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COMPARATIVE PERFORMANCE OF VEGETABLE OIL-BASED CUTTING FLUIDS DURING THE TURNING OPERATION OF EN24 STEEL

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Abstract

The present study was done to compare the performance of the three vegetable oil (i.e. coconut oil, soybean oil and sunflower oil) based cutting fluids during the turning operation of EN24 steel using a high-speed steel tool. The cutting speed (levels 80 m/min,100 m/min and 120 m/min), feed rate (levels 0.1 mm/rev, 0.2 mm/rev and 0.3 mm/rev) and depth of cut (levels 0.5 mm, 0.75 mm and 1 mm) were taken as the input parameters while the surface roughness, of the machined workpiece, and machining temperature were taken as the response parameters. The experimental design was based on Taguchi's orthogonal array and S/N ratio and ANOVA analysis were used to analyze the results using the MINITAB and MS excel software. Results reveal that feed rate is the most significant machining parameter followed by feed rate then cutting speed. Overall performance of coconut oil-based cutting fluid was the best followed by soybean oil-based cutting fluid and then sunflower oil-based cutting fluid.

1) Introduction

The role of the cutting fluid has always been crucial in any machining process. The merits and demerits, associated with the use of any cutting fluid, decides the usability of that cutting fluid. Most of the mineral and petroleum oil-based cutting fluids are non-biodegradable. Hence this creates the need for the usage of vegetable oil-based cutting fluid, which should efficient to use and be good for the environment.

2) Materials and methods

2.1 Preparation of cutting fluids

In this work, coconut oil, soybean oil and sunflower oil were used as base liquids for the formation of three vegetable oil-based cutting fluids.

Oleic acid is used as an emulsifier or solubilizer, not only as an agent to improve the lubricity of cutting fluids, but also as a friction modifier to reduce the coefficient of friction. Triethanolamine are used to provide the necessary alkalinity to prevent oxidation and act as an antioxidant. It also controls the rate at which water evaporates from the cutting fluid.

The coconut oil concentrate is prepared by mixing coconut oil with oleic acid and triethanol amine in a ratio of 2:2:1. To prepare 1 litre of oil concentrate, 400 ml of coconut oil was poured in a beaker and then 400 ml of oleic acid was poured slowly in it. The stirrer is used to stir the mixture thoroughly so that a homogeneous liquid is formed, then pour 200 ml of triethanol amine and mix well until a homogeneous mixture is obtained, thereby obtaining an oil concentrate. This homogeneous mixture is soluble in water in all proportions and acts as an oil-in-water emulsion. Now, 20% of this emulsion was mixed with 80% of water to form the desired coconut oil- based cutting fluid.

Similarly soybean oil and sunflower oil-based cutting fluids were formed.

Fig. Workpiece

2.2. Composition and work piece geometry

The work piece used for the study is EN24 steel equivalent to AISI 4340 rod with 25 mm diameter and 120 mm length and there is a total number of 27 work pieces having the same dimension. For this an EN 24 steel rod having 25 mm diameter and 4 meter long was purchased from the local market. EN24 is used for parts such as gears, shafts, studs, and bolts, with a hardness range of 248/302 HB.

Fig. Workpiece

The chemical composition and typical physical and thermal properties of EN24 steel are shown in Table 2.1 and Table 2.2 respectively.

Table 2.1 : Chemical Composition of EN24 steel

Element	C	Si	Mn	S	P	Cr	Ni	Mo
Composition	0.38-0.43	0.15-0.30	0.60-0.80	0.040	0.035	0.70-0.90	1.65-2.00	0.20-0.30

Table 2.2 : Typical physical and thermal properties of EN24 steel

Parameter	Value
Tensile Strength	850-1000 MPa
Yield stress	680 MPa
Elongation	13 %
Hardening Temperature	823-850 °C
Soft Annealing Temperature	700-710 °C
Hardness	248-302

3.3 Selection of cutting speed, feed per revolution and depth of cut

The experiment in this study was based on design of experiment (DOE) via Taguchi method and orthogonal array. With the application of Taguchi method ,twenty seven experiments were conducted to study the entire parameters space. This method will save both time and cost in experimentation. In this study, cutting speed, feed, depth of cut and types of cutting fluids were taken as the input variables for the experiments. Hence, the three input parameters each at three levels are shown in the table 2.3

Table 2.3 Machining parameters at each levels

Parameter	Level 1	Level 2	Level 3
Cutting speed(Vc)(m/min)	80	100	120
Feed rate(f) (mm/rev)	0.1	0.2	0.3
Depth of cut (mm)	0.5	0.75	1

2.4 Machinery used for turning operation

2.4.1 Lathe for turning experiment

The turning of EN24 steel alloy was carries out in CNC lathe machine installed at MSME TC.The experimental setup is shown in Fig.2.3**.**

Fig. 2.3 Experimental setup of CNC lathe machine for the turning operation

2.4.2 Cutting tool material

The cutting tool material selected was high speed steel.

