Performance Evaluation of Different Types of Cutting Fluids in the Turning of Mild Steel

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Abstract: This paper presents the performance evaluation of three cutting fluids in the turning of mild steel. The three cutting fluids chosen were soluble oil, semi-synthetic oil and vegetable oil. The experiments were designed to evaluate the performance of fluids at various cutting speeds of 200, 275 and 400 rpm, feed rates of 0.06, 0.09 and 0.12 mm/rev and depth of cuts of 0.25, 0.50 and 0.75 mm. The results were measured in terms of the average surface roughness of the machined workpiece and the cutting forces. Analysis of results has shown that, feed has greater influence on surface roughness of soluble oil and the depth of cut greater influence on cutting force of semi-synthetic oil. It was observed that performance of vegetable oil does not drastically change with variation to the cutting speeds, depth of cut and feeds. Thus, the choice of vegetable oil would be most appropriate for general machining usage. Vegetable oils also become a potential source of environmentally favorable metal working working fluids due to its biodegradability and better lubrication performance.

***Key Words**: Vegetable oils, cutting fluids, turning, mild steel, cutting force, surface roughness, feed, depth of cut.*

1. INTRODUCTION

Cutting fluid is a type of coolant and lubricant designed specifically for metalworking and machining processes. The primary function of cutting fluid is cooling and lubrication. A fluid cooling and lubrication properties are important in decreasing tool wear and extending tool life. A secondary function of cutting fluid is to flush away chips and metal fines from the tool/workpiece interface to prevent the damage of finished surface and to reduce the occurrence of built-up edge. The effect of use of fluids in metal cutting was first reported in 1894 by F. Taylor, who observed that by applying large amounts of water in the cutting area, increase the cutting speed up to 33% without reducing tool life [3].

Investigation on the performance of an emulsion of three different cutting fluids as mineral oil, semi-synthetic and synthetic cutting fluids when face milling AISI 8640 steel with coated cemented carbide tool. Dry cutting was also compared with cutting fluids. Tool life, power consumption and surface roughness were monitored during the machining trials [1].

Evaluation of the efficiency based on certain process parameters such as flank wear, surface roughness, cutting forces developed, temperature developed at the tool chip interface, etc. The performance of coconut oil is also being compared with another two cutting fluids namely an emulsion and a neat cutting oil [2]. Measurement of the efficiency, among other parameters, through cutting tool life and workpiece surface finish. The performance of three type of cutting fluids were compared to dry cutting when continuous turning hardened AISI 4340 steel using mixed alumina inserts [3].

Fig.1 -Experimental Set-up

The eco-friendly and hazard free alternatives to conventional mineral oil-based metal working fluids. Vegetable oils have become a potential source of environmentally favorable metal working fluids due to its biodegradability and better lubrication performance [6].

This paper primarily focuses on machining mild steel using HSS owing to its lower cost, ready availability, malleable and a wide range of applications from automotive to domestic goods to constructional steel and many other machine elements such as keys, rings, fence posts, tin cans, wires, nuts and bolts, chains, hinges, pipes, etc. The influence of cutting parameters on cutting force and surface roughness can be studied. This paper also studied the effect of cutting force and surface roughness by different cutting fluids.

2. MATERIAL AND METHODS

A. Machine

The experiment was carried out on medium duty centre lathe which enables high precision machining and production of jobs.

Technical specifications are: Centre height: 250mm, main motor power: 3hp, feed range: 0.02mm/rev to 0.35mm/rev.

B. The Tool

HSS tool contains the alloying element like manganese, chromium, tungsten, cobalt, etc. has comparatively better resistance to heat and wear. Tool length of 80mm (approx.) was taken so as to minimize undesirable vibrations, which would influence cutting force and surface roughness. The single point HSS tool specifications are as follows in Table-1

Table -1: Tool Specification

Back Rake Angle	12˚
Side Rake Angle	12˚
Clearance Angle	7˚
Front Cutting-Edge Angle	25˚
Side Cutting Edge Angle	8˚
Nose Radius	0.8mm

C. Workpiece

The workpiece used for experimentation was mild steel.Workpiece diameter: 30mm, Workpiece length: 250mm (approx.)

