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Experimental Investigation of Vegetable Oil Based Cutting Fluid (VBCF) on Surface Roughness in Turning EN-8 Steel

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ABSTRACT

In the present study, properties of the present work of the non-ionic surfactants have been recognized to formulate vegetable oil based cutting fluid (VBCF) palm oil for the emulsion as non-conventional lubricant. Surface finish is an important indicator of quality in manufacturing industries and thus it is regarded as one of the most important parameter to be considered. In this present study, different machining parameters were taken and their effect on surface roughness has been analyzed on vegetable oil based cutting fluid (VBCF) palm oil as non-conventional lubricant. Cutting parameter taken were spindle speed feed rate while the depth of cut was kept constant. EN-8 steel was the work piece material for the study. Further the analysis and optimization of surface roughness was also done using Taguchi method to find the contribution of different cutting parameters on surface roughness. The results show that all the input process parameters affect the surface roughness of EN-8 steel specimen but feed rate affect most.

Keywords: EN-8 steel, surface roughness, Taguchi method, VBCF

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INTRODUCTION

In metal cutting industry, cutting fluids (CFs) is the conventional choice to reducing the temperature and improves surface finished and providing lubrication to tool and work piece, which in turn leads to longer tool life and improved surface finish. Use of lubricants has a significant effect on the reduction of cutting force also, the reduction in cutting force leads to less power consumption which in turn leads to energy saving. The major objectives of the use of cutting fluids (CFs) are to:

(a) Reduce the tool forces and the amount of heat generated.
(b) Increase the tool life.
(c) Improve the 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 a new options like vegetable oil based cutting fluid (VBCF) in machining so as to reduce the tool force and the amount of heat generation, aiding both the production cost and the health of the workers.

Use of vegetable oil based cutting fluid (VBCF) in machining is one of these techniques which has caught interest of many researches around the world and has proved to be a feasible alternative to cutting fluid in controlling the cutting zone temperature without polluting the environment.

Below are some advantages of using vegetable oil based cutting fluid (VBCF) in machining:

1. The problem of pollution caused by conventional lubricants is removed.
2. Health risk caused by the conventional lubricants is eliminated.
3. The temperature reduction achieved by vegetable oil is greater as compared to using conventional lubricant.
4. It protects the tool and work piece from corrosion.

MACHINING

Machining is a process in which small chips are removed from the material or work piece with the help of a cutting tool. Machining is adopted to get better surface finish and close tolerances which are difficult to obtain otherwise. There are various machining process which use single point and multi point cutting tool but one of the most basic machining process is turning in which a single point cutting tool is used to remove the material from the rotating work piece.

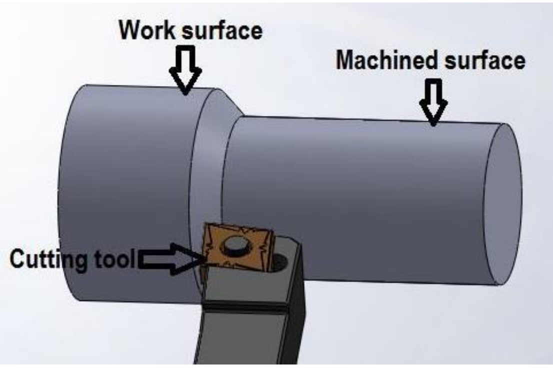

Fig. 1. *Schematic illustration of the basic turning operation.*

Turning operation is a basic metal machining operation which is used widely in industries dealing with metal cutting. In turning process the work material is rotated and the cutting tool will travels linearly, removes a surface layer of the work piece material which is shown in Figure 1. The selection of machining parameters for a turning operation is a very important task in order to accomplish high performance of machining. By high performance, we mean good machinability, minimum heat generation, less cutting forces, better surface quality, less tool wear, higher material removal rate, high rate of production etc.

SURFACE ROUGHNESS

The surface finish of a product is usually measured in terms of a parameter known as surface roughness, it is considered as an index of product quality. Better surface finish can bring about improved strength properties such as resistance to temperature, resistance to corrosion and higher fatigue life of the machined surface. Surface finish also affects production costs. For the aforesaid reasons, the minimization of the surface roughness is essential which in turn can be achieved by optimizing some of the cutting parameters like cutting speed, feed, depth of cut etc.