2.4.3 Surface roughness measurement system

The absolute values of the surface roughness profile ordinate (Ra values) were measured by a surface roughness measuring tester, Surftest SJ-210, Mitutoyo . For each work specimen, three Ra values were measured along the surface and then the average of the three was taken.

2.4.4 Temperature measurement

The machining temperature was measured using an infrared thermometer. During the turning operation of each work specimen, the temperature was noted.

2.5 Experimental procedure

The machining parameters used for the experiment work were designed using the Taguchi (3^3) orthogonal array as shown in Table 2.4. For each cutting fluid, turning operation of EN24 steel workpieces were carried out at 9 different machining parameters. Cutting fluids were applied to the machining place with the help of nozzle attached to the lathe machine. The cutting fluid was applied in the form of very fine spray through the nozzle. Tool was grinded to the initial geometry after each turning operation. The surface roughness of each machined piece was measured with the help of surface roughness tester Surftest SJ210. Three readings were taken for each workpiece. Then the average of the three was found. The machining temperature was recorded with the help of infrared thermometer during each turning operation.

3) Result and discussion

The objective of the present work was to determine the effects of three vegetable oil-based cutting fluids (coconut oil, soybean oil and sunflower oil) during the turning operation of EN24 steel. The analysis of the results were done using the MINITAB software 2020(trial version) using the SN ratio and ANOVA method. The Taguchi design criteria was chosen at "Smaller is better" for both SN ratio and ANOVA.

Table 3.1 and Table 3.2 shows the surface roughness values and S/N values for surface roughness obtained while machining the work pieces according to the 9 set of experiments for each cutting fluid.

Table 3.1 Surface Roughness values obtained for each cutting fluid at different machining parameters.

S.No	**Cutting speed(m/min)**	**Feed rate (mm/rev)**	**Depth of cut (mm)**	**Surface Roughness (μm)**		
				Coconut Oil	Soybean Oil	Sunflower Oil
1	80	0.1	0.5	2.39	2.45	2.61
2	80	0.2	0.75	2.92	2.80	2.90
3	80	0.3	1	3.49	3.30	3.53
4	100	0.1	0.75	2.51	2.56	2.87
5	100	0.2	1	3.09	3.17	3.67
6	100	0.3	0.5	3.17	3.30	3.45
7	120	0.1	1	2.53	2.76	2.80
8	120	0.2	0.5	2.67	2.89	2.99
9	120	0.3	0.75	2.83	2.90	3.23

Table 3.2 S/N ratio values calculated for surface roughness obtained for each cutting fluid at different machining parameters

S.No	**Cutting speed(m/min)**	**Feed rate (mm/rev)**	**Depth of cut (mm)**	**S/N Ratio (dB)**		
				Coconut Oil	Soybean Oil	Sunflower Oil
1	80	0.1	0.5	-7.5680	-7.7833	-8.3328
2	80	0.2	0.75	-9.3077	-8.9432	-9.2480
3	80	0.3	1	-10.8565	-10.3703	-10.9555
4	100	0.1	0.75	-7.9935	-8.1648	-9.1576
5	100	0.2	1	-9.7992	-10.0212	-11.2933
6	100	0.3	0.5	-10.0212	-10.3703	-10.7564
7	120	0.1	1	-8.0624	-8.8182	-8.9432
8	120	0.2	0.5	-8.5302	-9.2180	-9.5134
9	120	0.3	0.75	-9.0357	-9.2480	-10.1841

