RESPONSE SURFACE METHODOLOGY AND ARTIFICIAL NEURAL NETWORK TO EVALUATE TOOL WEAR IN MINIMUM QUANTITY LUBRICATION - TURNING FOR DIFFERENT CUTTING FLUIDS

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ABSTRACT

Cutting fluids play major role in chip removal, protection against oxidation and corrosion, improvement in tool life and the quality of the product. However, mineral-based cutting fluids are environmentally unfriendly and poisonous. These cutting fluids create numerous environmental evils. The worker may suffer from different life threatening disease. Cutting fluids also incur a main part of the total manufacturing cost. It is necessary to reduce the use of the cutting fluids without affecting the product quality. Minimum quantity lubrication (MQL) with vegetable-based cutting fluids will be a feasible option to the conventional machining. The main emphasis of this research study is to evaluate the performance of vegetable oils in terms of tool wear. The performance of different vegetable oils such as soyabean oil, sunflower oil, groundnut oil and coconut oil is compared with mineral-based cutting fluid blasocut-4000 during turning of AISI 4130 steel. A mathematical model for tool wear is developed to show the relation between significant parameters such as cutting speed, depth of cut and feed rate using response surface methodology. Analysis of variance (ANOVA) test is carried out to verify the capability of the developed model. The result shows that the developed models are accurate and adequate. Response surface methodology (RSM) results are compared with artificial neural network (ANN) results to validate the model. Reduction in tool wear has been observed for soyabean oil. Moreover, use of soyabean oil as cutting fluid is economical, environmentally friendly and provides healthy working conditions for an operator.

KEYWORDS*: MQL; Vegetable oil; response surface methodology; tool wear; ANN*

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1.0 INTRODUCTION

Nowadays, industry demands higher productivity and cost efficacy in machining. Higher productivity results into high material removal rate. However, machining with high material removal rate is associated with a large amount of heat generation and high cutting temperature. This high temperature results in increased tool wear and decreased tool life (Chattopadhyay et al., 1972). Deterioration of the product quality increases rejection. Rejection increases material cost, labor cost and thus affects the productivity. To reduce the undesirable effect of the temperature and friction, cutting fluid is used. Use of mineral oil based cutting fluids results in environmental degradation like soil pollution, water contamination, disposal and dumping problems. Recycling cost of the waste cutting fluid is high, as it requires a separate setup and maintenance (Adler et al., 2006). The main concern is the health of the operator. An estimated 1.2 million workers are possibly exposed to the dangerous chronic toxicological effects of cutting fluids. Various environment protection agencies (EPA) have prohibited the use of these chemicals as they are carcinogenic and have adverse effects on the gene (Bennett et al., 1987).

Due to poor surface quality, operator health, ecological concern and government regulations, enormous efforts are made to reduce the use of the mineral-based cutting fluids. Minimum quantity lubrication (MQL) with vegetable-based cutting fluid completely replaces toxic and expensive cutting fluids. Performing an experimental trial and deciding the optimum values from the experience is very skilled, time-consuming and costly affair. Taguchi analysis, response surface methodology, artificial neural network, different analysis software etc. are the tool for experimental analysis and prediction (Montgomery, 1997).

In the present work, effect of vegetable-based cutting fluids is evaluated on tool wear of cutting tool. Response surface methodology and an artificial neural network are used for validating the experimental results.