D. Cutting Fluids

The cutting fluids used for experimentation are soluble oil, semi-synthetic oil and vegetable oil (castor oil). The selection of appropriate cutting fluid is very important because it could affect machining performance (tool life, cutting forces, surface roughness, power consumption etc.) and the selection depends on some parameters such as workpiece material used, cutting tool material and type of machining process.

E. Lathe Tool Dynamometer

The instrument used for cutting force measurement was three component lathe tool dynamometer. Instruments operate on 230V, 50Hz AC mains. The cutting forces are suitably measured by using the change in strain caused by the force. The strain induced by the force changes the electrical resistance, of the strain gauges which are firmly pasted on the surface of the tool-holding beam. The change in resistance of the gauges connected in a Wheatstone bridge produces voltage output ΔV, through a strain measuring bridge. It comprises of three independent digital display calibrated to display force directly using three component tool dynamometer.

Table -2: Factors and their Levels

Parameters	**Level 1**	**Level 2**	**Level 3**
Speed (rpm)	200	275	400
Feed (mm/rev)	0.06	0.09	0.12
Depth of cut (mm)	0.25	0.50	0.75

F. Surface Roughness Measurement

The instrument used to measure surface roughness was Mitutoyo surface roughness tester model name sj-201. For a probe movement of 5mm, surface roughness readings were recorded at four locations at workpiece and the average value was used for analysis.

Specifications: gauge range: ±150µm, probe movement (max): 25.4mm, traverse speed: 0.5mm/sec.

3. EXPERIMENTAL PROCEDURE

The experiments were planned using Taguchi's orthogonal array in the design of experiments, which helps in reducing the number of experiments. The experimental trials were conducted according to a 3-level L_9 orthogonal array for each cutting fluids. The cutting parameters identified were cutting speed, feed and depth of cut. The experiment was carried out for each cutting fluid such as soluble oil, semi-synthetic oil and castor oil. The control parameters and their levels are indicated in table 3.

Table -3: The DOE Table

Expt. No.	Speed	Feed	Depth of Cut	Soluble Oil		Semi-synthetic oil		Vegetable oil	
				F_c	Ra	F_c	Ra	F_c	Ra
1	200	0.06	0.25	4	4.273	3	3.495	3	4.560
2	200	0.09	0.50	7	4.332	5	4.751	6	4.936
3	200	0.12	0.75	5	6.145	6	5.448	5	5.496
4	275	0.06	0.50	7	3.542	5	4.763	5	4.703
5	275	0.09	0.75	8	4.703	6	5.05	6	4.939
6	275	0.12	0.25	4	6.09	3	5.602	3	5.802
7	400	0.06	0.75	9	3.366	8	4.109	6	5.02
8	400	0.09	0.25	5	4.637	4	4.923	5	4.855
9	400	0.12	0.50	7	5.924	5	5.459	4	5.918

Taguchi's orthogonal design for three factors and three levels yielded 9 experiments for each cutting fluid. Then, the 27 experimental runs were carried out. The run order, cutting parameters and responses are shown in the design of experiments table. It is given in table 4.

Table-4: ANOVA for Cutting Force of Soluble Oil

Sr. No.	Factor	Degree of Freedom	Sum of Squares	Mean Squares	Variance	% Contribution
1	Cutting Speed	2	4.2222	4.2222	2.71	16.522
2	Feed	2	3.5556	3.5556	2.29	13.913
3	Depth of Cut	2	16.2222	16.2222	10.43	63.478
4	Error	2	1.5556	1.5556		
5	Total	8	25.5556	-	-	-

4. RESULTS AND DISCUSSION

A. Analysis of Variance (ANOVA)

The observed values of cutting force and surface roughness were used for determining the significant factors influencing the machining process. The significant parameters influencing the cutting force and surface roughness were found using ANOVA procedure. Table 5 show the ANOVA for cutting force and surface roughness of soluble oil, semi-synthetic oil and vegetable oil. From the calculation, it is being inferred that feed has more influence on surface roughness and depth of cut has more influence on cutting force. For vegetable oil, feed has influenced by 88.78% on surface roughness and depth of cut has influenced by 81.25% on cutting force. Vegetable oil shows intermediate performance for cutting force and surface roughness.