3.1 Effect of cutting speed, feed and depth of cut

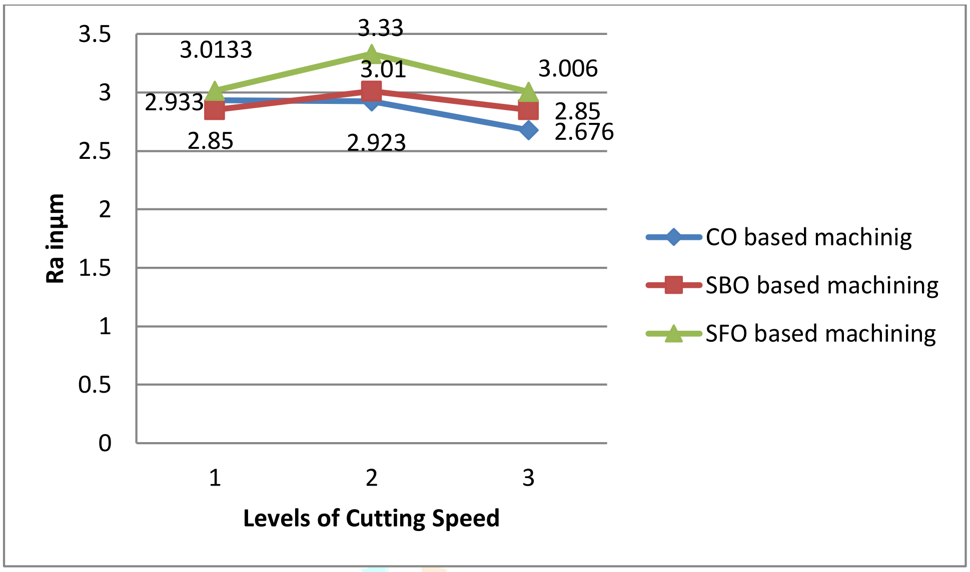

Fig 3.1 Effect of cutting speed on surface roughness

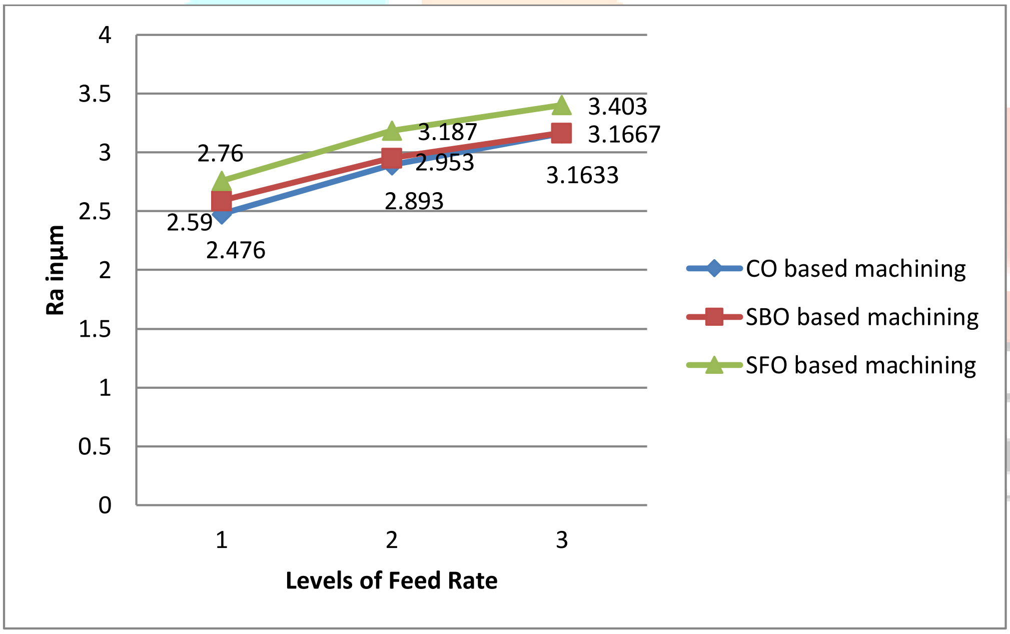

Fig 3.2 Effect of feed rate on surface roughness

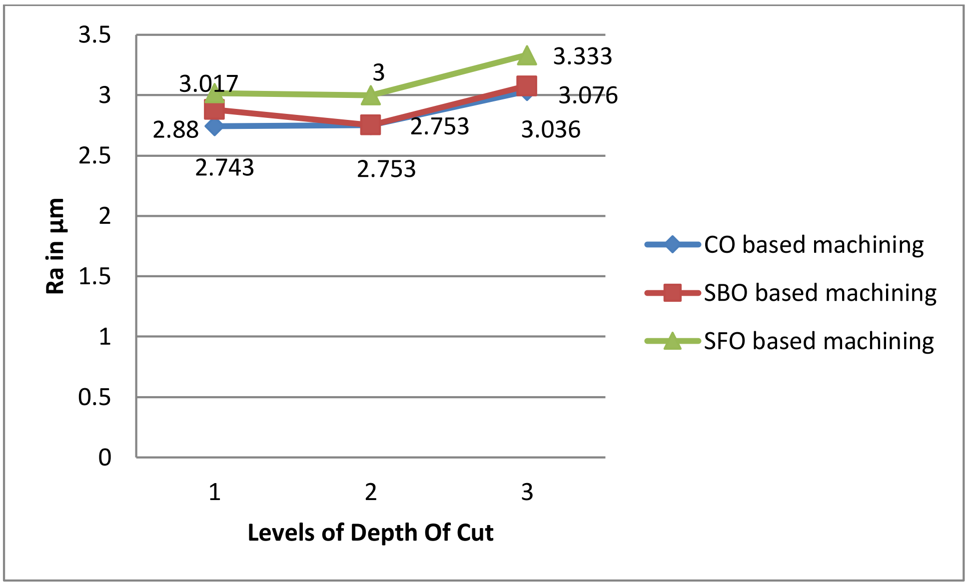

Fig 3.3 Effect of depth of cut on surface roughness

The effect of cutting speed, feed and depth of cut on the Ra values during the turning of EN 24 steel with three different cutting fluids viz. coconut oil (CO), soybean oil(SBO) and sunflower oil (SFO) based cutting fluids are shown in Fig 3.1, Fig 3.2 and Fig 3.3 respectively. It can be observed from Fig. 3.1 that with the increase in cutting speed, the roughness value decreased in case of coconut oil based machining while for soybean and sunflower oil based machining surface roughness increased then decreased with the increase in cutting speed.

As shown in Fig 3.2, for all the three cutting fluids, with the increase in feed rate the Ra value increases. It can be observed that increasing the feed rate by 200%, Ra values increased by 27.75%, 22.26 % and 23.29% during CO,SBO and SFO based machining respectively.

From Fig. 3.3,it can be observed that with increase in depth of cut , the Ra value first decreases then increased for all the three cutting fluids. Overall larger depth of cut lead to a poor surface finish. There is very less differences between the Ra value when the depth of cut is increased by 100%, but again increasing by 100 % Ra values increased. Overall 200% increase in depth of cut results in 10.68% ,6.8% and 10.47% increase in Ra value during CO, SBO AND SFO based machining respectively.

3.1 Surface roughness

3.1.1 S/N ratio

(a) Signal-to-noise (S/N) ratio analysis for coconut oil-based cutting fluid.
The main effects plot for S/N ratio for surface roughness is shown in Figure 3.4. From the figure, it can be observed that the optimal turning parameters using the coconut oil-based cutting fluid for the surface roughness are 120 m/min of cutting speed (level 3), 0.1 mm/rev of feed (level 1), 0.5 mm of depth of cut (level 1) .

