Performance Evaluation of vegetable oils in Turning AISI 4130 under Minimum Quantity Lubrication using Artificial Neural Network

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Abstract- Mineral-based cutting fluids are environment unfriendly, toxic and costly. It is essential to reduce the use of the cutting fluids without affecting the product quality. Minimum quantity lubrication (MQL) is an impending technique, which reduces the quantity of cutting fluid significantly. Minimum quantity lubrication with vegetable-based cutting fluids will be a viable option to the conventional machining. 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. Artificial neural network (ANN) is used to analyses the experimental results. Experimental Results are compared with ANN results. Machining using soyabean oil gave improved performance as compared to blasocut, sunflower oil, coconut oil and groundnut oil in terms of temperature, cutting force and surface roughness

Keywords: *MQL, Vegetable oil, Turning, ANN.*

I. INTRODUCTION

The role of the small domestic units is very important in the development of industrial hub in any country. Besides advancement in modern technology, small scale and medium industry sector is reluctant to use new techniques in the field of machining. In all developing countries, huge amount of mineral-based cutting fluids is used in industry. Large numbers of operators are illiterate and not familiar with the adverse impact of cutting fluids on the health. Most of the operators working on a machine are continuously exposed to a poisonous cutting fluid. They are suffering from skin disease, respiratory problems, the disease like bronchitis, asthma, throat cancer, lung cancer etc; however it was observed that 60% to 70% proprietors are unaware of the demerits of the cutting fluid.[2,3]

Minimum quantity lubrication technology is an emerging technology to reduce the uses of toxic cutting fluid. Different models of minimum quantity lubrication system were available in the market but they are costly. [15] Due to financial limitations, small scale industry is reluctant to use these advanced technique. To completely eliminate use of cutting fluids, vegetable oils are the best alternative due to their properties like viscosity, flash point etc.

Proper selection of input parameter is essential to get the desired output. Performing experimental trial and deciding the optimum values from the experience is very skilled, time-consuming and costly affair. The design of the experiment is an experimental strategy in which design variables are varied together, instead of one at a time. Taguchi analysis, response surface methodology, artificial neural network, different analysis software etc. are the tool for experimental analysis and prediction [1].

In the present work performance of vegetable oils is compared with mineral based cutting fluid in MQL environment. An artificial neural network is used for validating the experimental results.

II. LITERATURE REVIEW

To improve the machining performance, development of the new cutting method, new cutting fluids, different statistical techniques, use of analysis software are the associated areas of research. The study of literature is essential to know the basic concepts.

Marksberry et al. [1] revealed that contaminants, like nitrosamines, microbial agents, bacteria, fungi, shigella, E.Coli, salmonella, and pseudomonas occurred within the manufacturing system. Bennett et al. [2] studied the harmful effect of the mineral-based cutting fluid on the machine operator. According to K. Weinert and I. Inasaki et al. [3] dry machining operations, needed to be inspected appropriately due to higher temperature problems. Authors were of the view that minimum quantity lubrication system was not yet used in industrial application but different research activities might results into extensive use of this technique. M.A. Islam, N.R. Dhar et al. [4] investigated the role of grinding fluid in the performance of the grinding process. Temperature, change in hardness and microstructure of the work piece, burning and its consequences and micro cracks were observed in grinding AISI 1060 steel by diamond grinding wheel. Vegetable-based grinding fluid was used. There was significant reduction in surface roughness and the grinding zone temperature. Vamsi Krishna et al. [5] 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. M. Anthony Xavier et al. [6] aimed at the determination of the influence of cutting fluid on tool wear and surface roughness during turning of AISI 304 with a carbide tool. Coconut oil was used as cutting fluid. The results showed that coconut oil performed better than the other two cutting fluids in reducing the tool wear and improving the surface finish.

Pearson et al. [7] proposed principal component analysis. The principal component analysis approach preserved as original information as possible by significantly simplifying a large number of correlated variables into fewer unrelated and independent principal components. Yang et al. [8] used Taguchi DOE for optimization of cutting speed, feed rate and depth of cut for turning operations. Nian et al. [9] proposed Taguchi method with multiple performance characteristics to optimize of turning operations W.S. Lin, B. Y. Lee et al. [10] developed a prediction model for surface roughness and cutting force using an abductive network. Based on the process parameters (cutting speed, feed rate and depth of cut), the surface roughness and cutting force were predicted by this network. Davim et al. [11] developed linear regression models to predict surface roughness and tool wear. Predicted values from regression model were compared with the experimental results. Dadapeer, Umesh et al. [12] obtained optimal setting of turning process parameters cutting speed, feed rate and depth of cut resulting in an optimal value of Feed force, tangential force & surface roughness while machining hardened EN-24 steel with ceramic tool insert. Nexus Qehaja et al. [13] developed a model of surface roughness based on the response surface method. They investigated the effect of machining parameters like feed rate, tool geometry, nose radius and machining time on the surface roughness for dry cutting process. Feng et al. [14] analyzed experimental data using artificial neural network. Their results indicated that back-propagation neural network modeling provided better predictions.