VEGETABLE OIL BASED CUTTING FLUID IN MACHINING

Vegetable oil based cutting fluid in machining is a novel technique to reduce the machining zone temperature and provide lubrication. The present work involves the application of palm oil as vegetable oil based cutting fluid (VBCF). The triglyceride structure of palm oil based cutting fluid provides qualities desirable in lubricant. Long, polar fatty acid chains provide high strength lubricant film that interacts strongly with metallic surface, reducing both friction and wear. The strong intermolecular interactions are also resilient to change in temperature providing a more stable viscosity, or high viscosity co-efficient. Following are the advantages of palm oil based cutting fluid:

a) Reducing the cutting zone temperature and providing lubrication thus improving the tool life.

b) Provides better surface finish.
c) Flushing away the chips.
d) Operator friendly.
e) Provides a protective layer to the work piece thus preventing it from corrosion.
f) Machine tool cleaning is not required thus saving time and cost.
g) They can perform well under condition of high load and temperature also.

PROBLEM STATEMENT

In machining process, obtaining the accurate dimensions and achieving a good surface quality is most important. A machining process involves many process parameters which directly or indirectly influence the surface quality of the product. Temperature reduction is also very vital step in machining operation but due to harmful effects to the environment and the operator by the conventional cooling techniques there is a need to develop new user friendly and environmental friendly technique. In the present study, the effect of palm oil as vegetable oil based cutting fluid (VBCF) with two non-ionic surfactant Tween 20 and Tween 80 is studied by measuring tool temperature, cutting forces and surface roughness under various cutting parameters. Finally, a comparison of palm oil as vegetable oil based cutting fluid (VBCF) is made with dry cutting and conventional coolant for the same cutting parameters and measured responses to find the best cutting environment.

REVIEW OF LITERATURE

Vegetable Oil

Gunerkar and Kuppan, (2013) 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. 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 [1].

Elmunafi *et al.* (2015) 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 work piece is hardened stainless steel, hardness 48 HRC. Results obtained were then compared with dry cutting and a significant improvement was found. Work piece 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 [2].

Law al *et al*. (2013) 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. They found in results that cutting speed (64.64%) and feed rate (32.19%) both have marked effect on the surface roughness and depth of cut (33.1%) and type of cutting fluids (51.1%) also gave a marked effect on the cutting force [3].

Ozcelik *et al*. (2011) 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. [4] Sodavadia and Makwana (2014) investigated the application of lubricant suspension in coconut oil during turning of AISI 304 austenitic stainless steel with carbide tool. Lubricant of 50 μm particle size was suspended in coconut oil as base lubricant. So, the variation of average tool flank wear, surface roughness and cutting tool temperature with cutting speed and feed rate were identify with lubricant suspensions in coconut oil. Results shown that, cutting temperatures, surface roughness and tool flank wear were decreased significantly with lubricants compared to base oil, due to the better lubricating properties of it [5].

Surface Roughness

Nalbant *et al.* (2007) worked on Taguchi method to find the optimal cutting parameters for surface roughness in turning operation. The orthogonal array, signal- to-noise ratio, and ANOVA were employed to study the performance characteristics in turning process of AISI 1030 steel bars using TiN coated tools. Three cutting parameters namely, feed rate, depth of cut and insert radius, were optimized with considerations of surface roughness. Experimental results were provided to illustrate the effectiveness of this approach [6].

Davim *et al*. (2008) did study on the effects of cutting parameters during turning of 9SMnPb28k (DIN), free machining steel. The Artificial Neural Network model of surface roughness parameters (Ra and Rt) was developed with the cutting parameters such as cutting speed, feed rate, and depth of cut as the affecting cutting parameters. The experiments were planned as per L27 orthogonal array with three different levels defined for each of the parameter in order to develop the knowledgebase for artificial neural network training using error back-propagation training algorithm. The analysis conclude that feed rate and cutting speed has significant effect in decreasing the surface roughness, while the depth of cut has the least effect [7].

