RESPONSE SURFACE MODELING FOR CUTTING FORCE AND POWER CONSUMPTION DURING TURNING USING VEGETABLE OILS

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ABSTRACT

Minimum quantity lubrication (MQL) is an impending technique to reduce the amount of cutting fluid and to improve the performance of the manufacturing process. Nowadays, researchers are trying to eliminate the harmful mineral- based cutting fluids. It is necessary to develop a low cost MQL system and to evaluate its performance using vegetable oil as cutting fluid in comparison with dry and flood cutting. To sustain the quality, to reduce the machining costs and to increase the production rate, selection of optimal cutting parameters as such is an important task. Response surface methodology is used to examine the experimental results. Numerical model for each cutting forces and power consumption is developed to show the relation between significant parameters such as cutting speed, depth of cut and feed rate. Analysis of variance test is performed to make sure the adequacy of the developed model. To find out the best combination of the cutting speed, feed and depth of cut for desired performance, multi-response optimization is carried out. Desirability value shows the feasibility of optimization for multiple responses. The results showed that all the developed models are accurate and adequate. MQL with vegetable oil performed better as compared to mineral-based oil.

KEYWORDS: *RSM; MQL; Vegetable Oil; Cutting Fluids*

1.0 INTRODUCTION

In India, a large amount of mineral-based cutting fluids are used in both large scale and medium scale industries. Most of the operators working on machine suffer from skin disease and lung cancer. Mineral-based cutting fluids are very costly (King, 2001). Most of the small-scale and medium-scale industries are unaware of the demerits of the cutting fluids. Depleting nature of petroleum-based oils, health-associated problems, cost, pollution, government regulations force industries to develop alternative technologies. Enormous efforts are made to reduce petroleum-based cutting fluids. Dry cutting is one of the alternatives but it increases wear rate, and the elevated temperature is a major concern. Dry cutting is not proved as the best alternative to flood cutting. Minimum quantity of lubrication is emerged as a substitute for dry machining and flood cutting.

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The manufacturing industry struggles to achieve the minimum cost of production or the maximum productivity. These two measures are interrelated with a choice of cutting conditions. For turning operations, the input parameters like depth of cut, speed, feed, tool geometry etc. will decide the performance parameter. Proper selection of input parameter is very crucial to get the desired output. Performing experiment trial and deciding the optimum values from the experience require skill, are time consuming and costly. A factorial experiment is an experimental strategy in which design variables are varied together, instead of one at a time. Response surface methodology is one tool for obtaining the optimum values for the anticipated goal. Optimization is the technique to achieve the best outcome under specified situations. The condition at which performance of the system is maximum is an optimized condition. Desirability function method is the controlling tool for solving the multiple performance optimization problems, where all the objectives are accomplished with a definite goal simultaneously. The main aim of this paper is to compare the performance of different vegetable oils in terms of cutting forces and power consumption.

2.0 LITERATURE REVIEW

Mineral-based cutting fluids are expensive, as well as unsafe to human beings. The U.S. Occupational Safety and Health Administration, National Institute for Occupational Safety and Health has set a limit for the exposure level to metal-working fluids (NIOSH, 1998). Bennett et al. (1987) advised that exposure to cutting fluid increases risk of airway irritation, chronic bronchitis, asthma and cancer. Low et al. (1989) studied the health issues associated with metal-working fluid. In view of the limitations of the cutting fluid, dry cutting is considered as an alternative to flood cutting. Klocke et al. (1997) discussed the most recent developments in dry cutting. Sreejith et.al. (2000) focused on dry machining techniques like under cooling, intercooling, thermoelectric cooling and cryogenic system. Dry cutting has several limitations like elevated temperature, more tool wear and deterioration of product quality. Minimum Quantity Lubrication minimizes the use of cutting fluid. Heisel et al. (1994) applied MQL in machining with geometrically- defined edges. Minimum quantity of lubrication cannot eliminate the cutting fluid. Vegetable-based oil with MQL has been evolved as an innovative technique for machining. Khan M (2006) investigated the effect of MQL by vegetable oil on cutting temperature, tool wear, surface roughness and dimensional deviation in turning AISI-1060 steel. There was an improvement in the performance by using vegetable oil. S.Lawal et al. (2007) revealed that performance of cutting fluid from fixed oil-based cutting fluid was better in comparison with mineral-based cutting fluids. Lawal et al. (2008) assessed lubricants like black soap, groundnut oil, palm kernel oil, red palm oil and shea butter oil. Xavior (2009) determined the influence of coconut oil on tool wear and surface roughness during turning of AISI 304. Kuram et al. (2011) focused on the formulation of cutting fluids with vegetable oil-based and evaluation of the performance of these cutting fluids. Rahim and Sasahara (2011) studied the effect of the palm oil as MQL lubricant on high speed drilling of titanium. Shashidhara et al. (2013) observed that pongam and jatropha offered better performance as compared to commercially available branded mineral oil.

