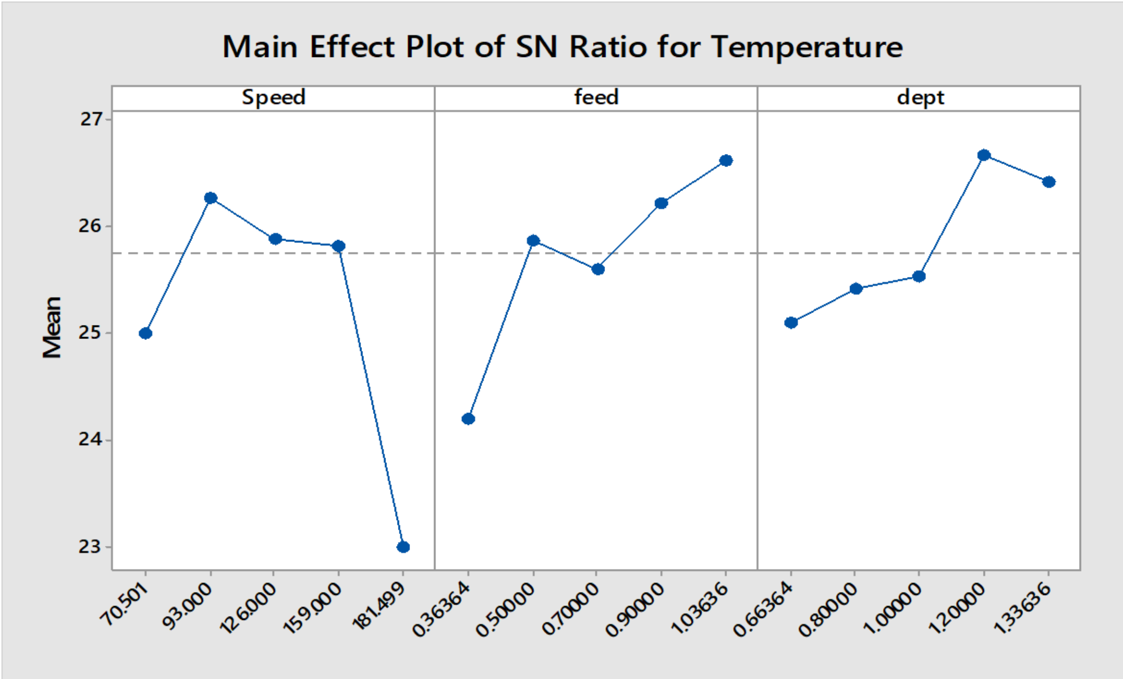

Fig. 7: Main effects plot S/N ratio for temperature (Commercial cutting fluid)

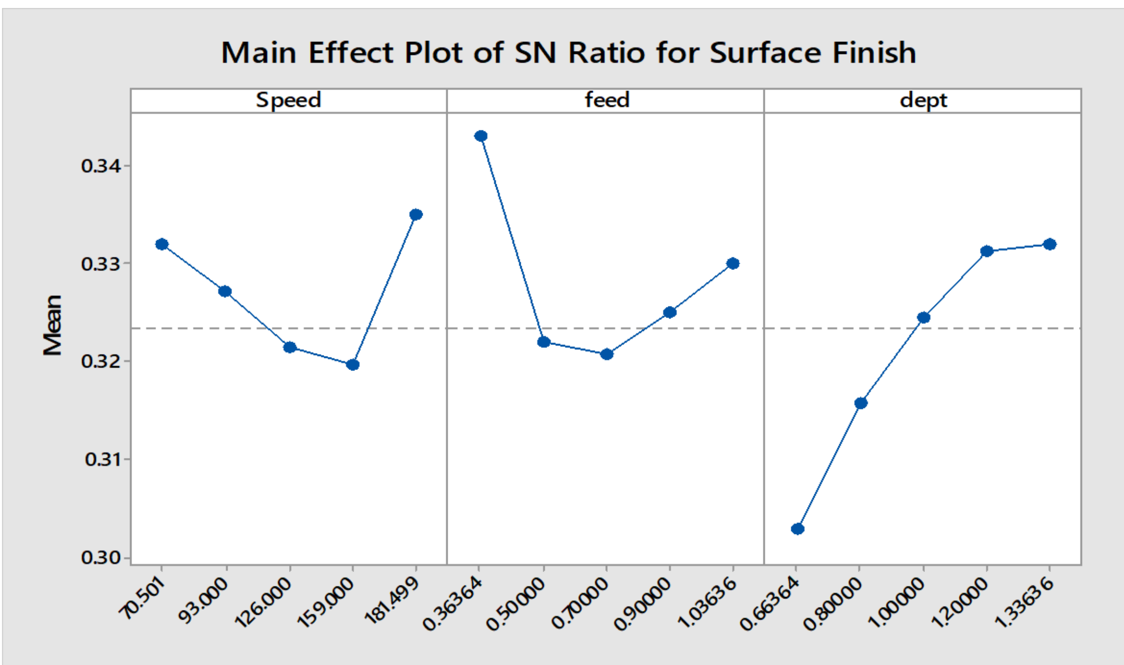

Fig. 8: Main effects plot S/N ratio for surface finish (Commercial cutting fluid)