Most of the multinational companies are using MQL technology. However, small-scale industries are not familiar with the development in the field of manufacturing. Illiteracy, casual approach towards health of the employee is the main obstacle in the growth of the industry. The MQL systems available in the market are costly. Different brands like UNIST, VOGEL and SKF are available in the market. One unit cost is around one-lakh rupees. There is need to develop low-cost MQL system so that small domestic units can afford. [15]

From the literature reviewed, it is observed that 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 low cost minimum quantity lubrication. This paper focuses on the study of various vegetable oils based on their performance in terms of cutting forces, temperature; surface roughness.

III. MATERIALS AND METHODS

Experimentation was conducted for three different cutting conditions namely dry cutting, flood cutting and MQL cutting. During MQL, cutting fluids like blasocut-4000, soyabean oil, groundnut oil, sunflower oil and coconut oil are used as cutting fluid. The lathe tool dynamometer is used to measure cutting forces. Surface roughness values are measured with the surface roughness tester. Temperature measured with the help of infrared thermometer. Experimentation was conducted as per full factor design with three-parameter act at three levels (3^3 levels). The feed is varied from 0.35 mm/rev to 0.45 mm/rev. The depth of cut is varied from 0.5 mm to 1.5 mm. The flow rate for flood cutting is one liter per minute while for MQL; the flow rate is adjusted at 60 ml/hr. AISI 4130 steel is extensively used for various industrial applications like valve bodies, pumps, fitting, welding tubing, structural application specifically in the aircraft industry. 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 12º and nose radius 0.4 mm is used for turning purpose. [16, 17] Figure 1 shows experimental setup comprising lathe machine, MQL unit, compressor, lathe tool dynamometer etc.

Figure 1 Experimental set up [16, 17]

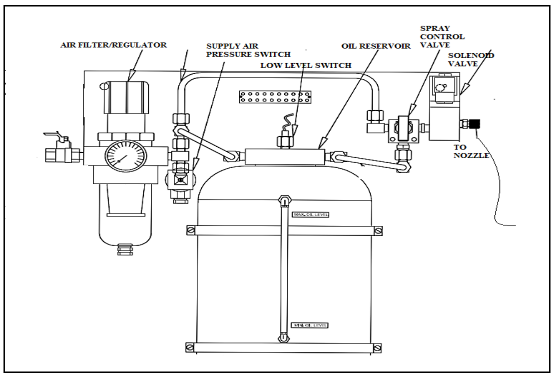

Figure 2. MQL System [16, 17]

For this research work, MQL set up is fabricated. The cost of the setup is very low as compared to the MQL units available in the market. The schematic of MQL set up fabricated for the experimentation is shown in figure 2.MQL system has various components, i.e. oil tank, air filter regulator, solenoid valve, spray lube unit, air flow control valve with built in check valve, siphon tube with suction strainer, oil control valve, coolant pipe, Pu tube, air pressure control valve, magnetic base, tee joint, mounting plate and nozzle etc. Air filter regulator is mounted between air compressor and oil reservoir. It regulates the pressure of the compressed air coming into the oil reservoir. Spray lube is used for siphoning the liquid from the reservoir and to supply at the desired pressure to the spray control valve. A solenoid valve is an electromechanical operated valve. The main tasks of solenoid valve are to shut off, release, dose, distribute or mix fluids. The oil tank is used to store the lubricant or coolant in the tank. [17]

4. ARTIFICIAL NEURAL NETWORK

An Artificial Neural Network (ANN) is an information processing system that has performance features in common with biological neural networks. Neural network consist of input and output layer. Some layers are hidden. The number of layers depends upon the problem. Neural network is used to predict output results from input.

The correlation coefficient was used as a measure of the predictive ability of the network [13-14].In the case of complex phenomenon involving non-linear function, Artificial Neural Network (ANN) simulation is used to validate the experimental data.