2.0 LITERATURE REVIEW

The approach considered while reviewing the literature are cutting fluids and related hazards, dry and MQL cutting, development of vegetable oil as a cutting fluid. Review of different statistical techniques, simulation method is also illustrated. Marksberry et al. (2004) revealed that contaminants, like nitrosamines, microbial agents, bacteria, fungi, shigella, E.Coli, salmonella, and pseudomonas react with cutting fluid and affect occupational health and safety. Bennett et al. (1987) studied the harmful effect of the mineral-based cutting fluid on the machine operator and warned that exposure to cutting fluid would result in increased risk of airway irritation, chronic bronchitis, asthma and even laryngeal cancer. Aronson (1994) pointed out the main weaknesses of flood lubrication and their storage system hygiene in the company premises. Klocke et al., (1997) studied the most recent developments in dry cutting. According to the author, until 2003, minimum quantity cooling (MQC) was not taken seriously. Weinert and Inasaki et al., (1997) presented a detailed analysis of the dry cutting and minimum quantity lubrication. Heisel et al., (1994) described the results of MQL in turning, broaching and milling, where the MQL technology in machining with geometrically defined edges is applied. Heisel gave a brief idea about applications of minimum quantity cooling systems in machining. McClure et al., (2001) proposed a concept of micro lubrication. Micro lubrication was also termed as near dry lubrication or minimum quantity lubrication. The flow rate for MQL was only 50 ml/hr-500 ml/hr, which was very less as compared to flood condition. For flood condition, oil flow rate was more than 2 liters to 4 liters per hr. There was extensive saving of cutting fluid. Dhar et al., (2007) performed experimental investigations to find the effect of MQL on cutting temperature, chip formation and product quality during turning of AISI-1040. Mobil cut-102 was used as cutting fluid. Tasdelen et al., (2008) investigated the effect of oil droplets and air in the aerosol at MQL cutting. Hadad and Sadeghi (2016) evaluated the performance of dry, MQL and flood lubricating conditions during machining of AISI 4140 steel. It was observed that cutting forces were higher for dry machining. During machining under MQL, least value of cutting forces was noticed.

The MQL research activities carried out, its comparison with dry and cutting, but the use of MQL is limited in small manufacturing unit of developing countries. Very few researchers have proposed the simple design of MQL system that small-scale industry, even small units of manufacturing plants can use. Toxicity, environment unfriendliness, health hazards, government regulations limits the use of mineral-based cutting fluid. The properties of vegetable-based oil are comparable to mineral-based cutting fluid and hence now days attracted the attention of researchers. Khan and Dhar (2006) elaborated the investigation results of MQL using vegetable oil on cutting temperature, tool wear, surface roughness and dimensional deviation during turning AISI-1060 steel. Vamsi and Nageswara (2008) conducted a comparative study of the pure coconut oil and SAE 40 oil along with nano boric acid powder suspension. They observed that cutting temperature, tool flank wear and surface roughness decreased significantly with coconut oil as cutting fluid. Kuram et al., (2011) focused on the formulation of cutting fluids with vegetable oil base and evaluation of performance of these cutting fluids. Chemical and physical analyses of formulated cutting fluids were conducted. Sodamade A et al. (2013) gave complete analysis of fatty acid composition of soybean oil, groundnut oil and coconut oil. High performance liquid chromatography test was used for determining the fatty acid composition. Sachin et al., (2014) determined the effect of lubricant to wear and frictional force by using a pin on disc machine with M2HSS tool. Vardhaman et al. (2015) carried out experimental investigations to examine the role of MQL by vegetable oil on cutting forces and tool wear in tune AISI 1040 steel using tungsten carbide cutting tool insert. The results revealed that, the performance of MQL by coconut oil found to be superior to that of dry turning, conventional wet turning and MQL by soluble oil on based on cutting force and tool life. Ghuge & Mahalle (2016) studied performance evaluation of different vegetable oils and found that soyabean oil gives good performance as compared to other vegetable oils.

All the studies highlighted the advantages of using MQL in machining processes under different lubricants. However, MQL system using vegetable oil as cutting fluid is still an innovative investigation area that needs to be explored. Different statistical techniques are developed which provide the design of experiment. With statistical design of experiments, large data is selected in a small number of experimental values. These techniques can be used to verify the experimental data and to predict the output. Davim et al., (2001) developed linear regression models to predict surface roughness and tool wear. Noordin et al., (2004) used response surface methodology for evaluating the performance of coated carbide tools during turning AISI-1045 Mathematical models developed to predict cutting force produced comprehensive results. Amman et al., (2007) used statistical methods and Taguchi's technique for examining machinability and minimizing power consumption. Ahmed and Dhar (2007) used response surface methodology to establish tool life prediction model for turning medium carbon steel. Guillot et al., (1997) studied the viability of a neural network technique to evaluate the surface roughness and dimensional deviations during machining.

From the literature reviewed, most of the research work has focused on comparison of vegetable oil with mineral-based oil. Very few researchers have worked on comparative study of the performance of different vegetable oil using minimum quantity lubrication. This research work will give study of various vegetable oils based tool wear and tool life.

3.0 EXPERIMENTATION

This research work studied effect of various vegetable oils as a cutting fluid on tool wear and tool life during turning operation. Sunflower oil, coconut oil, groundnut oil and soyabean oil are comparatively cheap, easily available, hence considered as a cutting fluid. Experiments are carried out by turning AISI 4130 steel bar with a diameter of 60 mm and a length of 120 mm. Uncoated brazed carbide tool (P-30, ISO-6, Make-Miranda, R1616) with back rake angle 12° and nose radius 0.4 mm is used for turning purpose.