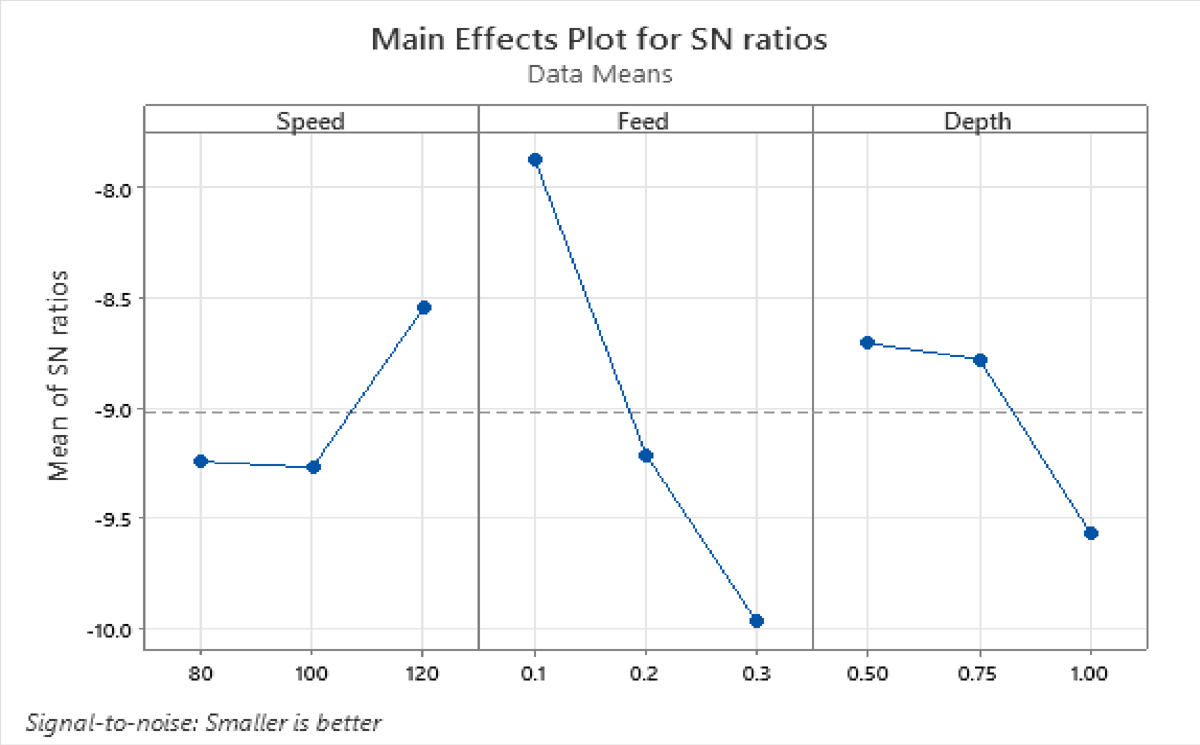

Fig. 3.4 Main effects plot for SN ratios

(b) Signal-to-noise (S/N) ratio analysis for soybean oil-based cutting fluid.

The main effects plot for S/N ratio for surface roughness is shown in Figure 3.5 . From the figure 3.5, it can be observed that the optimal turning parameters using the soybean oil-based cutting fluid for the surface roughness are 80 m/min of cutting speed (level 1), 0.1 mm/rev of feed (level 1), 0.75 mm of depth of cut (level 2) .

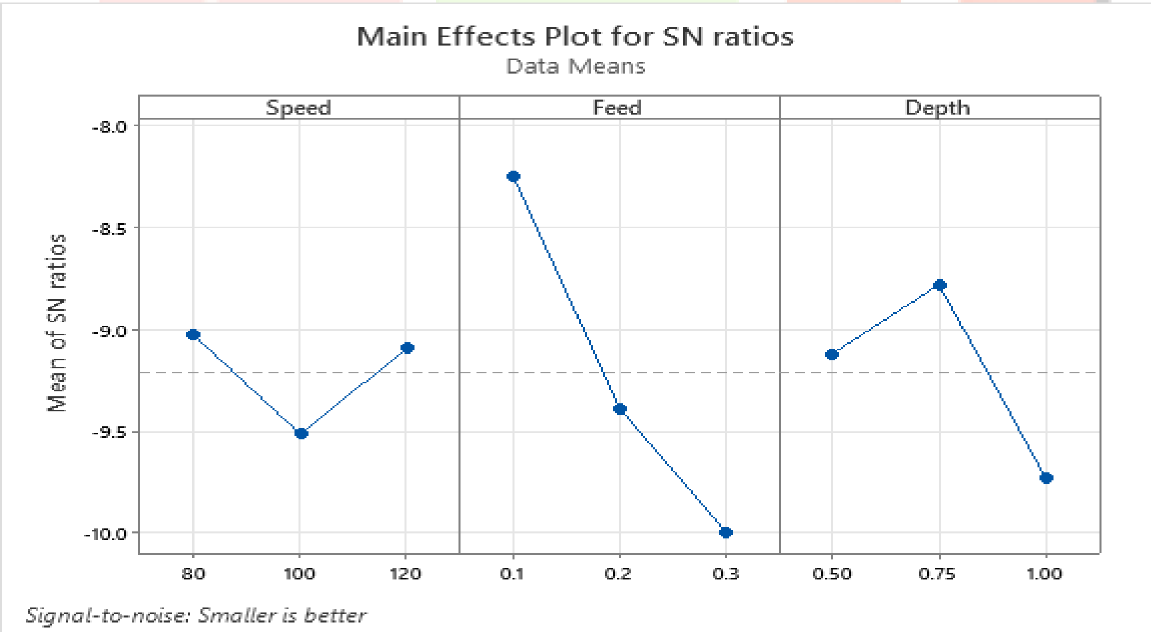

Fig. 3.5 Main effects plot for SN ratios

(c) Signal-to-noise (S/N) ratio analysis for sunflower oil based cutting fluid.

The main effects plot for S/N ratio for surface roughness is shown in Figure 3.6 . From the figure 3.6, it can be observed that the optimal turning parameters using the sunflower oil-based cutting fluid for the surface roughness are 80 m/min of cutting speed (level 1), 0.1 mm/rev of feed (level 1), 0.5mm of depth of cut (level 1) .

