Ph.D. Thesis

PERFORMANCE EVALUATION OF VEGETABLE OILS AS A CUTTING FLUID

A Thesis Submitted to
Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur
in fulfillment of requirements for the Degree of

Doctor of Philosophy

in

Mechanical Engineering
under the Faculty of Engineering and Technology

By
Nilesh C. Ghuge

Under the Guidance of
Dr. A. M. Mahalle
Associate Professor
Laxminarayan Institute of Technology, Nagpur

Laxminarayan Institute of Technology,
Rashtrasant Tukadoji Maharaj Nagpur University,
Nagpur.

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Laxminarayan Institute of Technology
Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur
Opp. Bharat Nagar, Amravati Road,
Nagpur, Maharashtra- 440033 (India)

Forwarded herewith to the **Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur, Maharashtra** the thesis titled **“Performance Evaluation of Vegetable Oils as a Cutting Fluid”** submitted by **Mr. Nilesh C. Ghuge** in the fulfilment of the requirements for the award of the degree of Doctor of Philosophy.

Dr. Ashish M. Mahalle
Supervisor,
Laxminarayan Institute of Technology, Nagpur.

Laxminarayan Institute of Technology
Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur
Opp. Bharat Nagar, Amravati Road,
Nagpur, Maharashtra- 440033 (India)

Certificate

This is to certify that the work presented in this thesis entitled: **“Performance Evaluation of Vegetable Oils as a Cutting Fluid”** is the own work of **Mr. Nilesh C. Ghuge** conducted in **Laxminarayan Institute of Technology, Nagpur** under my supervision. This work has not been submitted earlier to any University/ Institution for any diploma or degree.

Place: Nagpur

Date:

Dr. Ashish M. Mahalle
Supervisor,
Laxminarayan Institute of Technology, Nagpur.

ANNEXURE-VI

Declaration

I hereby declare that the work presented in this thesis entitled: **"Performance Evaluation of Vegetable Oils as a Cutting Fluid"** was carried out by me under the supervision of **Dr. Ashish M. Mahalle, Associate Professor, Laxminarayan Institute of Technology, Nagpur** from **12/01/2012 to 12/01/2016.** This work which or any part of this work is based on original research and has not been submitted by me to any University/ Institution for the award of any diploma or degree.

Date: **Mr. Nilesh C. Ghuge**

Nagpur

Abstract

Cutting fluids are used to reduce friction and heat generated during machining. They also play important 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 environment unfriendly and toxic. These cutting fluids create several ecological problems. The operator may suffer from different life threatening diseases. Cutting fluids also incur a major portion of the total manufacturing cost. It is essential to reduce the use of the cutting fluids without affecting the product quality. Dry cutting is one method to eliminate the cutting fluid but it fails on the performance criteria.

Minimum quantity lubrication (MQL) is an impending technique, which reduces the quantity of cutting fluid significantly. Now day's researchers are trying to eliminate the harmful cutting fluids. In this regards, interest in vegetable oil is growing. Minimum quantity lubrication with vegetable-based cutting fluids will be a viable option to the conventional machining. The main emphasis of this research study is to evaluate the performance of vegetable oils in terms of cutting forces, temperature, surface roughness and 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.

Response surface methodology is used to analyses the experimental results. A mathematical model for each performance parameter is developed to show the relation between significant parameters such as cutting speed, depth of cut and feed rate. Analysis of variance (ANOVA) test is performed to confirm the ability 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.

To find out the best combination of the cutting speed, feed and depth of cut for the desired performance, multi-response optimization is carried out. Desirability is calculated to show the feasibility of optimization for multiple responses. Statistical software Minitab-17 is used for optimization and desirability analysis.

Minimum quantity lubrication performed better as compared to the dry and flood cutting, due to the reduction in temperature, cutting force and surface roughness. 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. Reduction in tool wear and increase in tool life 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.