Table -5: ANOVA Comparison

Sr. No.	Factor	Percentage of Contribution (%)					
		Surface Roughness			Cutting Force		
		Soluble Oil	Semi-synthetic Oil	Vegetable Oil	Soluble Oil	Semi-synthetic Oil	Vegetable Oil
1	Cutting Speed	6.954	13.217	5.734	16.522	10.000	1.562
2	Feed	89.799	76.908	88.777	13.913	3.333	10.938
3	Depth of Cut	0.961	4.119	1.082	63.478	83.334	81.25

B. Cutting Force Analysis

From ANOVA analysis, cutting force is significantly influenced due to depth of cut. Cutting force increases almost linearly with the increase in depth of cut from 0.25 mm to 0.75 mm. From the main effect plots in Fig. 2-4, the optimal machining conditions were 200 rpm cutting speed (level 1), 0.09 mm/rev feed (level 2), 0.75 mm depth of cut (level 3) for cutting force of soluble oil, 200 rpm cutting speed (level 1), 0.09 mm/rev feed (level 2), 0.50 mm depth of cut (level 2) for cutting force of semi-synthetic oil, 200 rpm cutting speed (level 1), 0.06 mm/rev feed (level 1), 0.50 mm depth of cut (level 2) for cutting force of vegetable oil.

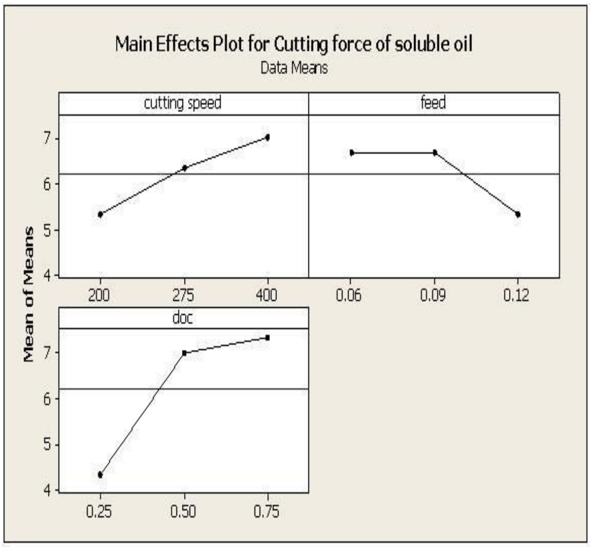

Fig.2 –Main effects plot for cutting force of soluble oil

From the main effects plots for cutting force indicates that cutting force is influenced significantly by feed and depth of cut, whereas, speed has an insignificant influence on cutting force.