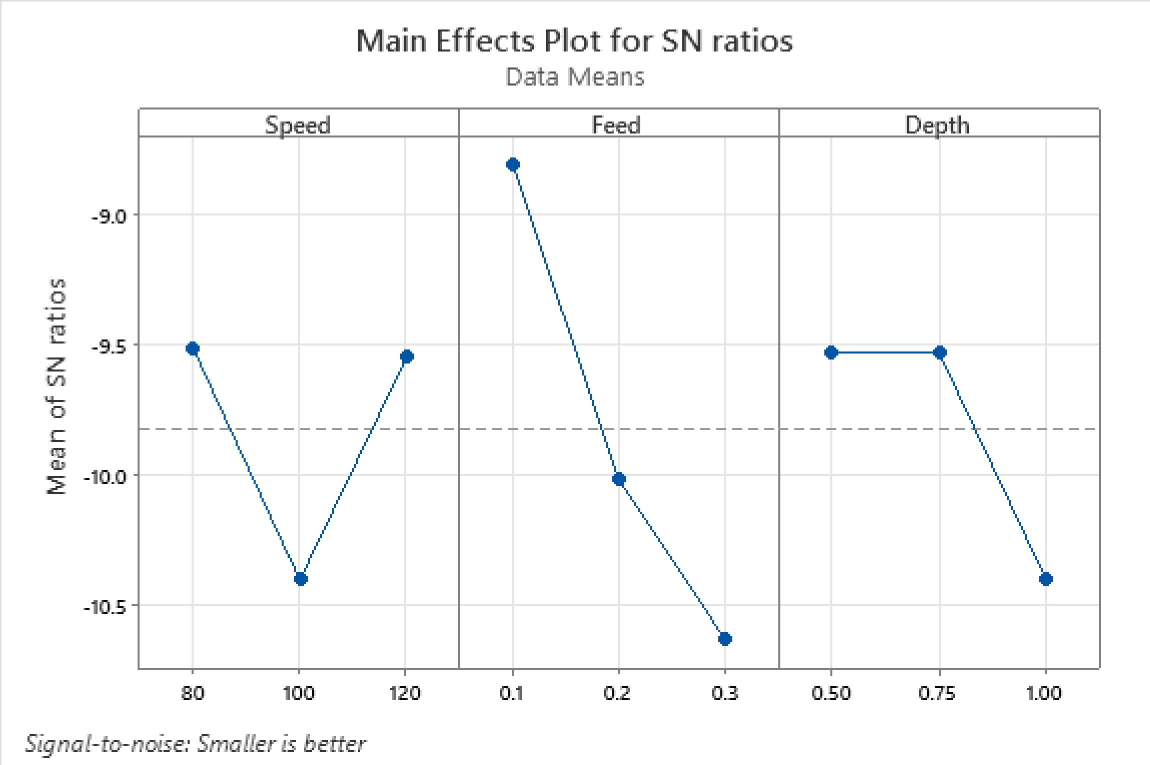

Fig. 3.6 Main effects plot for SN ratio

3.1.2 ANOVA analysis

Table 3.3, Table 3.4 and Table 3.5 show the results of ANOVA (for significance level α =0.05) for the surface roughness under three machining conditions viz. CO, SBO and SFO based turning.From the results, it can be concluded that in all the three machining conditions, the feed rate is the most significant machining parameter among the three parameters considered.The contribution in percent of each parameter on the measured surface roughness in coconut oil-based cutting fluid assisted turning is as follows :

i) Cutting speed : 12.23%

ii) Feed rate : 69.26%

iii) Depth of cut :16.05%

The contribition in percent of each parameter on the measured surface roughness in soybean oil-based cutting fluid assisted turning is as follows :

i) Cutting speed : 6.91%

ii) Feed rate : 68.87%

iii) Depth of cut : 21.51%

The contribition in percent of each parameter on the measured surface roughness in coconut oil-based cutting fluid assisted turning is as follows :

i) Cutting speed : 18.94%

ii) Feed rate : 59.42%

iii) Depth of cut :19.57%

The error percentage associated are 2.46% in CO based machining, 2.71% in SBO based machining and 2.07% in SFO based maching .Results show that the analysisis within the standard limits.

Table 3.3 : ANOVA results for surface roughness in coconut oil-based cutting fluid assisted turning

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Speed	2	0.12682	0.12682	0.06341	5.00	0.167	12.23
Feed	2	0.71802	0.71802	0.35901	28.32	0.034	69.26
Depth	2	0.16642	0.16642	0.08321	6.65	0.132	16.05
Residual Error	2	0.02536	0.02536	0.01268			2.46
Total	8	1.03662					100

Table 3.4: ANOVA results for surface roughness in soybean oil-based cutting fluid assisted turning

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Speed	2	0.05120	0.05120	0.02560	2.55	0.282	6.91
Feed	2	0.51007	0.51007	0.25503	25.42	0.038	68.87
Depth	2	0.15927	0.15927	0.07963	7.94	0.112	21.51
Residual Error	2	0.02007	0.02007	0.01003			2.71
Total	8	0.74060					100

Table 3.5: ANOVA results for surface roughness in sunflower oil-based cutting fluid assisted turning

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Speed	2	0.20487	0.20487	0.10243	9.15	0.099	18.94
Feed	2	0.64287	0.64287	0.32143	28.70	0.034	59.42
Depth	2	0.21167	0.21167	0.10583	9.45	0.096	19.57
Residual Error	2	0.02240	0.02240	0.01120			2.07
Total	8	1.08180					100

3.2 Machining temperature

Table 3.6 shows the variation of temperature in the three different machining conditions with different machining parameters.