Using statistical design of experiments, large data was selected in the minimum experimental trial. This resulted to time and cost saving. Davim (2003) developed regression equations stating relations between cutting speed; feed and the cutting time with the tool wear. Noordin (2004) used response surface methodology for evaluating the performance of coated carbide tools during turning AISI1045 steel. Faleh (2005) observed that power consumption is one of the most important parameters for condition monitoring. Suresh (2012) et al. used ANOVA to analyze the significant factors having effect on the output.

Very few studies are available on using soyabean oil, coconut oil, sunflower oil and groundnut oil as cutting fluid. Technical illiteracy, casual approach towards the health of employee are the main obstacle in the growth of the small-scale industry. The performance of the MQL using vegetable oil needs to be checked to decide the best cutting oil. For maximizing the performance or minimizing the production cost, the statistical tools like Taguchi and response surface methodology can be employed for determining the optimum parameter. The main objective of this paper is to compare the performance of different vegetable oils in terms in terms of cutting forces and power consumption.

3.0 METHODOLOGY

Conventional experimental design methods are very complex and difficult to use. They require a large number of trials when the number of process parameters is more. To reduce the number of trials, 3^3 full factorial design by one replica is selected for investigation.The values of the three input parameter i.e. speed, depth of cut and feed are selected on the basis of industry practices, particularly small industry, capacity and limitation of the lathe machine used. Cylindrical bar of AISI 4130 (diameter 60 mm and length of 120 mm) is used as work piece material.AISI 4130 contains 0.3 % carbon, 0.52 % Mn, 0.24 % Si, 1.06 % Cr along with sulphur, phosphorous and nitrogen. Uncoated carbide tipped brazed tools with the specification of back rake angle 12º, nose radius 0.4 mm is used for investigation.Turning was carried out on medium duty lathe machine at different cutting speeds, feeds and cutting depths under MQL conditions. Table 1 shows the machining parameter, coolant condition and details of the cutting tool selected for experimentation.

Table 1. Machining parameters

Experimental condition	Description
Cutting parameter	Cutting speed, *v* (m/min) = 35, 53, 80 Feed rate, *f* (mm/rev) = 0.35,0.40,0.45 Depth of cut , *d* (mm) = 0.5,1,1.5
Coolant flow rate	MQL-50 ml/hr
Cutting tool	Uncoated brazed carbide tool (P-30.ISO 6, Make-Miranda, R1616)

Figure 1. Experiment setup of medium duty lathe machine and MQL system

The experimental set up consists of medium duty lathe machine and MQL system. MQL system consists of air compressor, oil tank, flow control valve and nozzle as shown in Figure 1. Experiments were conducted for MQL cutting. Soya bean oil and sunflower oil are comparatively cheap and easily available. The properties of soya bean oil, sunflower oil are comparable to the commercially available cutting; hence theses oils are considered as cutting fluid for testing. Blasocut-4000 is a water miscible, mineral-based cutting fluid. It is used in medium and small-scale industries in large quantity; therefore, it is selected to compare against vegetable oils. Cutting forces were measured with the help of strain gauge type three-component lathe tool dynamometer. Consumption of power plays a very important role in any industry, where efforts are made to reduce the power consumed during any machining process. Power consumption can be determined by multiplication of cutting force to velocity.

4.0 MATHEMATICAL MODELING

The primary task of the manufacturers is to improve the productivity and to lower the production cost, for which selection of machining parameters plays a significant role. It is necessary to study the relationship between various machining parameters and the performance parameter. Regression analysis is used to develop mathematical models to predict the results when combinations of machining parameters interact under various conditions. Generally, a second-order model is utilized in response surface methodology.