Fig. 7 shows that the optimum cutting temperature was achieved using a cutting speed of 181.4 rev/min, feed rate of 0.3636 mm/rev, and depth of cut of 0.6636 mm for the commercial cutting fluid. Therefore, any alteration in the optimal process parameter will affect the value of the cutting temperature of the mild steel. Fig. 8 indicates that the best surface finish while machining the mild steel was obtained from a cutting speed of 159 rev/min, feed rate of 0.7 mm/rev, and depth of cut of 0.66 mm for commercial cutting fluid.

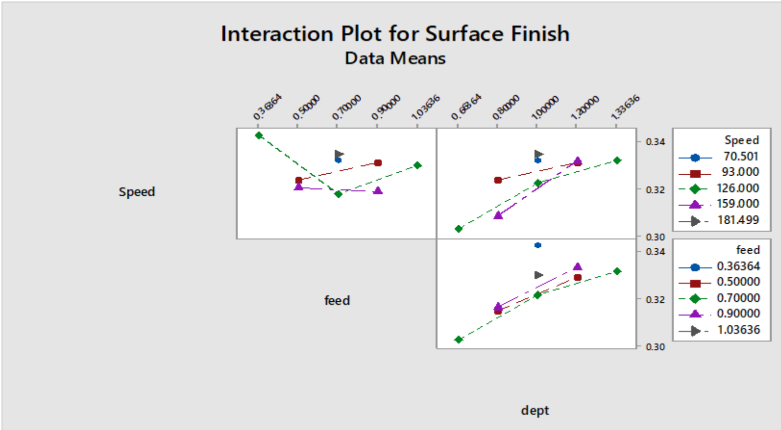

Fig. 9: Interaction plot for surface finish (Commercial cutting fluid)

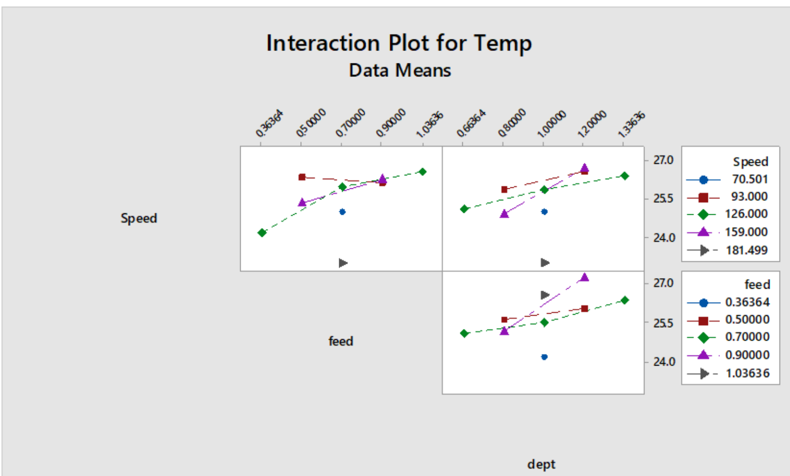

Fig. 10: Interaction plot for temperature (Commercial cutting fluid)

3.6 Interaction plots for commercial cutting fluids

The interaction plots of the commercial cutting fluid used for the experimentation are shown in Figs. 9 and 10.

In the graphs presented in Figs. 9 and 10, the lines are non-parallel, and this suggests there is an interaction. The graph in Fig. 9 shows that the speed of 126 rev/min, feed rate of 0.7 mm/rev, and depth of cut of 0.66364 mm are associated with better surface finish when machining mild steel. Also, Fig.10 reveals that when machining mild steel, the temperature is lower with a machining speed of 126 rev/min, feed rate of 0.36364 mm/rev and a depth of cut of 0.66364mm.

3.7 Comparison of shea butter and commercial cutting fluids.

The surface roughness obtained from machining mild steel and the machining temperature were compared and the results are shown in Figs 11 and 12. From these graphs, the shea butter cutting fluid produced a slightly better surface finish than the commercial cutting fluid and also, the machining temperature was lower by 5°C as compared with that of the commercial cutting fluid.