Chock Lingam and Wee (2012) conclude the effect of different coolant conditions on milling of AISI 304 stainless steel. Cooling techniques used in this research were water-based emulsion, flooding of synthetic oil and compressed cold air. The surface roughness and cutting forces were studied and tool flank wears were observed. The experiment results indicate that water-based emulsion gave better surface finish and lower cutting force followed by compressed cold air and synthetic oil. Different cooling condition required different cutting parameters in order to obtain lower surface roughness and cutting force [8].

Singh *et al.* (2012) studied the effects of electrical discharge machining (EDM) parameters on surface roughness. H 13 steel was used as work material.

Experiments were conducted using Taguchi methodology to determine the effects of EDM process parameter. Peak current, pulse on time, polarity, gap voltage, duty cycle, and concentration of abrasives powder in dielectric fluid were taken as process input parameters. An analysis of variance was carried out to identify the significant factors that affect the surface roughness. The results indicate that all the input process parameters affect the surface roughness of H13 steel specimen [9].

Makadia and Nanavati (2013) studied on the effect of turning parameters such as cutting speed, feed rate, depth of cut, and tool nose radius on the surface roughness of AISI 410 steel. The effect of these process parameters on the surface roughness was investigated by using Response Surface Methodology (RSM). The developed prediction equation indicates that the feed rate was the main factor followed by tool nose radius which influences the surface roughness. The surface roughness was found to increase with the increase in the feed rate and it reduced with increase in the tool nose radius [10].

Revankar *et al.* (2013) investigated the influence of cutting speed, feed rate and different amount of Minimum Quantity Lubrication on machining performance during turning of titanium alloy (Ti–6Al–4V) using poly crystalline diamond tool. The experiments had been planned as per Taguchi‘s orthogonal array and the second order surface roughness model in terms of process parameters was developed using response surface methodology (RSM). The parametric analysis had been carried out to analyze the interaction effects of process parameters on surface roughness [11].

MATERIAL AND METHODS

Material Selection

Present work basically involves the use of turning operation on as it is most widely adopted method for machining and also plays a crucial role in affecting quality of machined part. Equipment selection to measure the dependent parameters also play a crucial role as they provide the final outcome of the result. Thus, the requirements of experimental setups are as follows:

- Machine tool
- Work material
- Cutting tool
- Non-conventional lubricant and non-ionic surfactants
- Surface roughness measurement

Machine Tool

In accordance with objective of the present work, the complete set of experiment was performed using conventional center lathe HMT (Hindustan Machine Tool) LTM 20 (Figure 2).

Fig. 2. *HMT LTM 20 center lathe machine.*

Work Material

The work piece material used for the present study was EN-8 steel. EN-8 steel in its heat treated forms possesses good homogenous metallurgical structures, giving consistent machining properties and has a good tensile strength (Tables 1 and 2) (Figures 3 and 4).

Table 1. *Mechanical properties of EN-8 steel.*

Hardness	Elongation	Tensile Stress	Yield Stress	Max Stress
35 ±2 HRC	16% Min	550 Mpa	280 Mpa	700-850 Mpa

Table 2. *Chemical composition of EN-8 steel.*

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

Cutting Tool

Tool Holder

The tool holder used for the research work was PCLNR1616H12 I 6H manufactured by WIDAX. The rear position's height and width were made 12 mm each so as to ensure that it fits the dynamometer tool holder as shown in Figure 5.

Fig. 3. *Raw work piece material.*

Fig. 4. *Machined workpiece material.*

Cutting Tool Inserts

In present study, the tool insert chosen was a coated carbide tool CNMG120404 manufactured by Taegu Tec as shown in Figure 6.

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, cutting force and surface roughness by the change in spindle speed and feed in turning operation Figure 7.