Equations (1) to (3) represent mathematical models (regression equation) developed for cutting forces during blasocut, sunflower and soyabean oil cutting while Equations (4) to (6) represent power consumption model for blasocut, sunflower and soya bean oil respectively.

Cutting force (F_c)

Regression equations for MQL-(Blasocut)

$$F_{c,blasocut} = 1023 - 2.86v - 3616f + 167.2dp + 0.00826v \times v + 4397f \times f - 31.8dp \times dp + 4.14v \times f + 0.038v \times dp + 6f \times dp \quad (1)$$

Regression equations for sunflower oil

$$F_{c,sunflower} = 1034 - 2.80v - 3708f + 170.1dp + 0.00710v \times v + 4472f \times f - 36.8dp \times dp + 4.33v \times f + 0.016v \times dp + 23f \times dp \quad (2)$$

Regression equations for soya bean oil

$$F_{c,soya\ bean} = 565 - 1.99v - 1782f + 289.3dp + 0.0751v \times v + 2404f \times f - 45.9dp \times dp + 2.32v \times f - 0.147v \times dp - 219.3f \times dp \quad (3)$$

Power consumption (P)

Regression equations for MQL-(Blasocut)

$$P_{blasocut} = 0.895 + 0.00162v - 4.29f + 0.0304dp + 0.000004v \times v + 5.09f \times f + 0.0261dp \times dp + 0.00586v \times f + 0.001836v \times dp + 0.050f \times dp \quad (4)$$

Regression equations for sunflower oil

$$P_{sunflower} = 0.914 + 0.00157v - 4.39f + 0.0312dp + 0.000002v \times v + 5.16f \times f - 0.0294dp \times dp + 0.00609v \times f + 0.001794v \times dp + 0.067f \times dp \quad (5)$$

Regression equations for soya bean oil

$$P_{soya\ bean} = 0.421 + 0.00255v - 2.31f + 0.1632dp + 0.000001v \times v + 2.98f \times f - 0.0412dp \times dp + 0.00314v \times f + 0.001574v \times dp - 0.1872f \times dp\ldots \quad (6)$$

Residual graphs are plotted for cutting forces and power consumption for MQL cutting of blasocut, soyabean oil, sunflower as shown in Figure 2 to Figure 7.The normal probability curve for blasocut, soya bean and sunflower shows residual are falling on straight line. It indicates the model is accurate and adequate. The histogram shows bell-shaped curve, which designates that residuals are normally distributed. Residual vs. fitted values graph shows residual of mean values are distributed randomly. The graph of Residual vs. Order does not follow any structured pattern which indicates that these variables are independent. For all the cutting conditions, the nature of graph is analogous; this implies the entire developed models are significant and adequate.

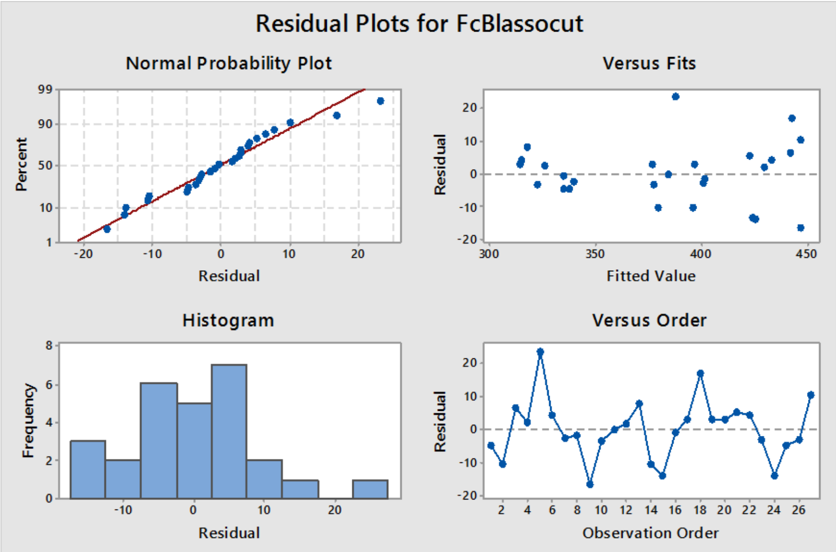

Figure 2. Residual plots for cutting forces (MQL- Blasocut)