The machining temperatures of the shear butter and commercial cutting oils were compared and it was observed that the developed oil produced a better surface finish of the mild steel at lower temperatures than the commercial cutting oil.

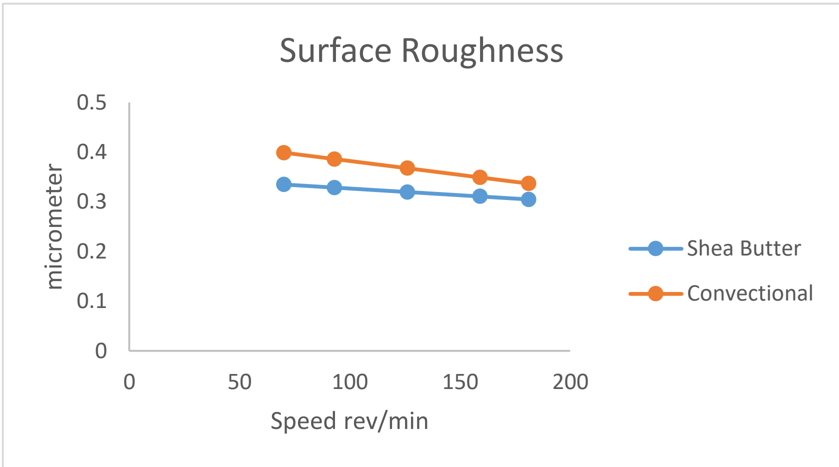

Fig. 11: Comparison of the surface Roughness of mild steel using Shea Butter oil and commercial oil cutting fluid.

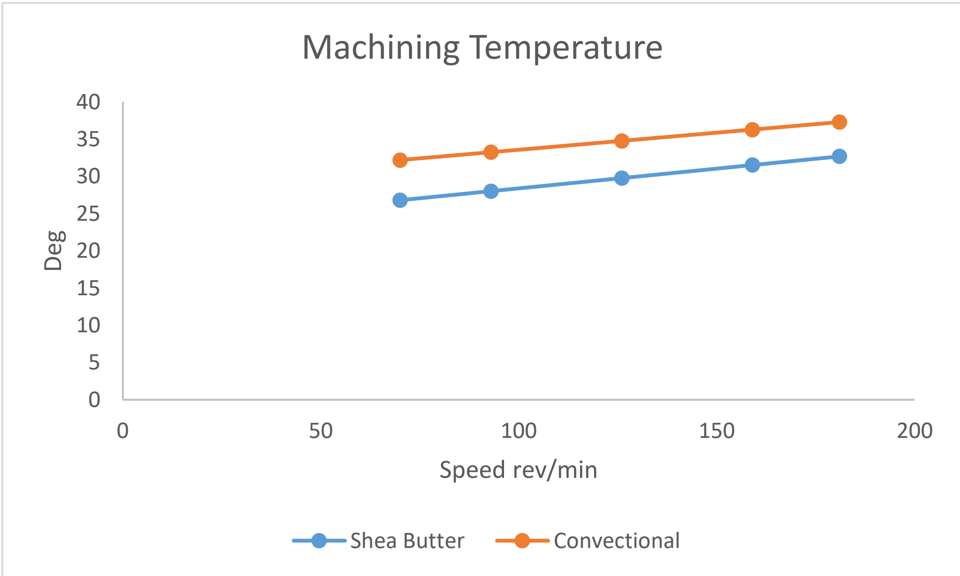

Figure 12: Comparison of the temperature of mild steel using shea butter oil and commercial oil cutting fluids.

It was also observed that the machining temperatures were lower by about 5°C when cutting with the formulated cutting oil as against cutting with the commercial cutting oil. Hence, it can be deduced that the formulated oil is a better cutting oil.

3.3 Contour plots for surface roughness

The effectiveness of both the shear butter and commercial oil lubricants were tested while machining a mild steel on a lathe machine and the contour plot of Temperature versus feed rate and depth of cut is presented in Fig. 13, while that for the surface roughness is shown in Figure 14.

