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Cutting Force Analysis on the Vegetable Oil-Based Cutting Fluid in Turning of EN8 Steel

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ABSTRACT

Many problems such as environment and health issues are recognized with the use of cutting fluids. There has been demand for developing a new environment friendly cutting fluid such as vegetable based cutting fluids (VBCF) to reduce these harmful effects. In this study, performance of VBCFs from palm oil with different ratio of additives likes tween 20 and tween 80 are evaluated for reducing cutting force during turning of EN8 steel with carbide insert tool. In this present work different machining parameters were taken and their effect on cutting force has been analyzed on vegetable oil based cutting fluid (VBCF) palm oil as non-conventional lubricant. Cutting parameter taken were spindle speed and feed rate while the depth of cut was kept constant. EN8 steel was the workpiece material for the study. Further the analysis and optimization of cutting force was also done using Taguchi method to find the contribution of different cutting parameters on tool temperature. The results show that all the input process parameters affect the cutting force of EN8 steel specimen but feed rate affect most.

Keywords: cutting force, EN8 steel, Taguchi method, turning, VBCF

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INTRODUCTION

In metal cutting industry, cutting fluids (CFs) have a crucial importance among machining factors, due to their lubricant and cooling properties to remove the heat generation and thus reducing the temperature and cutting force and providing lubrication to tool and work piece, which in turn leads to longer tool life and improved surface finish.

Use of conventional lubricants in machining has many side effects such as environmental pollution, adverse effect on health of worker and manufacture cost. The use of conventional lubricants is under substantial criticism by the health professionals. However, the use of lubricant cannot be swayed away because of the high temperatures and forces that are generated during machining. The heat generated in machining adversely affects the quality of the products. Researchers worldwide have been find new options like vegetable oil based cutting fluid (VBCF) in machining so as to reduce the tool force and the amount of heat generation and improved surface finish aiding both the production cost and the health of the workers.

LITERATURE REVIEW

Cutting Force

Alabi *et al*. (2010) [1] presented the effect of process parameters on cutting force during dry and wet machining by heat treated medium carbon steel. The results show that the cutting forces for the dry machining were higher than the wet machining. They also suggested that accuracy in machining, dry turning is also better and suggested cost saving and cleaner option compared to wet turning.

Agustina *et al.* (2013) [2] worked on experimental analysis of the data obtained during dry turning operation of aluminium alloy (UNS A97075); a design of experiments 2^4 was used to analyze the influence of the cutting parameters (feed rate, spindle speed and depth of cut) and types of tool (nose radius) on the cutting forces. As a conclusion, it could be affirmed that the cutting component of the forces was more sensible to the variations of the cutting conditions than the rest of components analyzed. Also, tools with nose radius of 0.4 and of 0.8 mm had similar features from the point of view of the cutting forces generated during the machining at low feed rate.

Renjith *et al*. (2013) [3] investigated deflection of a T-42 CT High speed steel single point cutting tool by varying cutting feed, rake angle and tool extension length during turning process on lathe machine. The selection of cutting parameters was determined by using Taguchi method. Cutting force components during turning process were measured by lathe tool dynamometer and detailed deflection analysis was obtained by using ABAQUS finite element software. The revelation made in this research would significantly contribute to optimization of cutting parameters for turning process.

Shihab *et al.* (2013) [4] investigated the effect of different cutting parameters like (cutting speed, depth of cut and feed rate) on material removal rate and cutting force components in dry and wet hard turning operations. The work material, hardened alloy steel AISI 52100 was machined on a CNC lathe machine with coated carbide tool under different combination of cutting parameters. The results were analyzed using an effective methodology of response surface methodology (RSM) to optimize cutting parameters. Statistical analysis of variance was performed to determine significance of the cutting parameters. The results show that cutting forces was influenced principally by the depth of cut, while the effect of both cutting speed and feed rate was less.

Vegetable Oil Based Cutting Fluid (VBCF)

Gunerkar and Kuppan, (2013) [5] studied on the application of two different vegetable based cutting fluids (VBCF) rapeseed oil and sunflower oil for the formation of emulsion as nonconventional lubricant. Cutting fluid, cutting velocity, feed rate, feed rate and depth of cut were considered as machining parameter. Machining with conventional and nonconventional lubricant in wet condition has been carried out upon SS16L work piece with carbide cutting inserts tool, to evaluate surface roughness, cutting force and tool life. The result shows that nonconventional lubricant performs better than conventional lubricant.