Table 3.6: Variation of temperature at different machining conditions

S.No	Cutting speed(m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Machining Temperature (°C)		
				Coconut Oil	Soybean Oil	Sunflower Oil
1	80	0.1	0.5	38.5	39.3	39.9
2	80	0.2	0.75	43	41.4	43.1
3	80	0.3	1	50.4	47.3	51.7
4	100	0.1	0.75	39.6	39.8	41.9
5	100	0.2	1	43.8	45.9	51.9
6	100	0.3	0.5	44.5	49.3	48.1
7	120	0.1	1	39.3	41.4	41.2
8	120	0.2	0.5	41.2	41.7	43.1
9	120	0.3	0.75	42	42.1	44.9

The effect of cutting speed, feed and depth of cut on the machining temperature during the turning of EN 24 steel with three different cutting fluids viz. coconut oil (CO), soybean oil(SBO) and sunflower oil (SFO) based cutting fluids are shown in Fig 3.7, Fig 3.8 and Fig 3.9 respectively. It can be observed from Fig. 3.7 that with the increase in cutting speed, the machining temperature decreased in case of coconut oil based machining while for soybean and sunflower oil based machining, temperature increased then decreased with the increase in cutting speed.

As shown in Fig 3.8, for all the three cutting fluids, with the increase in feed rate the machining temperature increases.

From Fig 3.9,it can be observed that with the increase in depth of cut, the machining temperature increased in case of coconut oil based machining while for soybean and sunflower oil based machining, temperature decreased then increased with the increase in depth of cut.