Acknowledgement

Pursuing Ph.D. is a learning experience. It is like climbing a high peak, step by step, filled with hardships, frustration, encouragement, trust and support from many, where one realizes that reaching to top is in fact a teamwork that got you there. Though this it will not be enough to express my gratitude in words to all those who helped me, I would still like to heartily thank all who played their part to enable me achieve this mammoth task. The satisfactions, which accomplish a successful completion of any task, are incomplete without the mentioning of the names of those people who makes it possible.

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It is the love, faith and care of these dear friends of mine, that has strengthened me in a work of mine. It is they who have never let me down even in the hardships of my life and have always reminded me of my goals.

Mr. Nilesh C. Ghuge

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Nomenclature

V	Cutting Speed	m/min
f	Feed Rate	mm/rev
dp	Depth of Cut	mm
Fc	Cutting Force	N
Ff	Feed Force	N
Fr	Radial Force	N
T	Temperature	N
Ra	Surface Roughness	µm
P	Power Consumption	KW
VB	Tool Wear	mm
t	Machining Time	min
R^2	Correlations Coefficient	%
R^2 adj.	Adjusted Regression Coefficient	%
R^2 pred.	Predicted Regression Coefficient	%
F	F-Ratio	

Abbreviations

MQL	Minimum Quantity of Lubrication
OSHA	Occupational Safety & Health Administration
NIOSH	The National Institute for Occupational Safety and Health
CPCB	Central Pollution Control Board
ISO	International organization for standardization
DOE	Design of Experiment
AISI	American Iron and Steel Institute
EPA	Environmental Protection Agency
ANOVA	Analysis of Variance
ANN	Artificial Neural Network
RSM	Response Surface Methodology
RPM	Revolution per minute
TAG	Triglycerides

List of Publications

Papers Published in Journal

1. Influence of Cutting Fluid on Tool Wear and Tool Life during Turning International Journal of Modern Trends in Engineering and Research (IJMTER), Volume 03, Issue 10, pp. 23-27, 2016

2. Performance Evaluation of Vegetable Oil Using MQL During Turning Of AISI 4130 in terms of Temperature and Surface Roughness , International Journal of Engineering Science and Computing (IJESC), Volume 6, Issue No.5, pp. 5879-81,2016

3. Experimental investigation on the performance of soyabean oil and blasocut-4000 during turning of AISI 4130 in terms of cutting forces, International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET),Volume 2 Issue 3, pp. 330-333,2016

4. Comparative study of different vegetable oil during turning in terms of cutting force and power consumption, Journal of Biological Science, Volume 2, Issue 5,pp. 91-94,2016

5. Minimum Quantity Lubrication, IOSR Journal of Engineering (IOSRJEN), National symposium on engineering and Research-2012, pp. 55-60, 2012

Papers Presented at Conference

1. Vegetable oil as a cutting fluid using minimum quantity lubrication: A review, International Conference on Advances in Civil and Mechanical Engineering System, Government College of Engineering, Amravati in Association with SVNIT, Surat, 22-24 Dec-2014

2. Experimental investigation of effect of MQL, dry and flood cutting in turning of AISI 4130, ICSTSD-2016 satellite conference at Sandip Foundation, Nashik, pp. 2084-2087, 26 May 2016

Papers Communicated

1. Performance Evaluation of Minimum Quantity Lubrication in Terms of Cutting Force and Temperature, Journal of Institution of Engineers (India) series C, submission ID-IEIC-D-16-00098) –Under Review, May 2016

2. Optimization of Cutting Parameter during Turning Using Different Cutting Fluids, Journal of Mechanical Engineering and Technology, ISSN 2180-8123, Malaysia Technical University, Paper ID-1109, Under Review , Oct 2016

3. Response Surface Modeling For Cutting Force and Power Consumption during Turning Using Vegetable Oils, Journal of Engineering and Technology, ISSN-21803811, Paper ID-1128, Under Review,Oct-2016

CHAPTER 1

INTRODUCTION

1.1 Research Background

Now a days, industry demands higher productivity and cost efficacy in machining. This insists high material removal rate and more tool life. 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. Cutting tool replacement and maintenance cost is high [1].