Saleem *et al*., (2013) [6] did a study on the application vegetable oil as alternative cutting fluid while performing turning operation on a lathe machine using single point cutting tool of H.S.S. Result on tool life and tool wear were compared against other conventional coolant such as (10% Boric acid + SAE-40 Base Oil). Result shows that the vegetable oil easily removed heat produced during the operation and give proper lubrication, thus reducing friction and wear, hence improving the tool life and surface finish.

Elmunafi *et al*. (2015) [7] used a technique called minimal quantity lubrication (MQL), which sprays small amount of cutting fluid (in the range of approximately 10 – 100 ml/h) to the cutting zone area with the aid of compressed air the advantages of both dry cutting and flood cooling are merged using MQL. Castor oil was used as the cutting fluid and the workpiece is hardened stainless steel, hardness 48 HRC. Results obtained were then compared with dry cutting and a significant improvement was found. Workpiece material was hardened stainless steel and coated carbide cutting inserts as cutting tools. A longer tool life was recorded as compared to dry turning, Surface roughness and cutting forces were also enhanced.

Lawal *et al*. (2013) [8] studied the selection of fluid additives for the formation of oil in water emulsion using palm kernel and cottonseed oils are not dangerous or problematic to environment or harmful to the workers. Design of experiment using full factorial method was employed in the process of the cutting fluid formation, while the effect of formulated cutting fluid on the surface roughness and cutting force in the turning AISI 4340 steel with coated carbide using Taguchi method were investigated. Results remarks that cutting speed (64.64%) and feed rate (32.19%) have important effect on the surface roughness and depth of cut (33.1%) and type of cutting fluids (51.1%) have considerable influence on the cutting force.

Ozcelik *et al*. (2011) [9] did a study on the performance of both new developed environmental friendly vegetable based cutting fluid (refined sunflower and canola oils) including different percentage of extreme pressure (EP) additive and two commercial cutting fluids were reported in this work. Performance of cutting fluids were compared with respect to the surface roughness, cutting and feed force and tool wear during longitudinal turning of AISI 304l. Experimental results were also compared with dry cutting condition. The results indicated that 8% of canola based cutting fluid performed better than the rest.

MATERIALS AND METHODS

Lathe Machine

As per the required objective of the present work a lathe machine LMT 20 is used to perform the experiments on surface roughness. The spindle speeds are selected at three level of 150, 250 and 420 rpm and feed rates are also selected at three levels at 0.05, 0.07 and 0.1 mm/rev which are available on the selected machine (Figure 1).

Fig. 1. *Lathe machine.*

Workpiece Material

EN 8 steel is the workpiece material for the study with a hardness of 35 HRC. The diameter of rod is 25 mm with a length of 220 mm. The composition of EN 8 steel is given in Table 1 and the figure of raw workpiece is in Figure 2.

Cutting Tool

Carbide Inserts are used for the present work for which tool holder PCLNR1616H12 I 6H is taken; designation of carbide cutting insert is CNMG 120408 (Figure 3).

MEASUREMENT OF CUTTING FORCE

In present study strain gauge type three component lathe tool dynamometer was used to measure the cutting forces. It was mounted on specially designed fixture as shown in Figure 4. It consists of three force components measurement circuit's i.e. cutting force, feed force and thrust force components with balancing for initial zero setting of the bridge settings. The lathe tool dynamometer was attached to the tool post of the lathe machine. The readings for cutting forces were noted after output stabilization was achieved. The readings obtained from the dynamometer are in kgf to obtain it into standardized unit the readings are multiply 9.81 to convert it into Newton. The specifications of lathe tool dynamometer used are shown in Table 2.