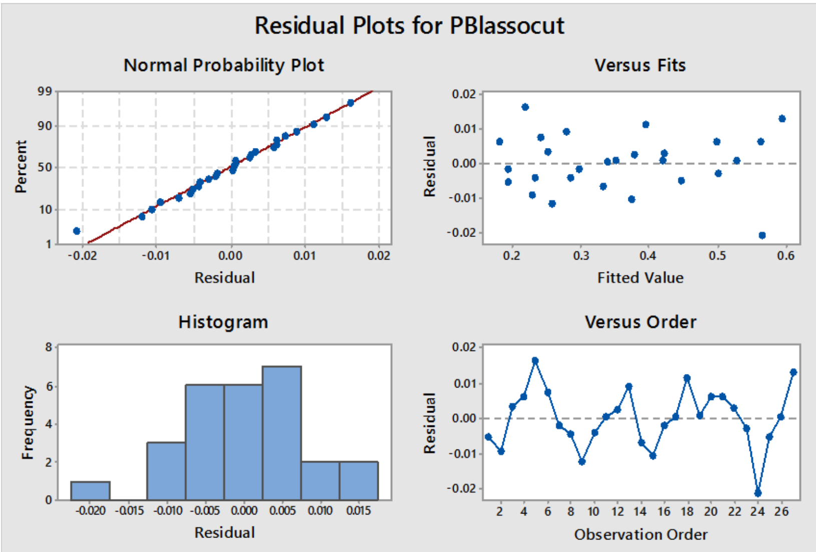

Figure 3. Residual power consumption (MQL- Blasocut)

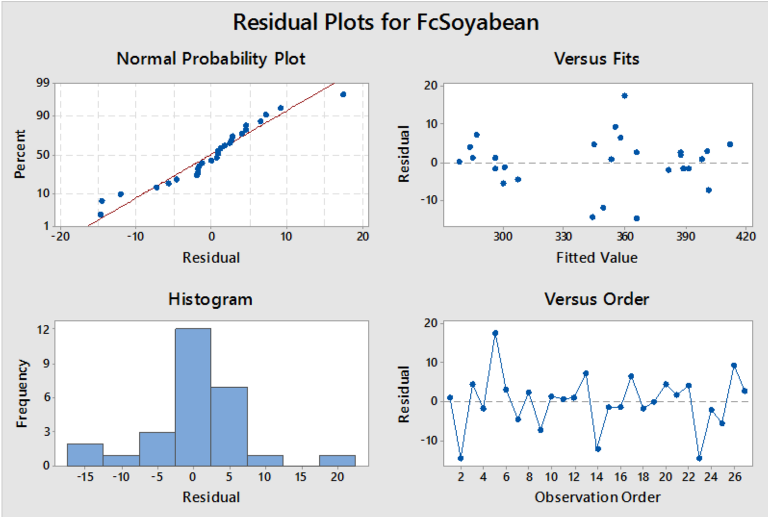

Figure 4. Residual plots for cutting forces (MQL- Soya bean)

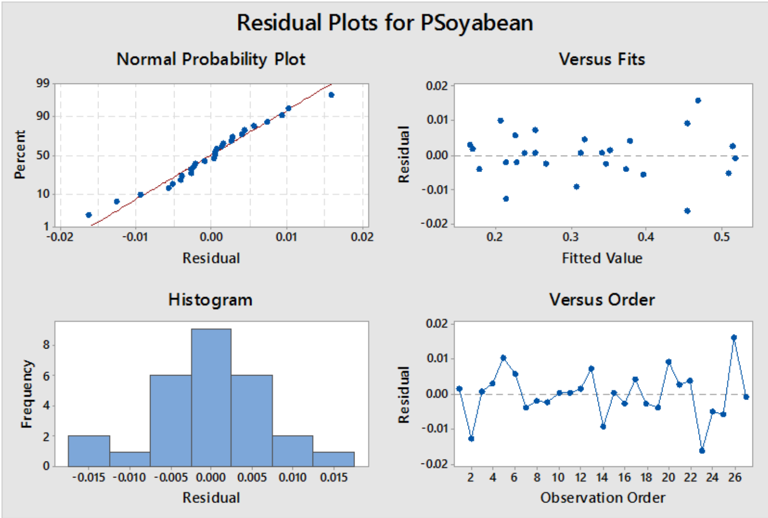

Figure 5. Residual plots for power consumption (MQL- Soya bean)