Experimentation is conducted for three MQL cutting. During MQL, cutting fluids like blasocut-4000, soyabean oil, groundnut oil, sunflower oil and coconut oil are used as cutting fluid. For measuring tool wear, toolmakers microscope is used. Experimentation was conducted as per full factor design with three-parameter act at three levels (3^3 level). The cutting speed (v), feed (f) and depth of cut (dp) are independent parameter. Tool wear measured with respect to machining time. For each test, machining interrupted after 5 minutes in order to measure the size of the flank width VB; i.e. the distance between the straight part of the original major cutting edge and the boundary of the flank wear land.

Figure 1. Experimental Set Up

3.1 Response Surface Methodology (RSM)

Response surface methodology (RSM) is used to formulate the mathematical models for different response. In addition, artificial neural network (ANN) is applied to predict the response. Artificial neural network and response surface methodology techniques are compared for their predictive capabilities. Equations (1) to (5) represent mathematical models developed with the help of Minitab-17. Figure 2 shows the residual plots plotted for different responses. Summary of the ANOVA is recorded in Table 1.

The Regression Equations for Tool Wear –MQL are given in Equations (1) to (5) as follows: -

(a) Blasocut

$$VB_{Blasocut} = -0.0350 + 0.00286\,V + 0.002546\,t - 0.000024\,V*V + 0.000019\,t*t + 0.000020\,V*t \quad (1)$$

(b) Soyabean

$$VB_{Soyabean} = 0.0415 + 0.000644\,V + 0.000318\,t - 0.000001\,V*V + 0.000034\,t*t + 0.000001\,V*t \quad (2)$$

(c) Sunflower

$$VB_{Sunflower} = 0.0358 + 0.000467\,V + 0.002394\,t - 0.000001\,V*V + 0.000012\,t*t + 0.000001\,V*t \quad (3)$$

(d) Coconut

$$VB_{Coconut} = -0.0064 + 0.00165\ V + 0.003308\ t - 0.000012\ V*V + 0.000002\ t*t + 0.000012\ V*t \quad (4)$$

(e) Groundnut

$$VB_{Groundnut} = 0.0461 - 0.000183\ V + 0.003091\ t + 0.000004\ V*V + 0.000007\ t*t + 0.000006\ V*t \quad (5)$$

Table 1. ANOVA Analysis

Factor	Blasocut	Soyabean Oil	Sunflower Oil	Coconut Oil	Groundnut Oil
R^2 (%)	98.01	97.99	98.71	97.72	98.46
Adj. R^2 (%)	97.77	97.15	98.78	97.45	98.01
Pre. R^2 (%)	97.28	97.34	98.61	97.04	98.28
P value	0.00	0.00	0.00	0.00	0.00
F (Model)	413.8	409.1	760.85	360.2	536.9

Analysis of variance is used to check the model accuracy. Table 1 represents the correlation coefficient, P value and F value for tool wear during machining while using soyabean oil as cutting fluid. The correlation coefficient R2 is approaching to 100% of all cases. It indicates that the regression equations developed from tool wear are statistically significant. It is observed that adjusted R2 and Predicted R2 are in good agreement. The regression equations truly represent the wear of the cutting tool.

The residual plot for tool shows that all the residual is along a straight line. The predicted vs residual plot indicates that residual slightly varies from the mean position. The Residual Vs Observation Order does not follow any pattern. This indicates that developed model for tool wear is valid and accurately represents the experimental data.