Table 1. *Chemical composition of EN8 steel.*

C	Mn	Si	S	P
0.36%–0.45%	0.6%–1%	0.2%–0.3%	0.025%	0.015%

Table 2. *Technical specification of the dynamometer.*

Components	Details
Sensing Unit	Consist of mild steel cylinder with strain gauges for measurement of three forces
Bridge Balancing Unit(Panel)	Consist of power supply and balancing pot for initial zero
Strains Gauges	Quantity=12 nos., Resistance = 350Ω, Gauge Factor 2±1
Balance pot (Tare)	Ten turn helical potentiometer for Balancing channel
Least Count	1 kg

Fig. 2. *EN 8 steel raw material.*

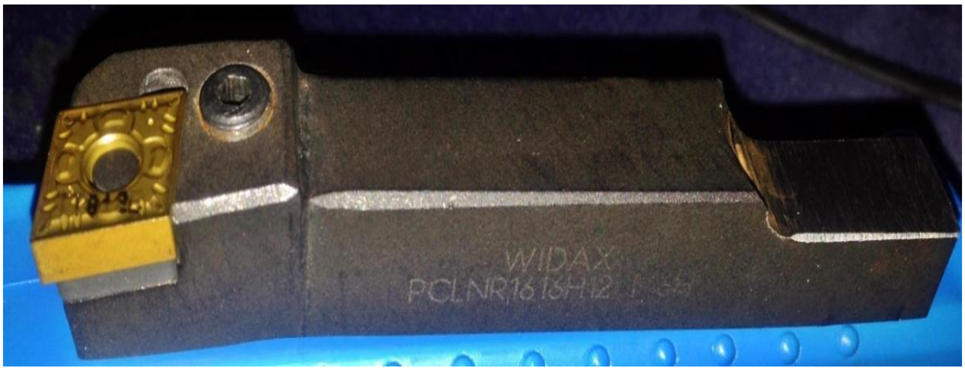

Fig. 3. *Tool holder with insert.*

(a) Dynamometer display *(b) Dynamometer tool holder*

Fig. 4. *Lathe tool dynamometer with tool holder.*

Vegetable Oil Based Cutting Fluid (VBCF)

The present work involves the application of palm oil with two different surfactants (tween 20 and tween 80) as vegetable oil based cutting fluid (VBCF) to evaluate its performance on tool temperature by the change in spindle speed and feed in turning operation.

Palm oil in water emulsion as non-conventional lubricant is prepared using two different non-ionic surfactants (tween 20 and tween 80) in different proportion and their properties are shown in Table 3.

The stability is evaluated by varying surfactant proportion. Higher the surfactant proportions higher the stability of the solution. Thus, maximum proportion of the surfactant used is 20% w/w (tween 20) and 15% w/w (tween 80).

EXPERIMENT PROCEDURE

Here are the steps for the experiment conducted to measure the tool temperature:

1) Checking and preparing the lathe machine ready for performing the machining operation.
2) Performing the initial turning on lathe machine to get the desired dimensions of the EN 8 steel workpiece.
3) Performing the turning operation for the given condition of spindle speed and feed rate.
4) Measuring cutting force with the help of lathe tool dynamometer.
5) After getting the different parameter to optimize the cutting force by using Taguchi method.

Table 3. *Properties of non-ionic surfactants.*

Type of surfactant	Chemical name	Class	HLB	MA (g/mol)	Density (g/cm^3)
Tween 20	Polyoxyethelene (20) Sorbitan monolaurate	Non-ionic	16.7	1228	1.10
Tween 80	Polyxyethelene (80) Sorbitan monooleate	Non-ionic	15.0	1310	1.07

RESULTS AND DISCUSSION

Table 4 indicates the values of cutting force taken for various values of spindle speed and feed rate for EN 8 steel. Depth of cut was kept constant at 1 mm. Three levels of spindle speed and feed are used here. For spindle speed 150, 250 and 420 rpm are taken and for feed 0.05, 0.07 and 0.1 mm/rev are taken which are shown in Table 3.