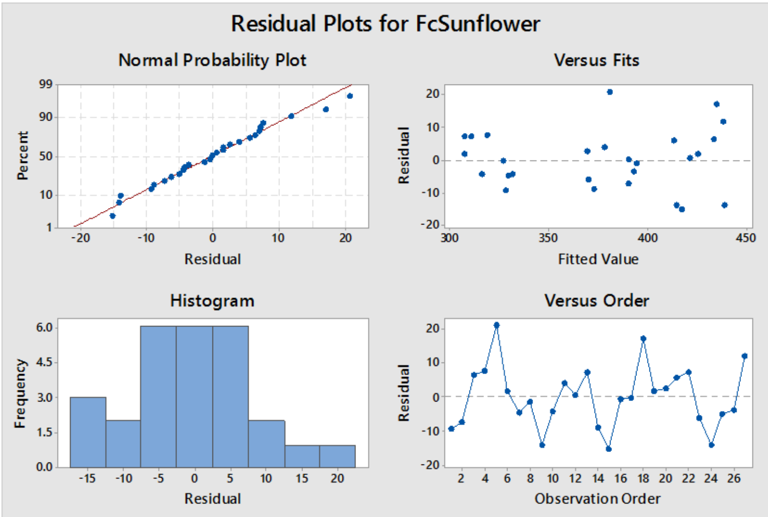

Figure 6. Residual plots for cutting forces (MQL- Sunflower)

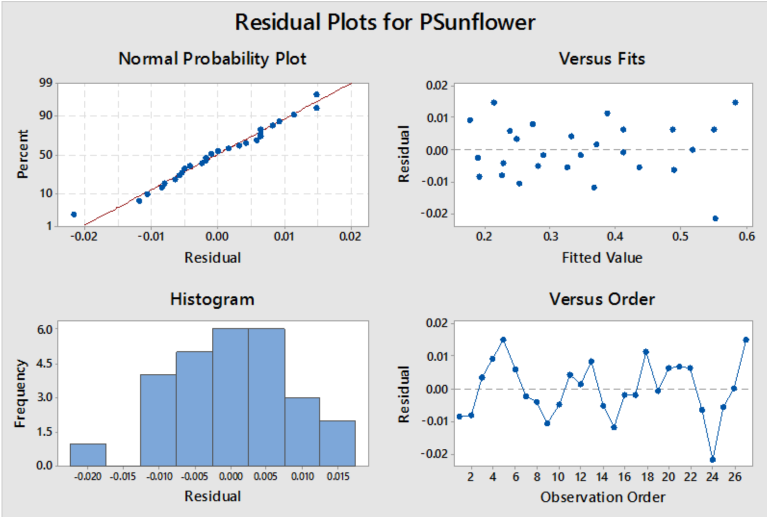

Figure 7. Residual plots for power consumption (MQL- Sunflower)

Analysis of variance (ANOVA) test is carried out to check the adequacy of the model. *F* and *P* value will be helpful for deciding the most significant factor. Table 2 shows the results of the ANOVA testing for different cutting fluid.

Table 2. ANOVA table for different cutting fluid.

Oil / Factor	Blasocut		Sunflower oil		Soya bean oil	
	Cutting Force (N)	Power (KW)	Cutting Force (N)	Power (KW)	Cutting Force (N)	Power (KW)
R^2 (%)	96.34	99.57	96.28	99.52	97.50	99.63
Adj. R^2 (%)	94.40	99.35	94.31	99.26	96.18	99.44
Pre. R^2 (%)	90.77	99.38	90.40	98.70	94.508	99.18
Model F	49.65	442.53	48.90	389.1	73.76	510.1
P	0.000	0.000	0.000	0.000	0.000	0.000

4.1 Cutting Force and Power Consumption Model for MQL (Blasocut)

The *P* value for the cutting force model is less than the significant level. The model value for cutting forces during Blasocut cutting is 49.65, which is larger than the critical value. Model is significant. R^2 value is 96.34 %, which indicates that the second order model was adequate to represent the machining process precisely. Adj. R^2 and Pre. R^2 are in decent agreement with each other (94.40 % and 90.77 % respectively).