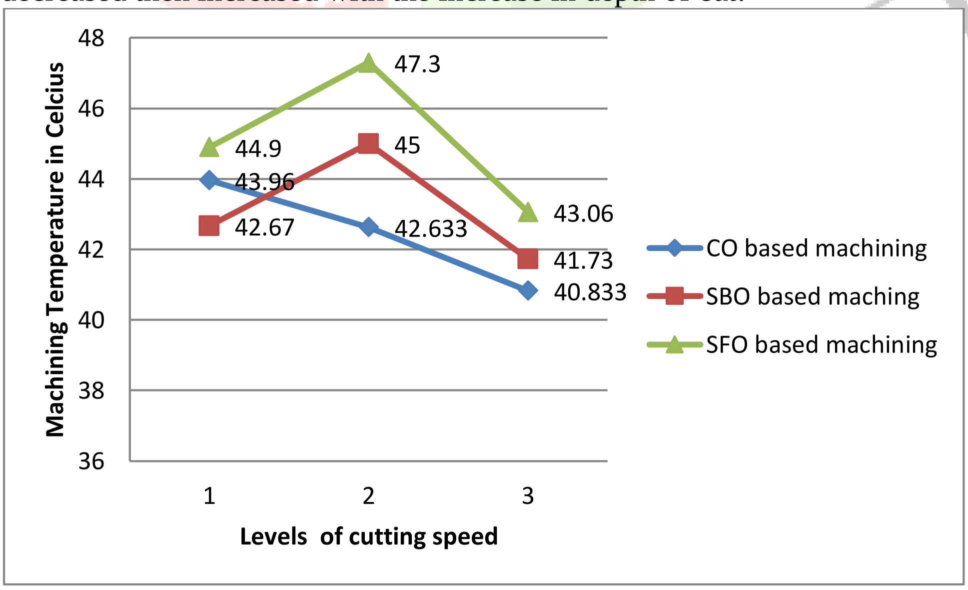

Fig 4.7 Effect of speed levels on machining temperature

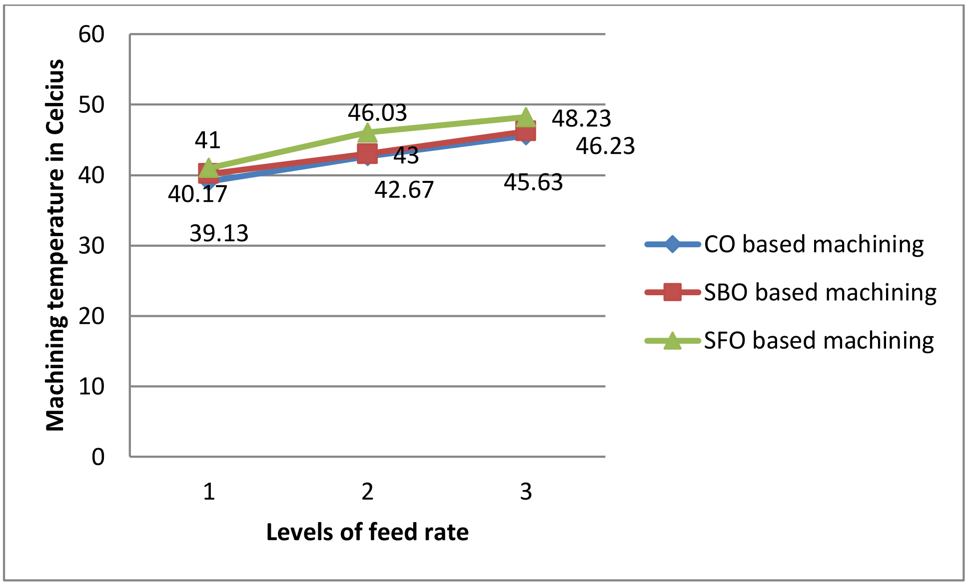

Fig 3.8 Effect of feed levels on machining temperature

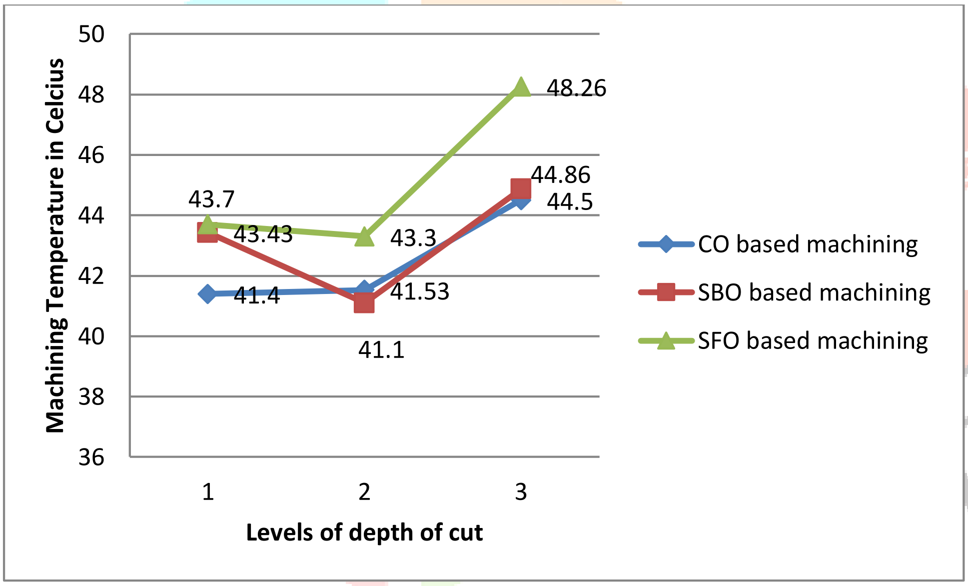

Fig.3.9 Effect of depth of cut on machining temperature

4) Conclusion

This research presents a study of the comparative performance of vegetable oil-based cutting fluids during the turning of the EN24 Steel. The vegetable oils used to form the cutting fluids are coconut oil, soybean oil and sunflower oil. The effects of the machining parameters i.e. cutting speed, feed rate and depth of cut while machining with the three vegetable oil-based cutting fluids have been studied. From the results, we arrive at the following conclusions :

1.With the increase in cutting speed, the surface roughness values decreased while the increase in feed rate and depth of cut deteriorated the surface finish.

2. The optimal turning parameters using the coconut oil-based cutting fluid for the surface roughness are 120 m/min of cutting speed (level 3), 0.1 mm/rev of feed (level 1), 0.5 mm of depth of cut (level 1)

3.The optimal turning parameters using the soybean oil-based cutting fluid for the surface roughness are 80 m/min of cutting speed (level 1), 0.1 mm/rev of feed (level 1), 0.75 mm of depth of cut (level 2) .

4. The optimal turning parameters using the soybean oil-based cutting fluid for the surface roughness are 80 m/min of cutting speed (level 1), 0.1 mm/rev of feed (level 1), 0.75 mm of depth of cut (level 2) .

5. The feed rate is the most significant machining parameter among the three parameters considered followed by depth of cut then cutting speed.

6. The error percentage associated are 2.46% in CO based machining, 2.71% in SBO based machining and 2.07% in SFO based machining .Results show that the analysis is within the standard limits.

7. With the increase in cutting speed, the machining temperature decreased while the increase in feed rate and depth of cut machining temperature increased.

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