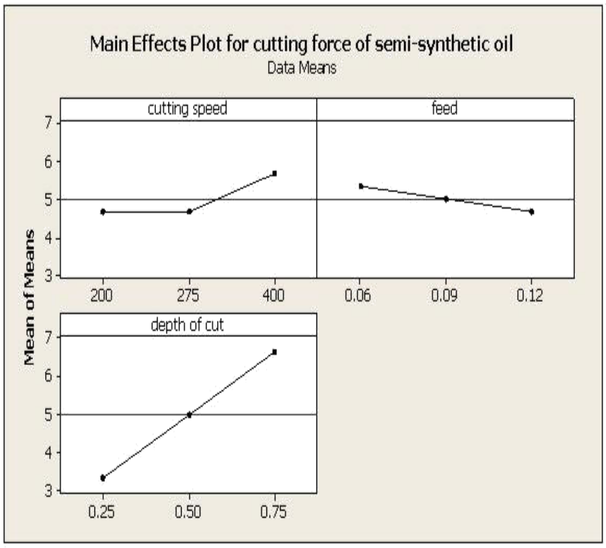

Fig.3 –Main effects plot for cutting force of semi-synthetic oil

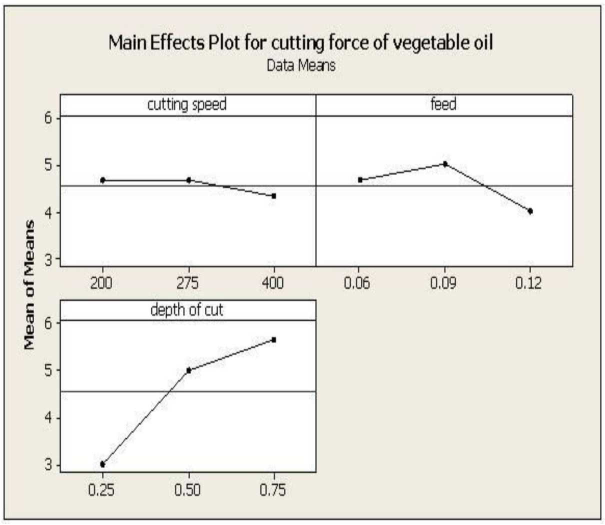

Fig.4 –Main effects plot for cutting force of vegetable oil

C. Surface Roughness Analysis

From ANOVA analysis, surface roughness is significantly influenced due to feed. Surface roughness increases almost linearly with the increase in feed from 0.06 mm/rev to 0.12 mm/rev. From the main effect plots in Fig. 5-7, the optimal machining conditions were 275 rpm cutting speed (level 2), 0.09 mm/rev feed (level 2), 0.50 mm depth of cut (level 2) for surface roughness of soluble oil, 400 rpm cutting speed (level 3), 0.09 mm/rev feed (level 2), 0.75 mm depth of cut (level 3) for surface roughness of semi-synthetic oil, 275 rpm cutting speed (level 2), 0.09 mm/rev feed (level 2), 0.75 mm depth of cut (level 3) for surface roughness of vegetable oil.

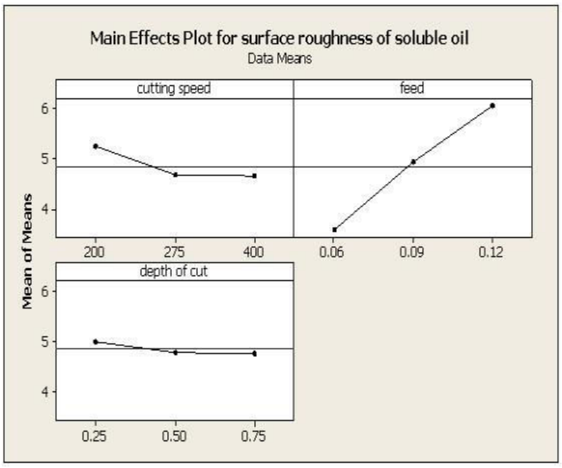

Fig.5 –Main effects plot for surface roughness of soluble oil

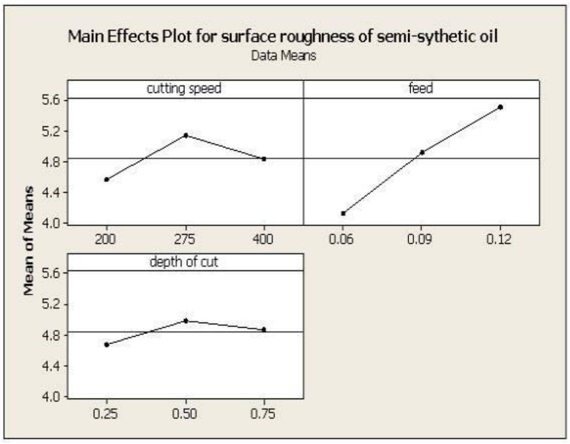

Fig.6 –Main effects plot for surface roughness of semi-synthetic oil

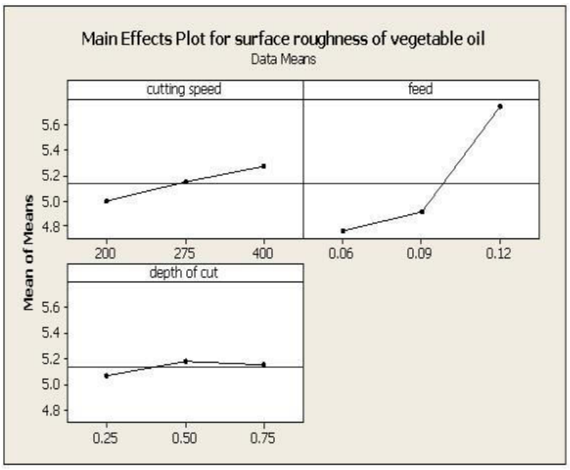

Fig.7 –Main effects plot for surface roughness of vegetable oil

From the main effects plots for surface roughness indicates that surface roughness is influenced significantly by cutting speed and feed, whereas, depth of cut has an insignificant influence on cutting force.