Deterioration of the product quality increases rejection. For any manufacturing industry, rejection of the product is not tolerable. Rejection increases material cost, labor cost and thus affects the productivity. To reduce the undesirable effect of the temperature and friction, cutting fluids are used. In most of the industries, mineral-based cutting fluids are used. Mineral-based cutting fluids are harmful hence need to be replaced. Minimum quantity lubrication reduces substantial amount of cutting fluid Vegetable-based oil has a potential to be used as cutting fluid. To investigate the performance of vegetable oil during turning, the study of metal cutting is necessary and important.

1.2 Mechanism of Metal Cutting

A wedge-shaped tool is forced to move relative to the workpiece in such a way that a layer of metal is removed in the form of a chip. When force is applied to the cutting tool, the material of the workpiece ahead of the cutting edge deforms sowing to the shearing action. It reaches a point of plastic flow passing across the face of the tool. Constant application of force causes the material to rupture. The metal cutting operation is represented by figure 1.1.

In the case of orthogonal cutting, the cutting edge of the tool is at right angle to the direction of relative motion between tool and workpiece. For Oblique cutting, the edge is inclined at an angle less than 90°. Orthogonal cutting represents a two-dimensional problem while oblique cutting represents a three-dimensional problem [2].

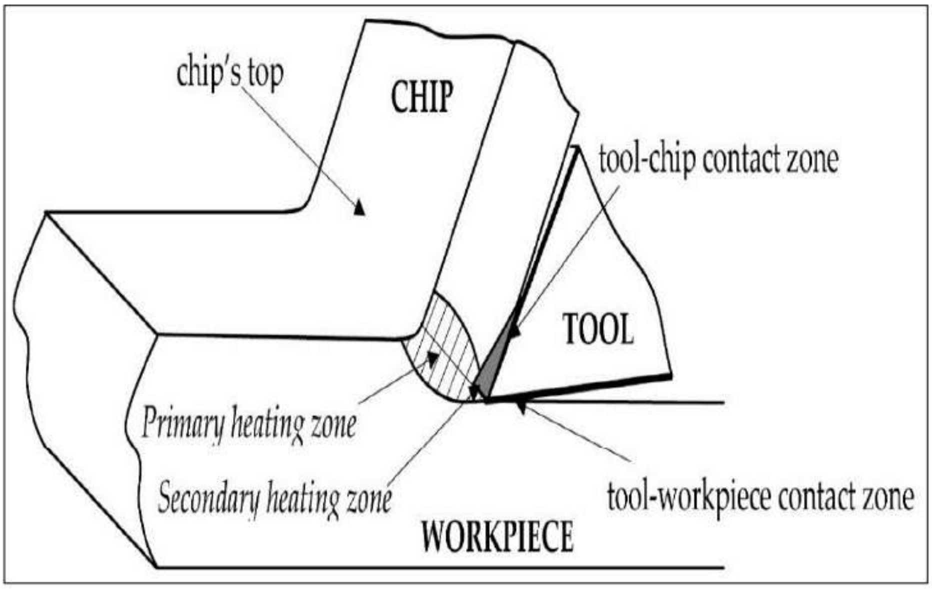


Figure 1.1 Mechanism of Metal Cutting [2]

1.3 Turning Operation

Turning is the material removal process used to produce a smooth finish on the metal surface. The cutting parameters for turning operation are speed, depth of cut and feed rate. Cutting speed refers to the speed of spindle or workpiece. Feed is the rate at which tool travels along its cutting path. The depth of cut denotes the amount of material removed.