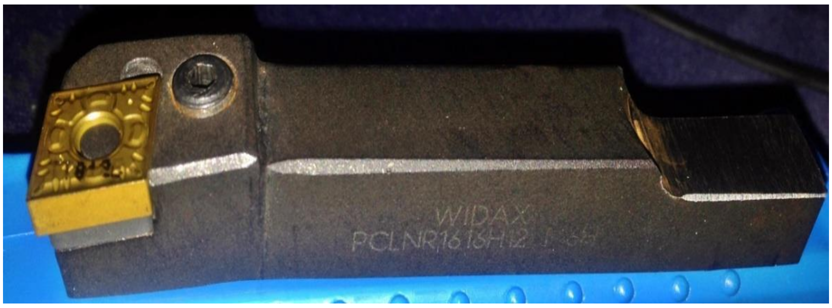

Fig. 5. *Tool holder with cutting insert.*

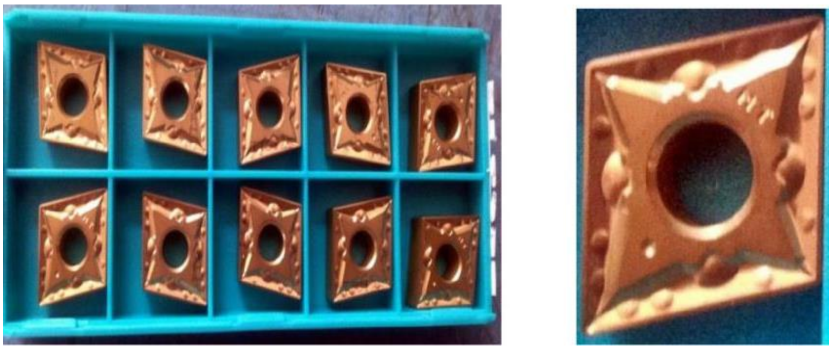

Fig. 6. *Cutting insert.*

Fig. 7. *Palm oil based cutting fluid.*

The triglyceride structure of palm oil provides qualities desirable in Lubricant. Long, polar fatty acid chains provide high strength lubricant film that interacts strongly with metallic surface, reducing both friction and wear. The strong intermolecular interactions are also resilient to change in temperature providing a more stable viscosity, or high viscosity co-efficient.

Lubricant Delivery System

For the present study, lubricant supply system was developed which would deliver the conventional and non-conventional lubricant (VBCF) at the machining zone. The vegetable oil based cutting fluid was kept in a container and placed above the machining axis. The container was kept open to atmosphere and the flow of vegetable oil based cutting fluid was controlled by a regulating valve. The rate at which the conventional and non-conventional lubricant (VBCF) was applied at the tool chip interface is 10 mml/min. The line diagram of the delivery system is shown in Figure 8(a) and the actual diagram is shown in Figure 8(b).

Surface Roughness Measurement

There are two different surface roughness measurement techniques, which are divided as in-process and post-process measurement. For the present work, post process measurement technique was used which is done after completion of the machining process and surface roughness of the finished work piece material was measured using Mitutoyo SURFTEST SJ-210 which shown in Figure 9.

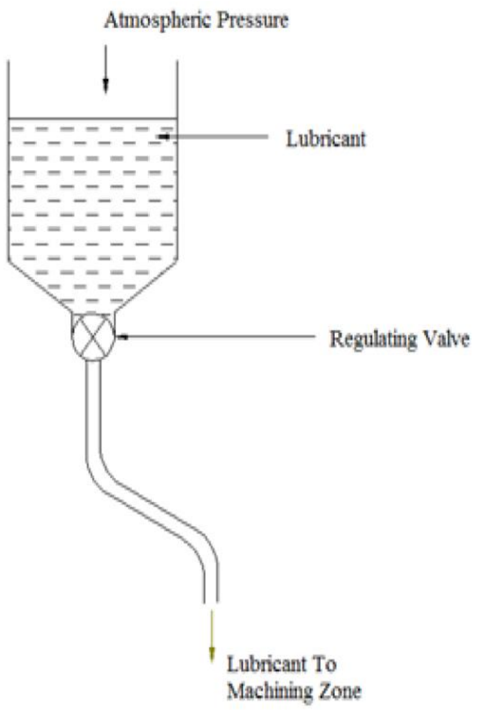

Fig. 8. *Vegetable oil based lubricant delivery system. (a) Line Diagram. (b) Actual Setup.*

Fig. 9. *Mitutoyo Surf Test SJ-210.*

EXPERIMENTAL PROCEDURE

In the present study, an attempt has been made to experimentally investigate the effects of cutting parameters using different kinds of cutting environments i.e. dry, conventional coolant and vegetable oil based coolant on surface roughness, tool temperature and cutting force.

The present work involves the application of palm oil as vegetable oil based cutting fluid (VBCF). 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).