Figure 3 Training Performance of the ANN for Cutting Force

The train function outputs the trained network and history of the training performance. Figure 3 shows variation of errors 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. The next step in validating the network is to create a regression plot, which shows the relationship between the outputs of the network and the targets. Equal network output and target indicates the perfect training. The regression plots represent the training, validation, and testing of data. The dashed line in figure 4, represents the perfect result - outputs = targets. The solid line signifies the best-fit linear. The R-value show of the correlation between the outputs and expected results. The relationship between target values varies between zero to one. Zero value of R shows no relation output and target while R-value approaching towards one indicates agreement between output and target.

Figure 4 shows better agreement in ANN data and experimental data. The R-value is 0.97467, approaching to one shows that training data indicates a good fit.

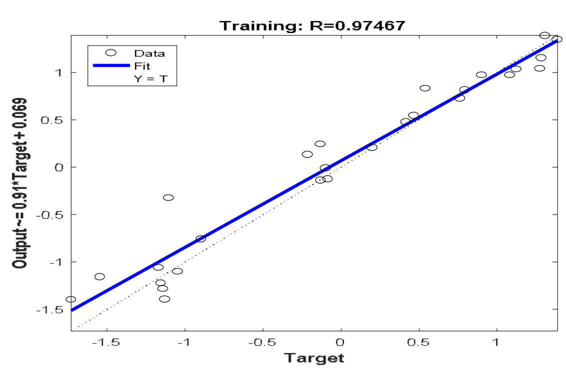

Figure 4 Regression Plot for the ANN for Cutting Force

5. RESULTS AND DISCUSSION

5.1 Variations of Cutting Forces at Different Cutting Conditions

The variation of the cutting forces as per experiment order for all cutting environment is shown in figure 5. The outermost circle signifies higher cutting forces while innermost circle shows the least cutting forces. The deviation of the lines from the outermost circle to innermost circle indicates that there is a decrease in cutting forces. The yellow lines for soyabean oil are approaching to the innermost circle, which specifies less cutting force for soybean oil. The outermost circle in white lines indicates higher cutting forces for dry cutting. In dry cutting, there is no cooling media. There is adhesion between cutting tool and work piece, hence cutting forces seems to be higher at dry cutting. For flood cutting, adhesion between tool and work piece is less hence there is a decrease in cutting forces, while in case of MQL, due to high velocity coolant jet, adhesion is lowest. Machining with MQL, give better results as compared to dry and flood cutting. MQL shows approximately 5%-10% and 10%-15% reduction in cutting forces as compared to flood and dry respectively. Cutting forces are inversely proportional to speed. An increase in depth of cut, results in increased tool contact length, hence frictional force will be more.

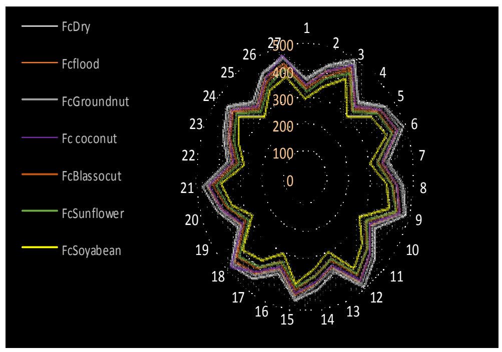

Figure 5 Variation of Cutting Force at Different Cutting Conditions

All the vegetable oil gave comparable results when compared to mineral-based oil blasocut. Vegetable oil has dipolar molecule having opposite charge. This oil has an affinity for the metal surface and hence forms a strong lubricant film, which results in reduction in cutting forces. Soyabean oil shows 6% to 7 % reduction in cutting forces as compared to sunflower oil. The soyabean oil has more viscosity and less evaporation losses. Soyabean oil lubricates the interface as well as protects the sharpness of the tool by its additional cooling capability as compared to other vegetable oils.

5.2 Variation of Temperature at Different Cutting Conditions

During machining, heat is produced due shear and plastic distortion to at the primary deformation zone occurs. The secondary deformation and sliding causes heat generation at tool chip interface. Observation number 1-3, 4-6, 7-9 etc. shows an increasing trend towards temperature. It indicates that temperature increases as the depth of cut and feed rate increases as shown in figure 6. The temperature increases due to more energy inputs and more friction between the tool and work piece. It is observed that in case of dry machining, temperature is highest. There is a significant reduction in temperature for MQL cutting as compared to dry and flood cutting. In MQL, the mixture of high-pressure air and coolant removes heat excellently. Due to high velocity, the particle of coolant penetrated easily. In MQL, lubricant particles are converted into atomized form. For a given volume, smaller the size of the individual particle, greater will be the surface area leading to enhanced evaporative heat transfer, which facilitates lower cutting temperature. The use of MQL reduces the temperature approximately by 10%-20%, 2%-5% as compared to dry and flood cutting respectively.