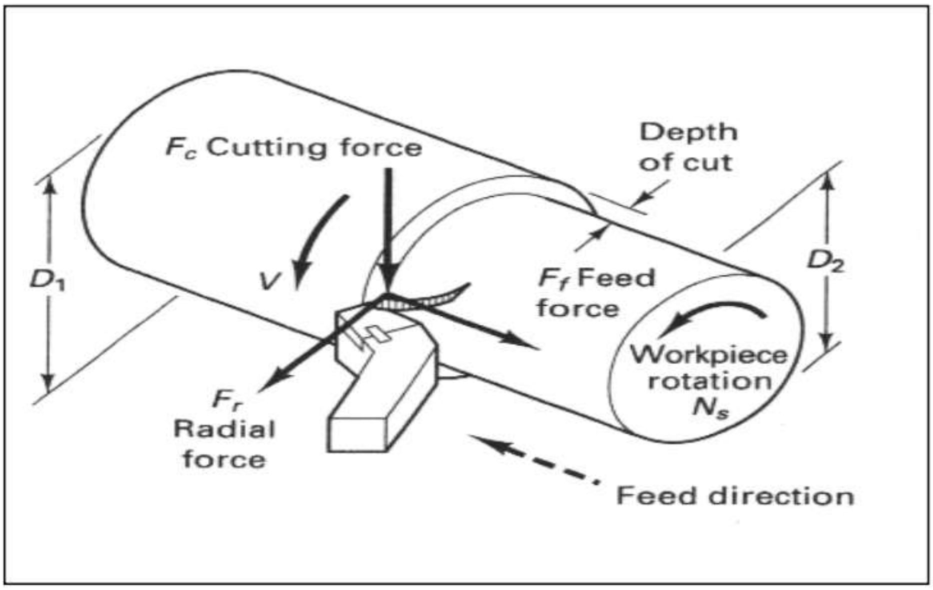


Figure 1.2 Cutting Forces during Turning [3]

Single point cutting tool is used to remove the material during turning. The materials for cutting tools are high carbon steel, high-speed steel, cemented carbide. Tungsten carbide tools are used in the form of inserts, which are brazed or fixed to the steel shank. Diamond tip, Cubic boron nitride (CBN) inserts are used for hard turning [2].

The principal forces are acting during turning are shown in figure 1.2. The cutting force (F_c) acts downward on the tool tip allowing deflection of the workpiece upward. It supplies the energy required for the cutting operation. The thrust force acts in the longitudinal direction. It is also called the feed force (F_f) because it is in the feed direction of the tool. This force tends to push the tool away from the chuck. The radial force acts in the radial direction and tends to push the tool away from the workpiece [3].

1.4 Introduction to Cutting Fluid

Cutting fluids are extensively used throughout industry in several machining operations such as turning, milling, grinding and boring. The function of a cutting fluid is cooling and lubrication. The coolant removes the heat in the cutting zone by absorbing the heat in the workpiece, chip and tool. Therefore, the temperature of the tool and the workpiece is reduced. The reduction in temperature results in the decrease in thermal distortion and provides better dimensional accuracy. The reduced temperature of the cutting tool also results in an increase in tool life. In addition to cooling, cutting fluids also act as a lubricant. It lubricates the interface between the tool's cutting edge and the chip, which reduces the friction. Lubrication also prevents welding of the chip onto the tool [4-5].

1.4.1 Types of Cutting Fluids

Cutting fluids are categorized into four main groups: water-soluble oils, straight oil, synthetics, and semi-synthetics.

Soluble oil fluids form an emulsion when mixed with water. The mixture consists of a base mineral oil and emulsifiers. They provide good lubrication and heat transfer performance. They are least expensive among all cutting fluids.

Straight oils are non-emulsifiable. They are not diluted when used in machining operations. They are composed of a base mineral or petroleum oil. Generally, straight oils consist of polar lubricants such as fats, vegetable oils and esters as well as extreme pressure additives such as chlorine, sulphur and phosphorus. Straight oil is the best lubricants, but poorest coolant. Their cost is high, but they provide the longest tool life for a number of applications.

Synthetic fluids contain no petroleum or mineral oil base. They are formulated from alkaline inorganic and organic compounds. Additives added for corrosion inhibition. They are commonly used in a diluted form. Synthetic fluids often provide the best cooling performance among all cutting fluids.

A mixture of synthetic and soluble oil fluids forms a semi-synthetic oil. It consists of 2%-30% of petroleum and mineral oil base. Semi-synthetics oil possesses better lubricity for moderate and heavy machining [6-7].