The oil in water emulsion is prepared using mechanical stirred; the solution is stirred for 15 minutes still stability is achieved at 1400 RPM continuously. To observe the stability of the emulsion visually, emulsion is keep in a closed test tube for some hours and its dilution produces very stable cutting fluid emulsion maintaining the stability between oil and water phase up to 36 hours. Viscosity is measured using redwood viscometer at 40 degree Celsius. Vegetable oil based cutting fluid (VBCF) is mixed with water in oil to water ratio of 1:100.

Firstly, experimental data analysed and after that comparison between different cutting environments made to find the most effective cutting environment based on the measured responses, then for the most effective cutting environment the best combination of the cutting parameters will be deduced.

The present study is divided into three stages, in the first stage experimental design for the selection of levels and run is carried out. Secondly, the experiments are performed for each run at different levels and the collection of data for the research work is done. Finally, the third stage focuses on analysis of the collected data using mathematical and statistical tools.

RESULTS AND DISCUSSION

Table 3 indicates the values of surface roughness 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 3. *Surface roughness for different independent parameters using palm oil based coolant.*

Independent Parameters		Dependent Variable	
Spindle Speed (rpm)	**Feed Rate (mm/rev)**	**Mean Surface Roughness (µm)**	**S/N Ratio**
150	0.05	2.604	-8.3128
150	0.07	3.910	-11.8435
150	0.10	4.939	-13.8728
250	0.05	1.989	-5.9727
250	0.07	3.400	-10.6296
250	0.10	4.725	-13.4880
420	0.05	1.589	-4.0225
420	0.07	2.558	-8.1580
420	0.10	4.234	-12.5350

The influence of cutting parameters such as cutting speed and feed rate on the surface roughness of machined work material in palm oil based coolant is discussed with the help of statistical approach. The experimental results of surface roughness in palm oil based coolant and corresponding S/N ratios for the results obtained are presented in Table 3.

TAGUCHI METHOD FOR SURFACE ROUGHNESS

For the analysis of surface roughness in Palm oil based coolant, S/N ratio is calculated based on 'the smaller is better' criterion for surface roughness. Influences of each Independent parameter on surface roughness is obtained from the response table and main effect plot for S/N ratio which shown in Table 4 and Figure 10 respectively.

Table 4. *Responses of S/N ratio for surface roughness using palm oil based coolant.*

Level	Spindle Speed	Feed Rate
1	-11.343	-6.103
2	-10.030	-10.210
3	-8.239	-13.299
Delta	3.105	7.196
Rank	2	1

ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS

The analysis of variance (ANOVA) was applied to study the effect of the input parameters on the surface roughness. Table 5 shows the results of ANOVA with the surface roughness of machined work material in palm oil based coolant. The 4th column of the Table 5 indicates the percentage of contribution of the each parameter on the surface roughness.