Table 4. *Tool Temperature values at different cutting parameters.*

Independent parameters		Dependent variable	S/N ratio
Spindle	Feed rate	Maximum cutting force (N)	
Speed (rpm)	(mm/rev)		
150	0.05	434.87	-52.7672
150	0.07	457.73	-53.2122
150	0.10	503.54	-54.0407
250	0.05	454.49	-53.1505
250	0.07	477.35	-53.5767
250	0.10	516.59	-54.2629
420	0.05	470.78	-53.4564
420	0.07	487.16	-53.7534
420	0.10	536.21	-54.5867

Responses and Main Effect Plots

The response table for S/N ratio and means are shown in Table 5, respectively. The main effect plot for S/N ratio and Means are shown in Figures 5 and 6, respectively. The main effects plot indicates that cutting force is significantly influenced by feed rate and spindle speed, which are shown in Figures 5 and 6. Optimum condition for the cutting force is achieved at a feed rate value of 0.1 mm/rev for a speed of 420 rpm and constant depth of cut 1 mm. Further, the model satisfactorily explains the total variance in cutting parameter and it is also reasonably a good fit (R-sq=92.50%, R-sq (add) = 85.01%), shown in Table 5.

Table 5. *Responses of S/N ratio for tool temperature using palm oil based coolant.*

Level	Spindle speed	Feed rate
1	-53.34	-53.12
2	-53.66	-53.51
3	-53.93	-54.30
Delta	0.59	1.17
Rank	2	1