1.4.2 Limitations of the Cutting Fluid

Cutting fluids are considered as an addition to the high productivity and high-quality machining operations. However, the effect of cutting fluid is insignificant at high speed because of failure of the cutting fluid to reach the interface. The fluid moved outward more rapidly than it could be forced between the tool and chip. The effectiveness of the fluid in lowering the tool temperature decreases with increase in cutting speed. Along with the performance of cutting fluid at high speed, its cost and hazardous impact on human beings are the main limitations.

1.4.3 Cost of the Cutting Fluid

The economy of production system depends on upon equipment, cutting tools, energy consumption, labor cost and cutting fluid cost. According to King et.al. [8], the cost associated with the cutting fluid was between 7% to 17% of the total production cost. The percentage share of the cost associated with cutting fluid is shown in figure 1.3. Cutting fluid cost is approximately 8%-16% of the total manufacturing cost, which is more than cutting tool cost (4% only). The cost linked with the cutting fluids in machining processes is multifold. The cost includes the price of the cutting fluid, the cost of the installation and maintenance of extensive fluid handling equipment. The cost of paying employees suffering from adverse effects of exposure to these cutting fluids is the most important. Thus, decreasing the amount of the cutting fluid will result in a saving of the money as well as time.

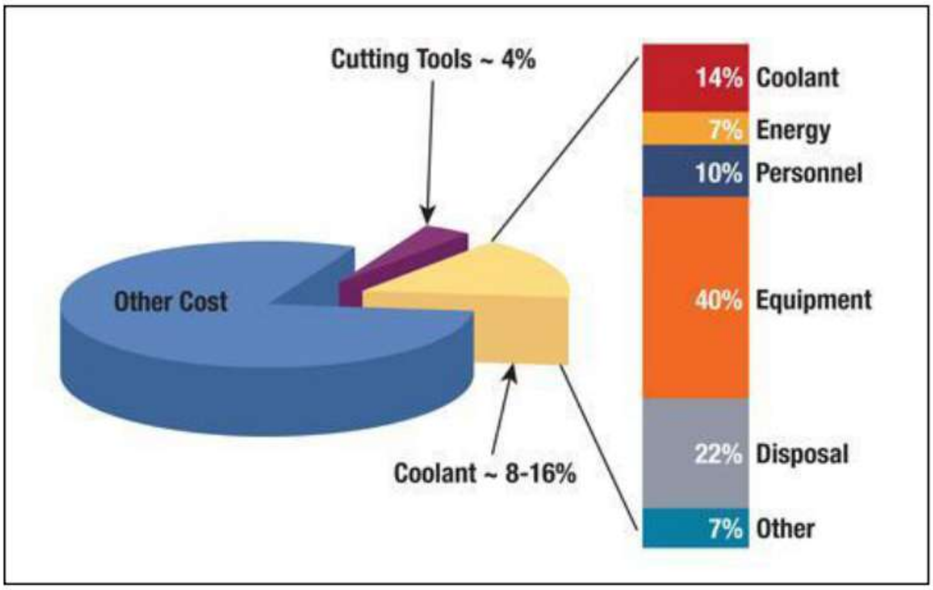


Figure 1.3 Cutting Fluid Cost [107]

1.4.4 Social Impact of the Mineral Based Cutting Fluid

A huge amount of cutting fluids is used in the industry. Approximately 60%-70% of the used cutting fluid is needed to be disposed of. Waste management of the cutting fluid is a very hot issue from an environmental point of view. The mineral oils are not renewable sources. Gases exerted from these oils contribute to global warming. Thus, mineral oil based cutting fluids are responsible for disturbing the natural system balance [9]. Increased use of 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 [10].