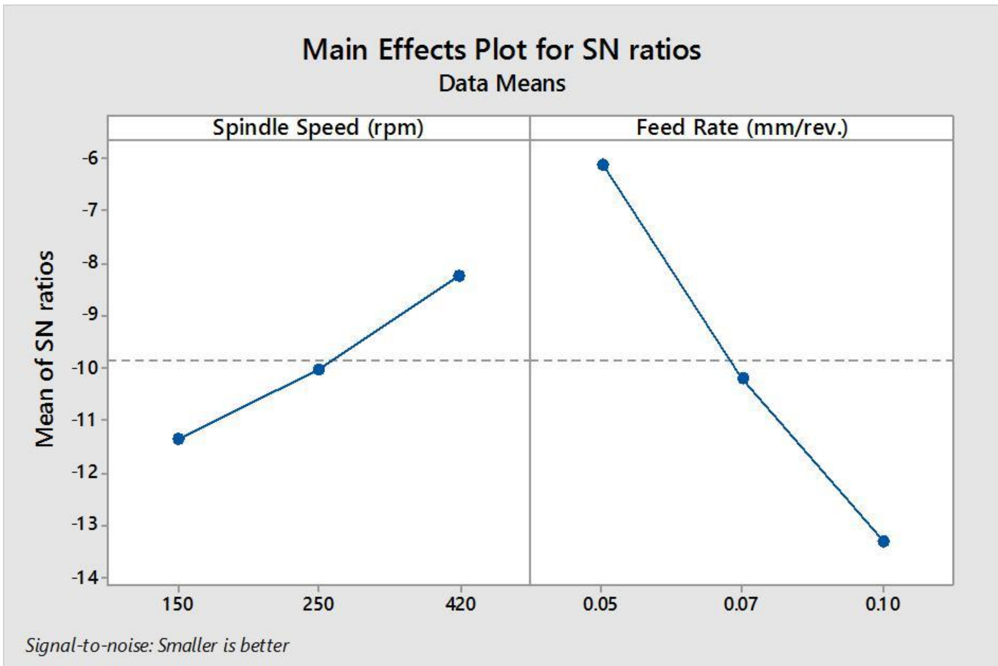

Fig. 10. *Palm oil based coolant main effect plot of S/N ratio for surface roughness.*

Table 5. *Palm oil based coolant analysis of variance for surface roughness.*

Source Value	DF	Seq. SS	Contribution	Adj. SS	Adj. MS	F Value	P Value
Spindle Speed (rpm)	2	1.5815	13.58%	1.5815	0.79074	23.44	0.006
Feed Rate (mm/rev)	2	9.9294	85.26%	9.9294	4.96468	147.15	0.000
Error	4	0.1350	1.16%	0.1350	0.03374	–	–
Total	8	11.6458	100.00%	–	–	–	–
S = 0.183679			R-sq = 98.84%		R-sq (adj) = 97.68%		

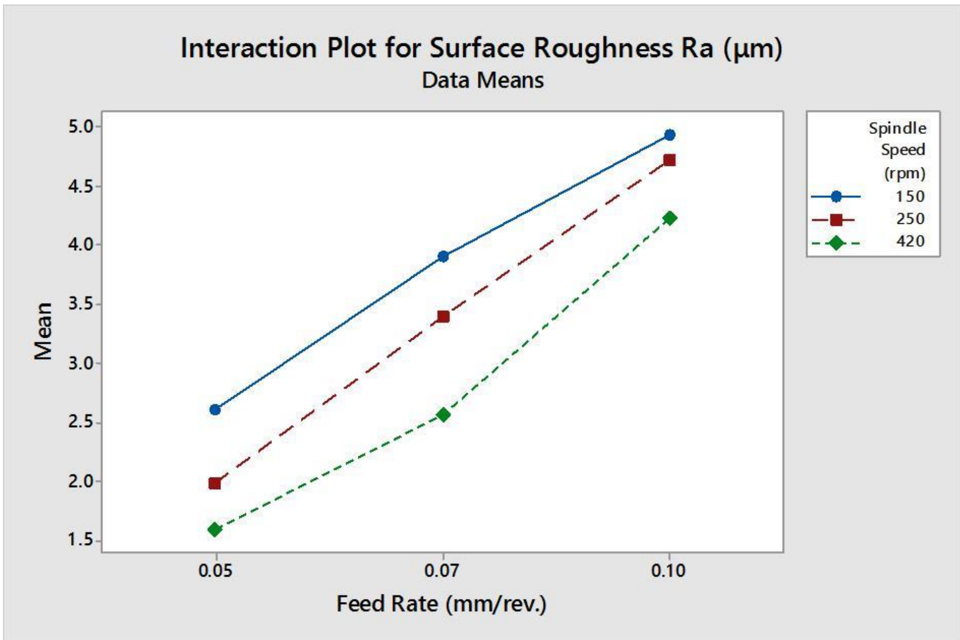

Fig. 11. *Interaction plot for surface roughness in palm oil based coolant.*

From the Analysis of variance, the contribution of the spindle speed is 13.58% and feed rate is 85.26% on surface roughness which is in similar order as shown in Table 4. R-sq value represents the significance of the experimental work which is 98.84%. Table 5 shows that feed rate is more significant parameter as it has high F value while spindle speed is less significant parameter as it has lower F.

The interaction plot generated for given experimental measurements show the change in surface roughness for given parameters of spindle speed and feed rate in Figure 11.

CONCLUSIONS

- Surface roughness and cutting parameters (i.e. SS and FR) have high non-linear relationships among them for all cutting environments.
- Amongst the cutting parameters, feed rate affects the surface roughness to greatly extent while the spindle speed has least effect on surface roughness.

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