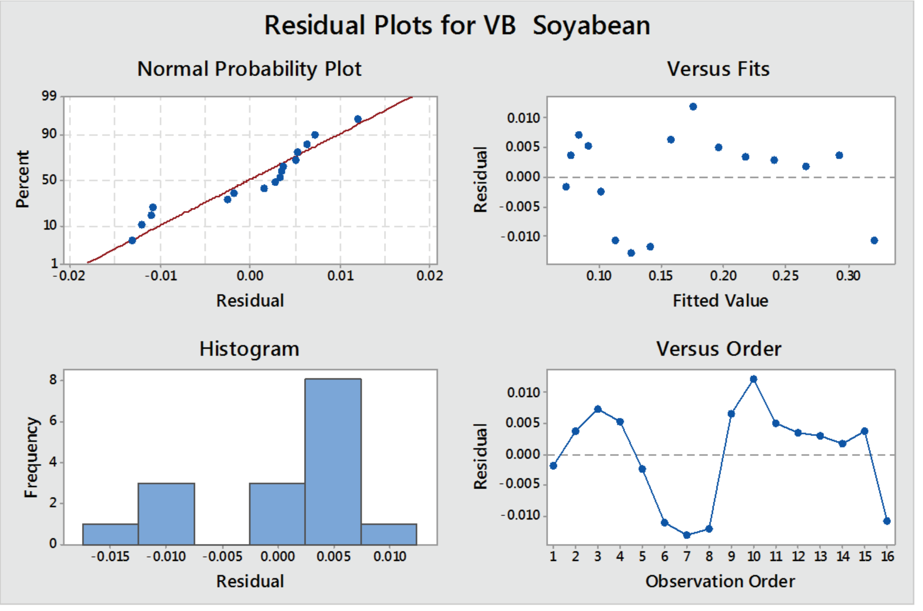

Figure 2. Residual Plots for Tool Wear -Soyabean Oil

3.2 Artificial Neural Network

An Artificial Neural Network (ANN) is an information processing system that has performance features in common with biological neural networks. The number of input and output neurons is fixed by the nature of the problem. The objective of a neural network is to compute output values from input values. In order to determine the optimum number of neurons in the hidden layer, a series of topologies was examined. The correlation coefficient was used as a measure of the predictive ability of the network (Montgomery, 1997; Azouzi & Guillot, 1997).

In the case of complex phenomenon involving non-linear function, Artificial Neural Network (ANN) simulation is used to validate the experimental data. MATLAB software is used for developing ANN simulation program. Artificial analysis was performed for MQL machining with soybean oil as a cutting fluid to predict tool wear.

3.2.1 *Development of ANN Model for Tool Wear (Soyabean Oil)*

The architecture of the ANN model for tool wear is shown in Figure 3. It has a three-layer ANN, with tangent sigmoid transfer function (tansig) at hidden layer with 27 neurons and linear transfer function (purelin) at the output layer. After repeated trials, it was found that a network with 27 hidden neurons produced the best performance.

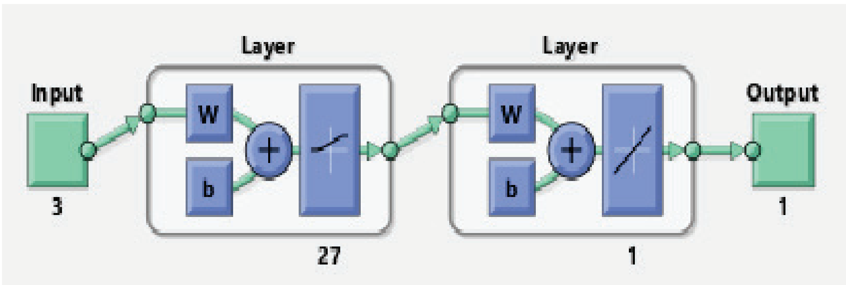

Figure 3. Architecture of ANN Model for Tool Wear (Soyabean Oil)

Figure 4 represents a training of network for tool wear prediction during turning with soyabean oil.

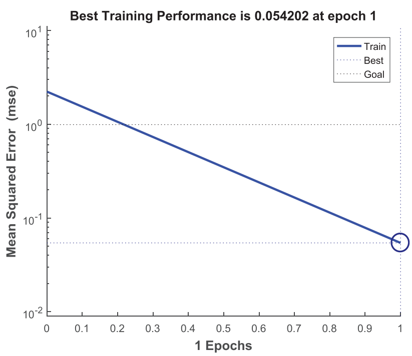

Figure 4. Training Performance of the ANN for tool wear

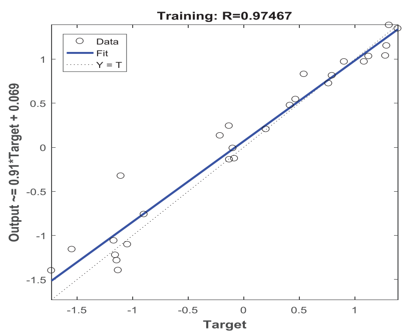

Figure 5. Regression Plot for the ANN for Tool wear

The train function outputs the trained network and history of the training performance. The errors are plotted with respect to training epochs. The property tr. best epoch (Best training performance at one epoch) indicates the iteration at which the validation performance reached a minimum error (Rangwala & Dornfield, 1989).