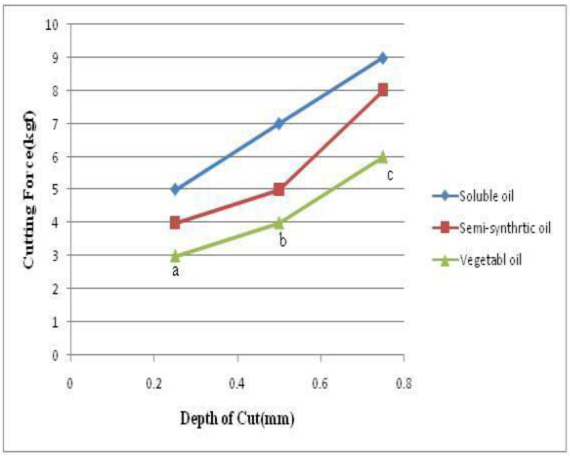

Fig.8- Depth of cut Vs. Cutting force, cutting speed: 400rpm; feed: 0.09, 0.12, 0.06mm/rev at the three points a, b and c, respectively.

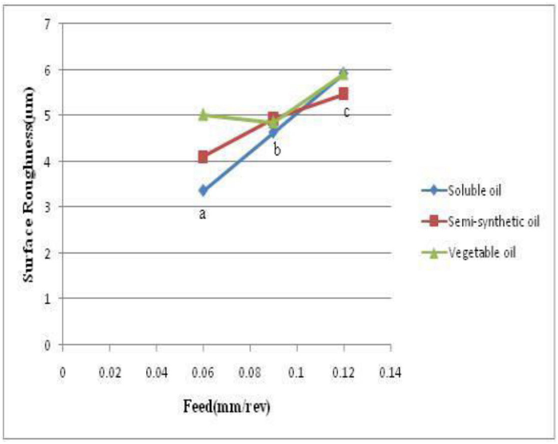

Fig.9- Feed Vs. Surface Roughness, cutting speed: 400rpm; depth of cut: 0.75, 0.25,0.50mm at the three points a, b and c, respectively.

From the recorded values Fig. 8 and 9 were plotted between cutting force Vs depth of cut and surface roughness Vs feed. From the graphs it is being inferred that for any combination of cutting parameters vegetable oil always outperform the other two cutting fluids. In fig. 9, the vegetable oil performs better at the feed of 0.09 mm/rev and 0.12 mm/rev. It was observed that performance of vegetable oil does not drastically change with variation to the cutting speeds, depth of cut and feeds.

5. CONCLUSION

Experiments involving high speed steel tool and mild steel work material under varying machining parameters and with three different cutting fluids are performed. Cutting fluids are considered as important parameters in the machining process along with cutting speed, feed rate and depth of cut. Optimum surface roughness can be achieved by selecting relatively higher value of speed (>400 rpm), higher values of depth of cut (>0.75 mm) and relatively lower value of feed rate (<0.06 mm/rev). Further it is observed that cutting fluid has considerable influence on both surface roughness and cutting force.

An analysis of variance was made, and it was found that feed rate has greater influence on surface roughness (89.79% contribution) of soluble oil and depth of cut has greater influence on cutting force (83.33% contribution) of semi-synthetic oil. It was found that soluble oil and semi-synthetic oil had more considerable effect on the surface roughness and cutting force than that of vegetable oil.

From the main effects plots for cutting force indicates that cutting force is influenced significantly by feed and depth of cut, whereas, speed has an insignificant influence on cutting force. From the main effects plots for surface roughness indicates that surface roughness is influenced significantly by cutting speed and feed, whereas, depth of cut has an insignificant influence on cutting force.

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