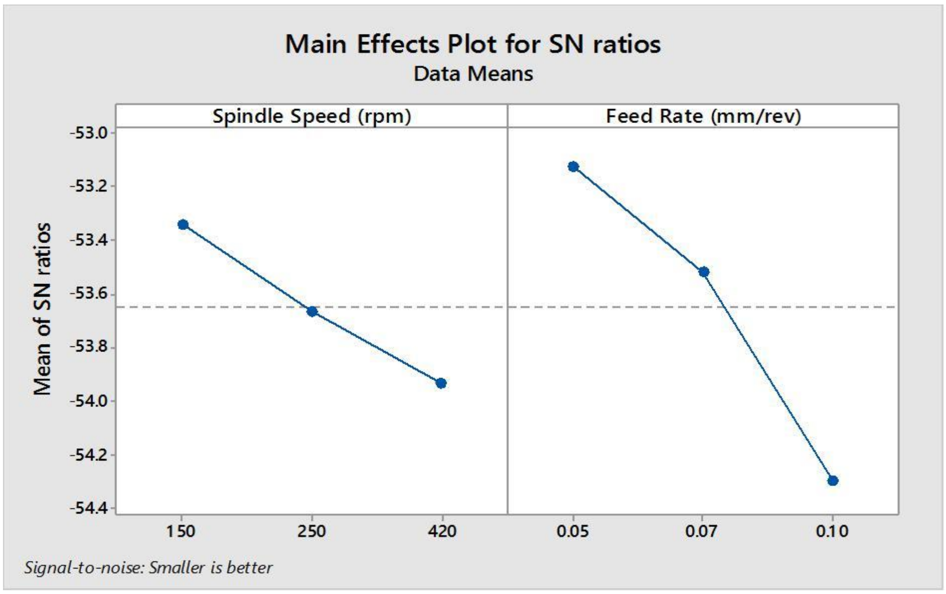

Fig. 5. *Main effects plot of S/N ratio.*

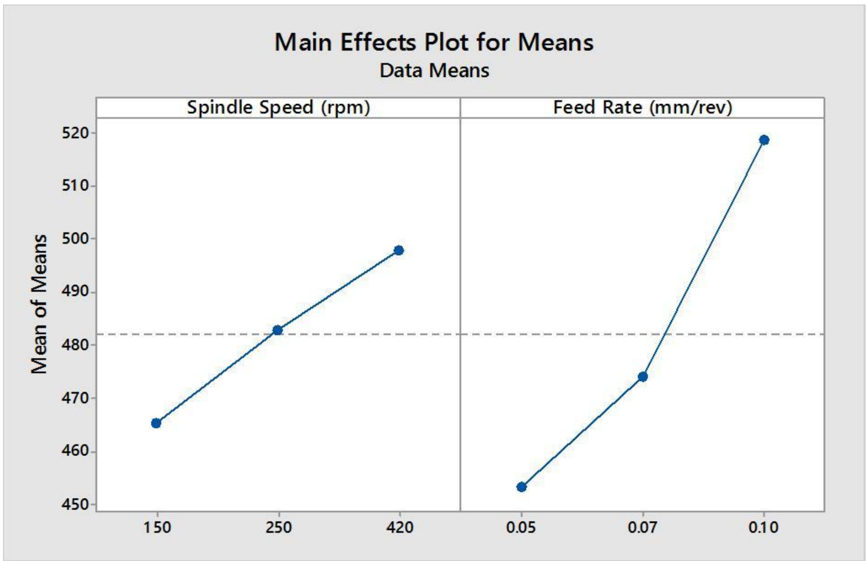

Fig. 6. *Main effect plot for means.*

Analysis of Variance

Table 6 shows variation of actual values of each input parameter with experimental results obtained. Average value of cutting force was statistically analyzed using Minitab 17 Software. Analysis of variance was performed to study the significant of input machining parameters on tool temperature.

It is clear from Table 6 that the effect of spindle speed and feed rate on cutting force is 19.22% and 80.38%, respectively, which is same as obtained from response table for S/N ratio. R-sq represents the significance of experiment work which is 99.60%.

In Analysis of variance, F value is also an indication of more and less affecting parameter. Parameter which has more or less F value indicates most and least affecting parameter. From Table 6, it is seen that the feed rate is more significant parameter as it has high F value spindle speed is less significant parameter as it has less F value (Figure 7).

Interaction Plot

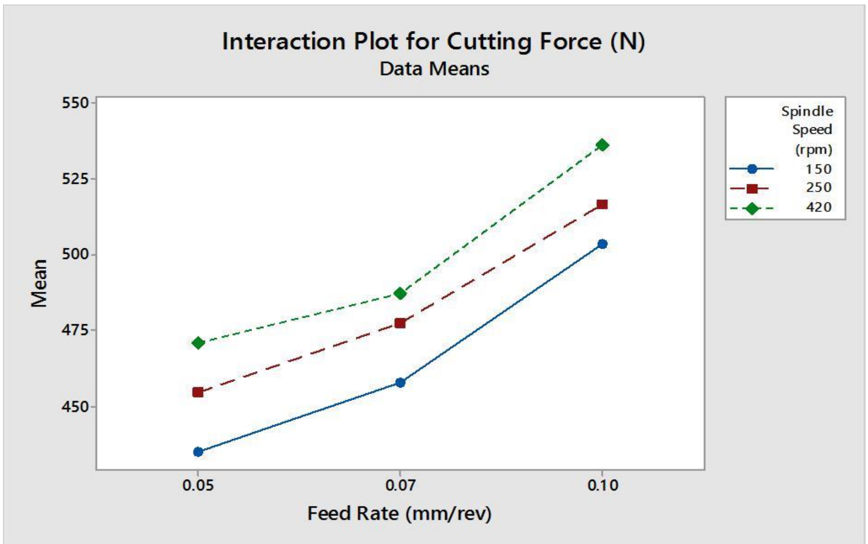

Fig. 7. *Interaction plot for cutting force.*

Table 6. *Response table for means.*

Source value	DF	Seq. SS	Contribution	Adj. SS	Adj. MS	F Value	P Value
Spindle							
Speed	2	1603.39	19.22%	1603.39	801.70	96.64	0.000
(rpm)							
Feed							
Rate	2	6703.74	80.38%	6703.74	3351.87	404.07	0.000
(mm/rev)							
Error	4	33.18	0.40%	33.18	8.30	–	–
Total	8	8340.31	100.00%	–	–	–	–
S = 2.88016			R-sq = 99.60%		R-sq (adj) = 99.20%		

CONCLUSION

In the present research, the cutting force obtained in palm oil (vegetable oil) based cutting fluid turning of EN 8 Steel has been studied. The interest of the study is due to the reasons: to remove the heat generation and thus reducing the cutting force which in turn leads to longer tool life.

For the palm oil (vegetable oil) based cutting fluid, cutting force was analyzed following first-order modals. For cutting force parameter, the most influential factor was feed rate. The investigation results show that optimal condition of cutting force, such as the depth of cut (1 mm constant), feed rate (0.1 rev/min) and seep (420 rpm) can be used to achieve better cutting force reduction in EN 8 steel.

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