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 [11]. Pollutants such as nitrosamines, microbial agents, bacteria, fungi, shigella, E. coli, salmonella and Pseudomonas occur within the manufacturing system. These contaminants react with cutting fluid and affect occupational health and safety [12]. The operator may suffer from dermatological, respiratory disease, which may lead to cancer. Some cases of an effect of cutting fluid on the skin are shown in figure 1.4. Exposure to cutting fluids has a tendency to develop tumors that relate to the human epidemiology. Paraffin, trosamines, thanolamine, alkanolamines, triethanolamine, tri-ethanolamine, and nitroso diethanolamine are the contents of cutting fluid, additive or results of the reaction. Various environment protection agencies (EPA) have prohibited the use of this chemical as they are carcinogenic as well have adverse effects on the gene (DNA structure) [13-14].

Figure 1.4 Cases of Dermatitis, Folliculitis and Keratosis [109]

It is observed that use of cutting fluids made the working places dirty and unhygienic. They also damage the machine tool by corrosion [15].

Presently every rising ecological problem is reflected as a serious threat to the existence of the society. The industrial sector is considered as one of the main causes of environmental contamination. For every business enterprise, it is essential to conform to ISO 9000 quality management standards, ISO-14000 standards, occupational health and safety assessment series. Environmental issues are now discussed at international levels and it is obligatory for each country to keep the pollution level below a certain limit. Different regulatory bodies like the national institute for occupational safety and health (NIOSH), occupational safety and health administration (OSHA), environmental protection agency (EPA) and central pollution control board (CPCB) sets the limit for exposure level of the metalworking fluid. Stringent environmental protection regulations imposed on many prominent developed countries for the disposal of dangerous and toxic product waste [16].

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. Manufacturing organizations are looking for new techniques to reduce the amount of cutting fluids in machining operations due to environmental and financial burdens.

Initially, dry cutting attracted great attention because of the absence of the cutting fluid. It was also termed as green manufacturing [17]. However, dry cutting flops when greater machining efficiency, superior surface finish and severe cutting conditions are essential. Increased wear rate, the elevated temperature is also the major concern. Thus, dry cutting is not proved as the best alternative to flood cutting.

The industries are looking for possible means of dry, clean, neat and pollution free machining. Near-dry machining or micro lubrication or minimum quantity lubrication emerges as a substitute to dry machining and flood cutting [18].

1.5 Minimizing the Use of Cutting Fluid

The minimum quantity lubrication uses very small amount of cutting fluid (50 ml/hour to 500 ml/hour) which is very low than conventional flood lubrication system (1 liter/min to 10 liter/min).

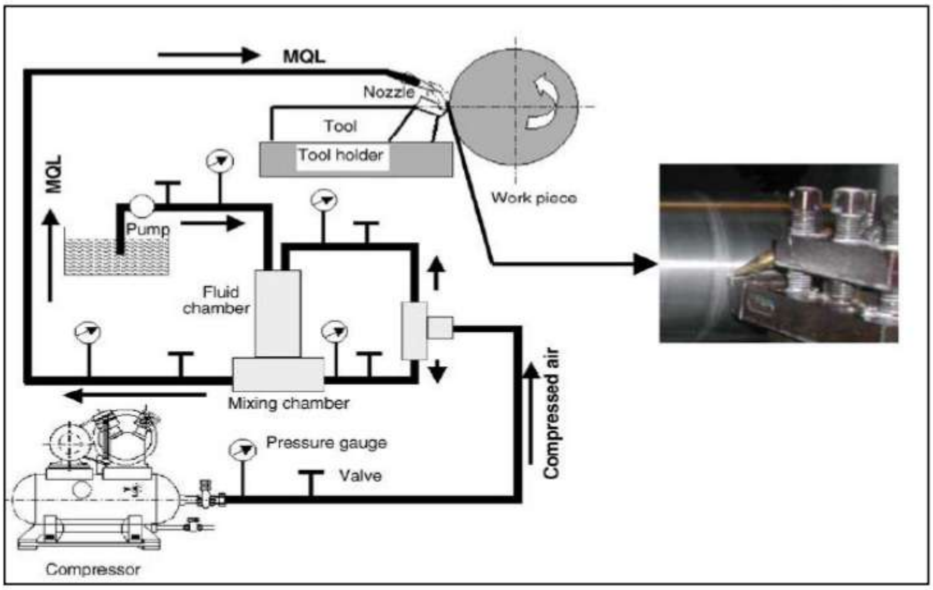


Figure 1.5 Schematic of MQL System [30]