The regression plots represent the training, validation, and testing of data. The dashed line in Figure 5, represents the perfect result - outputs = targets. The solid line represents the best-fit linear regression line between outputs and targets. The R-value is an indication of the relationship between the outputs and targets. If R = 1, this indicates that there is an exact linear relationship between outputs and targets. If R is close to zero, then there is no linear relationship between outputs and targets. The R-value is 0.97467, approaching to one shows that training data indicates a good fit.

The percentage error between the experimental results and ANN predicted values for tool wear is shown in Figure 6. The error percentage is very less, which reveals that the models can be effectively used for predicting the tool, wears for soyabean oil. Figure 7 shows good agreement in between the neural network model output and experimental results. The blue lines and red lines represent close agreement. A variation occurs at observation number 25; it might be due to uncertainty during experimentation.

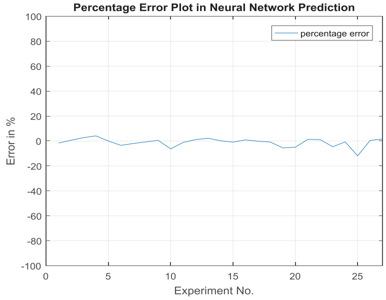

Figure 6. Percentage Error in ANN for Tool wear

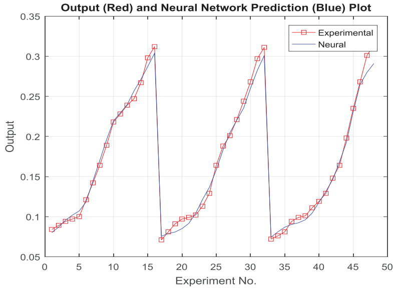

Figure 7. Comparison of Tool Wear (Expt. Vs ANN)

ANN and RSM techniques were compared for their predictive competences. The comparison of the RSM and ANN methods are based on the coefficient of determination (R-value) and percentage of error in comparison with experimentation. The coefficient of determination was used to compare the performance of the RSM and ANN models. The R-values for ANN and RSM are 99.81% and 99.87% respectively. It indicates that the model is accurate and acceptable.

4. RESULTS AND DISCUSSION

4.1 Tool Wear for Different Cutting Fluid

Tool wear is described as the gradual failure of cutting tools due to regular turning operation. Measurement of tool wear is a tough job as it is a destructive test. The rate of tool failure is more at higher values of speed, depth of cut and feed rate. Hence, to minimize the number of experiment and time constraint, tool wear was measured at maximum speed, feed and depth of cut. Observations were recorded at 5 minute intervals. Figure 8 shows the variation of tool wear for different cutting fluids. The intense rubbing action of the two surfaces in contact results into adhesive and abrasive wear. At the beginning, the rate of wear is rapid, settling down to a steady state during the process and accelerating again at the end of tool life. The tool wear rate was highest in dry machining compared to flood and MQL. In MQL, the high velocity spray of air oil mixture decreases temperature and cutting forces. It also flushes away the chips, thus decreases the tool wear. Better lubrication and thermal conductivity of vegetable oil shows the reduction in tool wear as compared to mineral-based oil. Soyabean oil shows less tool wear as compared to other oils. Approximately 25% less wear is observed for soyabean oil in comparison with blasocut. Among all the vegetable oil, soyabean oil and sunflower oil shows significant reduction in tool wear