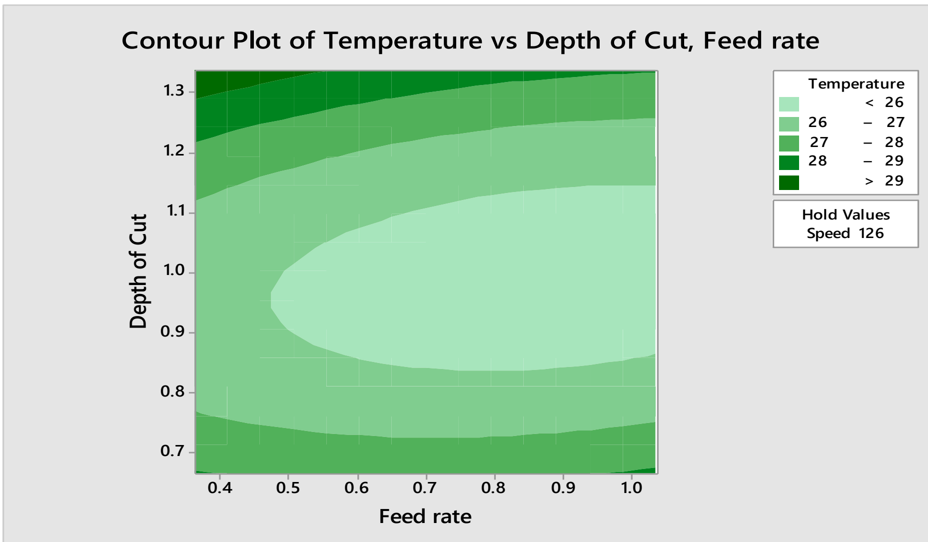

Fig. 13: Contour plot of Temperature against feed rate, depth of cut.

The plot in Fig. 13 indicates that when the feed rate is increased, depth of cut also increases exponentially. Also, it can be observed that cutting temperature is higher when both feed rate and speed are lower/higher. It shows that the work piece temperature during machining when depth of cut and speed are varied and feed rate kept constant (0.7mm). This shows that depth of cut, and speed of machining have a linearly relationship with negative slow slope. From the Fig. 13, it can be deduced that the work piece is cooler when the depth of cut is kept within 0.95mm – 1.15mm and speed has been increased gradually.

Fig. 14 shows that the surface roughness profile at constant depth of cut (1mm) while varying feed rate and machining speed. This reveals that better surface finish will be recorded at and machining speed of more than 120 rev/min and a feed rate of less than 0.9 mm.

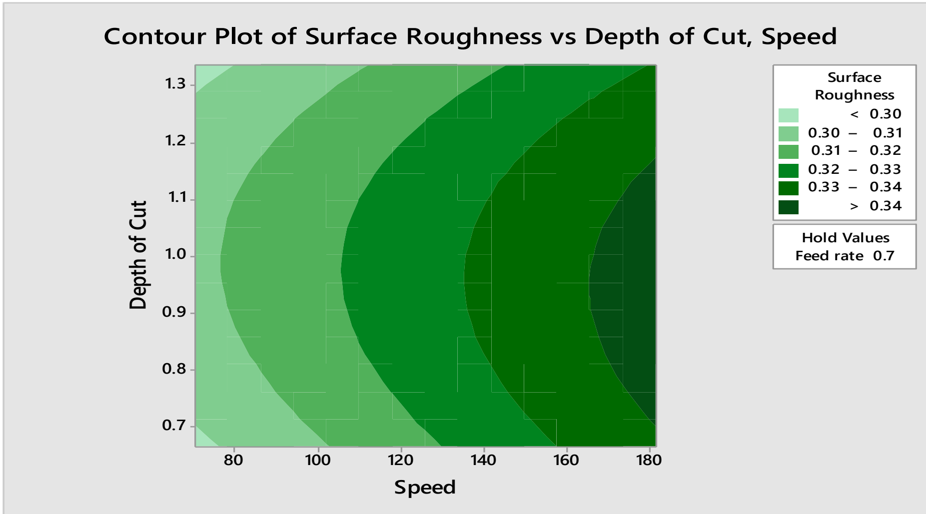

Fig. 14: Contour plot of surface roughness against depth of cut, speed.

4.0 Conclusion

In this work, a vegetable cutting fluid was formulated from shear butter and oil additives. A factorial design method was used to evaluate and compare the performances of the formulated shear butter and commercial cutting fluids. The results of the characterization of the shear butter oil show that its properties are within the required range for an oil-based cutting fluid. Its cooling ability is much better compared to the commercial cutting fluid. The result showed that during he machining of the mild steel, the temperature was observed to be 5^{o}C cooler using shear butter oil when compared to the commercial cutting oil. Also, the surface finish of the mild steel was found to be a little bit better with the shear butter cutting fluid. The average surface finish of the mild steel while turning with shear butter cutting fluid was 0.32 µm, as against 0.47µm with the commercial cutting fluid.

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