Model *F* value for power consumption is 442.53. It is more than $F_{critical}$, which depicts that regression equations representing the true machining process. The R^2 value for power consumption is 99.57 %. This concludes that regression models fit into the observed data. Adj.R^2 is 99.35 %, Pre. R^2 is 98.88 %. Both values are in reasonable agreement.

4.2 Cutting Force and Power Consumption Model for MQL (Sunflower oil)

The *P* value for cutting force of sunflower oil model is zero, which states that model term is significant. R^2 are 96.28 %., which shows that second order quadratic model is acceptable. Adj. R^2 is 94.31 % and Pre. R^2 is 90.40%. Adj. R^2 and Pre. R^2 are in good agreement as shown in Table 2.

The *p* value for power consumption model term is zero as shown in Table 2. Model *F* value is very large as compared to $F_{critical}$. Model term is statistically significant. The R^2 value for power consumption is 99.52 %. Adj. R^2 is 99.26 % and Pre. R^2 is 98.70 %. Adjusted and predicted R^2 values are in reasonable agreement.

4.3 Cutting Force and Power Consumption Model for MQL (Soyabean Oil)

The *F* value for cutting forces model for soya bean oil is 73.76 as shown in Table 2, which is larger than the $F_{critical}$. This evidences that the model is significant. R^2 for cutting forces during MQL using soya bean oil cutting is 97.50%. Adj. R^2 and Pre. R^2 are in respectable agreement as shown in Table 2.

Model *F* value for power consumption for soya bean oil (510) is very large as compared to $F_{critical}$. The *p* value is 0.000. The R^2 value for power consumption is 99.63 % which approves that there is only 0.37 % chance of error in the developed equation. This infers that regression models fit into the observed data. Adj.R^2 is 99.44 %. Pre. R^2 is 99.18 %. Adjusted and predicted R^2 values are in complete agreement.

5.0 RESULTS AND DISCUSSION

Variation of cutting forces with respect to the different cutting condition is shown in Figure 8 while Figure 9 represents the variation of power consumption with respect to different cutting fluid. Points 1 to 27 in both figures represent the observation number of the experiment. Points 1 to 9 indicate observation at speed 34.27 m/min, while observations 10 to 18 show cutting forces at 53 m/min. Points 19 to 27 are observation numbers at speed of 79.27 m/min.

Cutting forces increase with increasing feed rate and decreases with increase in speed. With an increase in cutting speed, frictional forces are decreased Outermost circle in Figure 8 represents highest cutting forces while innermost circle shows the least cutting forces. Deviation of the lines from outer most circle to innermost circle indicates that there is a decrease in cutting force. The green lines for soyabean oil are approaching to the innermost circle, which indicates that less cutting forces are noticed in the case of soyabean oil. The outer most circle in blue color indicates highest cutting forces for blasocut cutting.