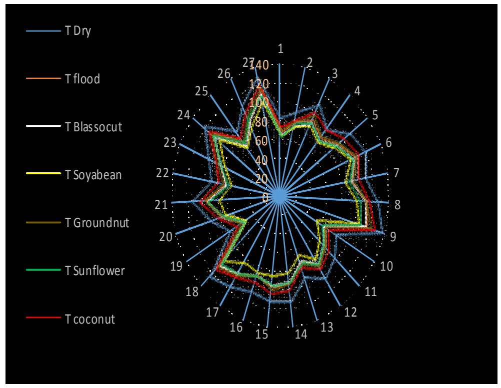

Figure 6 Variations of Temperature at Different Cutting Conditions

Vegetable oils have more viscosity, which offers better lubrication. As mentioned in the references normally, thermal conductivity of vegetable oil is better than mineral oil. Heat transfer coefficient of soyabean oil is (859 W/m^2K) higher as compared to sunflower oil (660 W/m^2K), groundnut oil (312 W/m^2K), coconut (318 W/m^2K) [19, 20]. Therefore, heat dissipation is more in case of vegetable oil. Blasocut showed approximate 7% more temperature than soyabean oil. Soyabean oil shows the least temperature as compared to other oils. Soyabean oil and sunflower oil are represented by yellow and green line in figure 6, which indicates the lower most temperature line as compared to other cutting fluids. Soyabean oil shows 7% decrease in temperature as compared to sunflower oil. Viscosity index of soyabean oil (220), sunflower (218) is higher as compared to mineral-based oil (100-150). High viscosity index indicates better performance at higher temperature [20]. The viscosity of vegetable oil decreases slowly as compared to mineral oil when machining temperature increases.Conversely, as the temperature falls; vegetable oil remains more fluid, facilitating quicker drainage from chips and work piece. The lubricity of soyabean and other vegetable oil is not affected at higher temperature.

5.3 Variation of Surface Roughness at Different Cutting Conditions

Surface finish is a key factor of machinability because it affects the performance and service life of the machined component. Surface roughness is more for dry cutting and flood cutting as compared to MQL. There is average 8% and 38% reduction in surface roughness in MQL as compared to flood cutting and dry cutting respectively.

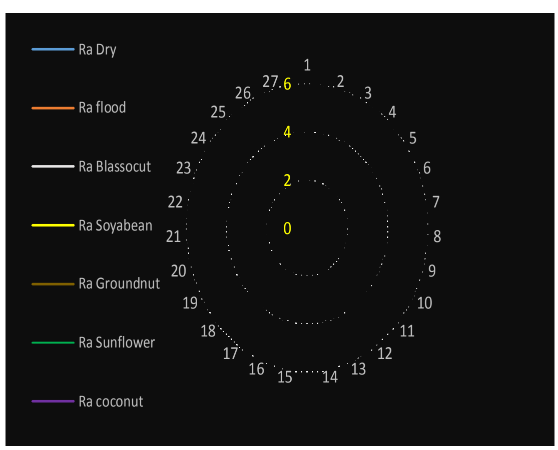

Figure 7 Variation of Surface Roughness at Different Cutting Conditions

When vegetable oils are used as a cutting fluid with MQL, the surface roughness is greatly reduced. The yellow and green line in figure 7 denotes soyabean oil and sunflower oil. These lines are approaching towards inward circle which indicates the lower surface roughness value.MQL machining with soyabean oil shows average16 % decrease in surface roughness value as compared to blasocut. This is due to less cutting forces in case of soyabean oil. The lubricating action of the dipolar molecule of soyabean oil reduces the frictional force. Soyabean oil has higher molecular weight, which reduces the chances of evaporation of cutting fluid as compared to the mineral based oil. This decrease the temperature results in the lesser tool wear, thus resulting in surface quality improvement. Machining with soyabean oil shows 4%, 8% and 15% of less roughness values as compared to sunflower oil, groundnut oil and coconut oil respectively. It is noticed from figure 6.5 that there is a drastic decrease in roughness value when speed is changed from 53 m/min to 79.72 m/min. At higher cutting speed, the chip-tool contact length decreases, which results in lower the coefficient of friction.