Minimum quantity lubrication system consists of an air compressor, oil tank, mixing chamber and nozzle. Schematic of the MQL system is shown in figure 1.5. In minimum quantity lubrication system, a droplet of the fluid is atomized by high-pressure airflow. The mixture of high-pressure air and cutting fluid applied directly to the interface of cutting tool and workpiece. This high-pressure air-oil jet penetrates the tool-workpiece interface area more precisely than flood cutting [29]. This results in a substantial decrease in temperature and frictional forces. The minimization of cutting fluid leads to saving of the cutting fluid. It also reduces the chances of the contact of the operator with cutting fluid [30].

1.6 Vegetable Oil as a Potential Cutting Fluid

Cutting fluid is regarded as a medium between machine, workpiece, and tool. Using minimum quantity lubrication, cutting fluid quantity is decreased significantly. However, awareness of the health hazard, ecosystem problems resulted into strict legislation to regulate the usage of the mineral oil based cutting fluids. Efforts are made to eliminate the mineral-based cutting fluid.

Vegetable oils are a plant-based agricultural product. They can be cultivated, genetically modified hence renewable, biodegradable and nontoxic. They possess high viscosity, boiling point, and flash point. The triglyceride structure of the vegetable oil provides desirable quality of the boundary lubrication and high viscosity [47]. Vegetable oil molecules give a strong and homogeneous film. Due to a high flash point, they can be used for high-temperature applications. It also reduces the risk of smoke formation and fire hazard. High boiling point and greater molecular weight result in considerably less loss from evaporation. Vegetable oils are, thus arisen as a feasible substitute to petroleum-based cutting fluids [50].

1.7 Modeling and Optimization of Machining Processes

The manufacturing industries struggle to achieve a minimum cost of production or a maximum production rate in machining. These two measures are interrelated with a choice of cutting conditions like speed, feed, and depth of cut. 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 [106]. In the present work, response surface methodology and an artificial neural network are used for validating the experimental results.

1.8 Research Motivation

Industrial growth of a country depends on the multinational industry, the small-scale industry as well as small domestic units. The role of the small domestic units is very important. Nearly 80% of the small-scale industries have basic production machines like lathe, milling, and drilling machines. The small, medium industry sector is reluctant to use new techniques in the field of machining.

While surveying, Nashik industrial area (Satpur MIDC), it was observed that 60% to 70% proprietor are unaware of the demerits of the cutting fluid. Some are unwilling to use MQL techniques due to financial limitations. Large numbers of operators are illiterate and not familiar with the adverse impact of cutting fluids on the health.

In India, a large amount of mineral-based cutting fluids is used in both large scale, medium scale industry. 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. This is very serious. There is an urgent need to create awareness about the demerits of mineral-based cutting fluid. It is needed to design a simple, low-cost MQL system that will use vegetable oil, which will give improved performance as that of mineral-based oil without affecting the environmental system.

1.9 Research Objectives

1. To verify the effect minimum quantity lubrication system in comparison with dry and flood machining on cutting forces, temperature, surface roughness, power consumption and tool wear etc.

2. To evaluate the performance of vegetable oils (Soyabean oil, Groundnut oil, Sunflower oil and Coconut oil) as cutting fluids in comparison to petroleum-based cutting oil (Blasocut-4000).

3. To compare the performance of different vegetable oils in terms of cutting forces, cutting temperature, surface roughness, power consumption, tool wear, and tool life.

4. To develop a mathematical model to validate experimental results and to optimize the turning parameter for maximum performance.

1.10 Organization of the Thesis

The organization of various chapters with brief contents is provided.

Chapter 1 introduces the subject and describes the aims and objectives of the study. It also discusses the motivation of the study. The introduction provides the background to this research, giving reasons as to why the research was conducted and describes the structure of the thesis.