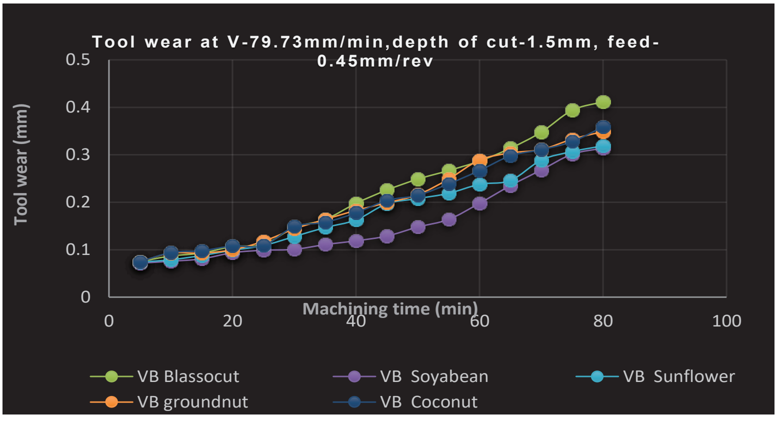

Figure 8. Variation in tool wear with respect to time

4.2 Validation of RSM and ANN Results for Soyabean Oil

Response surface methodology (RSM) and artificial neural network (ANN) techniques are effectively used together for modeling as well as an optimization in several engineering applications. The experimental results, response surface methodology prediction results and artificial neural network results were compared to evaluate the tool wear in machining using soyabean oil as cutting fluid.ANN and RSM techniques were compared for their predictive competences. The comparison of the RSM and ANN methods are based on the coefficient of determination (R-value) and percentage of error in comparison with experimentation.

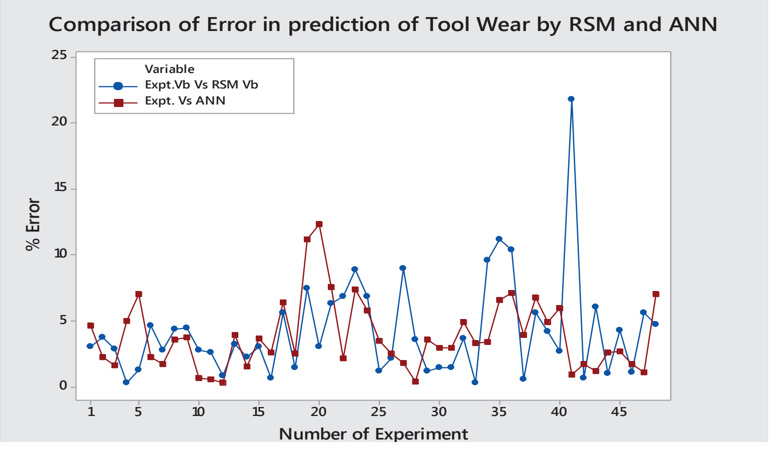

Figure 9. Validation of Tool Wear by RSM and ANN

The coefficient of determination was used to compare the performance of the RSM and ANN models. It shows that R-values for both RSM and ANN are close to one, which indicates that both the model is accurate and acceptable. The percentage error between experimental results and predicted values for response surface methodology, artificial neural network is calculated. Figure 9 shows the comparison between errors for response surface and artificial neural network for different cutting parameters. Blue line represents the percentage error in case of RSM results while the red line represents a percentage error for ANN.

The red and blue lines are very close which indicates the difference in error is negligible for tool wear. The average percentage errors between experimental results and predicted values of the RSM model are 4.23% for tool wear. Good agreement is seen between the actual experimental results and predicted values based on RSM model and ANN model. The results showed that the models could be used efficiently for forecasting the machining performance in turning. The percentage of errors is less than 5% in RSM and ANN. The average errors in the prediction of all parameters by ANN (2.55%) are slightly less than that of the response surface methodology (2.58%).

6.0 CONCLUSION

The main objective of this research study is to evaluate tool wear using various vegetable oil as a cutting fluid. Response surface methodology and artificial neural network are used to validate the experimental results. From the comprehensive experimental investigation, analyses of numerical and statistical techniques, conclusions are drawn with regard to the suitable cutting fluid, prediction model and experimental results comparison, the RSM and ANN capability comparison and least cutting fluid cost.

Tool wear for soyabean oil is less than other cutting fluids. Soyabean shows average 5%, 6%, 13% and 16% of the reduction in tool wear as compared to groundnut oil, sunflower, blasocut and coconut oil.

A mathematical model was developed using response surface methodology to predict the tool wear during turning for the different cutting environment. The ANOVA tests were carried out to check the competency of the model. The predictions of the model matched well with the experimental results.

In order to validate the response surface methodology (RSM) based on the regression model, artificial neural network (ANN) is used to predict the responses. The results of these methodologies were compared for their predictive capabilities. It is noticed that the result of the ANN model shows close matching in between RSM model output and experimental results. It has been confirmed numerically that the results obtained from the derived modeling equation are consistent with the experimental results.

Soyabean oil is less costly as compared to other vegetable oils so from the observations and study, it is concluded that soyabean oil can be emerged as a substitute to mineral-based cutting fluid.

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