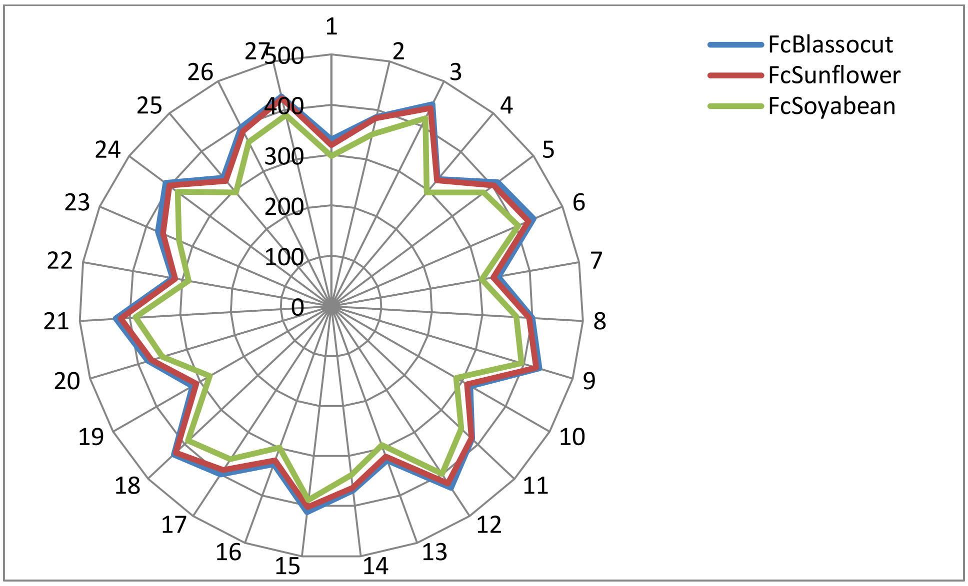

Figure 8. Variation of cutting forces for different cutting fluids

Power consumption is proportional to speed, as speed increases, power consumption increases as shown in Figure 9. To increase speed, more driving power is required and this results to higher power consumption.

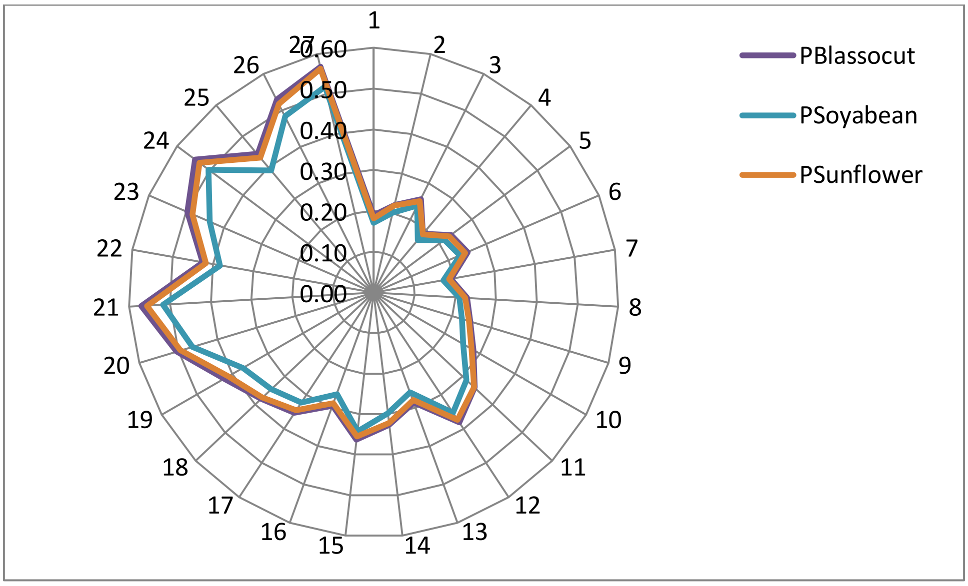

Figure 9. Variation of power consumption for different cutting fluids

Power consumption is very less at 34.27 m/min and 53 m/min as shown in Figure 9. There is a drastic increase in power when speed increased to 79.27 m/min. Power consumption is highest at observation number 21. (V-79.72 m/min, f-0.35 mm/rev, dp-1.5 mm) in all cutting environment.

With more lubricity, soya bean offers less resistance for cutting force and has less consumption of power. In Figure 9, soya bean oil shows approximately 9% reduction in power consumption as compared to mineral-based blasocut. Machining with sunflower also gives a comparable performance as compared to blasocut. Figure 9 shows that green color line indicates the soyabean while violet line indicates the cutting using blasocut. A green color line is at innermost part of the circle, which reveals that power consumption is less for soyabean oil.

6.0 CONCLUSION

Based on the results of the experiments and analysis carried out the following conclusions are drawn. There is a notable decrease in value of cutting forces approximately in the case of soya bean oil as compared to blasocut. Use of soya bean oil as cutting fluid results to a decrease in cutting forces as compared to blasocut. Average 9 % reduction in cutting forces is observed as compared to blasocut. Sunflower oil also shows less cutting forces as compared to blasocut. Power consumption is highest for blasocut. It is observed that the power consumption for soya bean oil is less by average 7 %, and 9 %, in comparison with power consumed by sunflower oil and blasocut respectively. Mathematical models are developed to validate the experimental data. ANOVA test is carried out to check the adequacy of the model. Mathematical models developed for all parameters are accurate and acceptable.

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