5.4 Comparison of Experimental and ANN Results for Various Machining Parameter (MQL-Soyabean Oil)

The training, testing and validation of the ANN model was performed using experimental results for the responses like cutting force, temperature, tool surface roughness with respect to soyabean oil. Figure 8 shows the comparison between the experimental output and neural network prediction for cutting forces respectively for soyabean oil. The blue line of neural prediction results almost overlaps the red line of the experimental result. This indicates that the model is true and accurate. The comparison between experimental and ANN predicted results for surface roughness and temperature is given by figure 9 and figure 10 respectively. The results of the neural network model show good agreement between the model output and the measured responses with very marginal error.

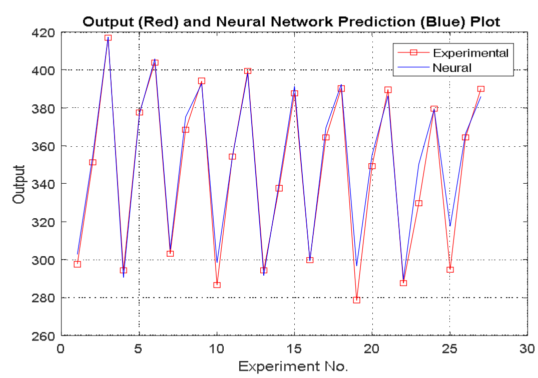

Figure 8 Comparison of Cutting Force (Expt. Vs ANN)

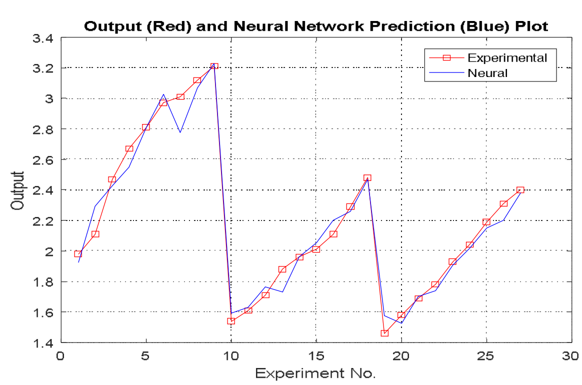

Figure 9 Comparison of Surface Roughness (Expt. Vs ANN)

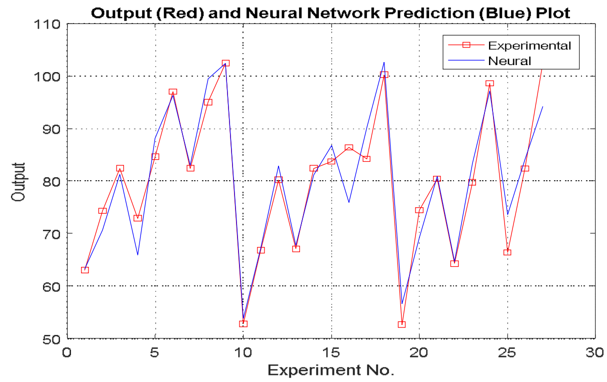

Figure 10 Comparison of Temperature (Expt. Vs ANN)

6. CONCLUSION

The main objective of this research study is to evaluate the performance of various vegetable oil using MQL based on cutting forces, temperature, surface roughness, power consumption and tool wear and tool life. Artificial neural network is used to validate the experimental results. From the comprehensive experimental investigation, analysis of numerical and statistical techniques following remarks and conclusions are drawn.

Minimum quantity lubrication provided significant improvements in the performance during turning of AISI 4130 steel. The use of MQL results in lower cutting temperature and surface roughness.

The cutting forces during MQL turning are considerably reduced. MQL also saves the large quantity of the cutting fluid. Soyabean oil recorded the lowest cutting forces by 9 % compared to blasocut.

MQL using vegetable oil as cutting fluid shows notable enhancement in the overall performance during turning as compared to blasocut.

There is approximately 3%, 7%, 12% and 16% of the decrease in temperature for soyabean oil as compared to blasocut, sunflower oil, groundnut oil and coconut oil respectively.

An improved surface roughness of about 4%, 8%, 15% and 16% is reported for MQL with soyabean oil over sunflower oil, groundnut oil, blasocut and coconut oil respectively.

Artificial neural network (ANN) is used to predict the responses. It is noticed that the result of the ANN shows close matching with experimental results.

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