Chapter 2 provides the review of the research work on dry, flood and MQL cutting, vegetable oil, optimization methodology used. Summary of the literature review with concluding remark is added at the end of the chapter.

Chapter 3 describes the methodology and experimental setup, instruments used to perform the conducted research.

Chapter 4 demonstrates the mathematical modeling, and validation of the model developed. RSM and ANN are used for model analysis.

Chapter 5 elaborates the optimization process for machining parameter.

Chapter 6 summarizes the results obtained from the experimental work. This chapter gives a comparative analysis of the experimental results, response surface analyses, and artificial neural network results.

Chapter 7 gives concluding remark of the complete research work. It also provides information about the future scope of the research.

Chapter 8 includes the details of the references used for the research work.

Appendix A gives observation of the experimentation for all machining environments.

Appendix B gives details of the mathematical modeling for dry cutting, flood cutting, blasocut, sunflower oil, coconut oil and groundnut oil.

Appendix C contains optimization plot for different vegetable oils.

Appendix D contains a graphical representation showing the effect of cutting parameters on the response.

CHAPTER 2

LITERATURE REVIEW

The performance of machining process is measured in terms of the output parameters and cost associated with it. 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. It also helps to acquire knowledge on the latest development in the related areas.

This chapter presents a comprehensive study of the literature related to research work. 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 also exemplified in this section.

2.1 Flood Cutting and Health Hazards

The heat dissipated during metal cutting affects the product quality as well as productivity. Cutting fluids are used to reduce the temperature. Mineral-based cutting fluids are costly as well as unsafe to the human being. According to the different researcher, the hazardous effect of the cutting fluid is a threat to the society.

Marksberry et al. [12] revealed that contaminants, like nitrosamines, microbial agents, bacteria, fungi, shigella, E.Coli, salmonella, and pseudomonas occurred within the manufacturing system. These contaminants react with cutting fluid and affect occupational health and safety.

Bennett et al. [13] studied the harmful effect of the mineral-based cutting fluid on the machine operator. He warned that exposure to cutting fluid would result in increased risk of airway irritation, chronic bronchitis, asthma and even laryngeal cancer.

Mackerel et al. [14] exposed the health issues associated with metal working fluid. The application of cutting fluids within a machining operation frequently produces an airborne vapor. Medical evidence showed that exposure to cutting fluid vapor leads to respiratory disorders and several types of cancer.

Aronson [15] pointed out the main weaknesses of flood lubrication. The drawbacks of the cutting fluids were also discussed. They were as follows-dirty working place, corrosion, mixing lubricant and coolant, environmental pollution, harmful gases and biological hazards, the requirement of additional systems for local storage, pumping, filtration, recycling, re-cooling, disposal of the cutting fluid, soil contamination, and pollution. This adds to the cost of the total production system.

Survey of occupational exposure to metalworking fluids in the engineering industry was conducted. A. T. Simpson [16] recapitulates work-related hygiene findings from the survey. Survey results showed that grinding and drilling operations produced higher exposures than turning and milling. It was found that fluid management in industries was not up to the mark. High levels of bacteria, endotoxin were found in oil sumps. The results of this work contributed to set out good industry practice and to decide the values for metal working fluid mist and sump fluid contaminants.

Exposure to the chemical content of the cutting fluid leads to life-threatening diseases, hence different regulatory bodies decided to limit the exposure level of the cutting fluid. The occupational safety and health administration regulations of mist/aerosol in manufacturing plants were 5 mg/m^3 for an 8-hour time-weighted average for mineral oil mist and 15 mg/m^3 for particulates. The national institute for occupational safety and health recommended similar exposure limit [11] [16].

Considering the dangerous effect of cutting fluids, it is necessary to increase awareness about health hazards to the operator in developing countries. It is essential to minimize the use of poisonous fluid. Dry cutting can be treated as a substitute to flood cutting. In dry cutting, no cutting fluid is used.

2.2 Dry Cutting

F. Klocke et al. [17] studied the most recent developments in dry cutting. Along with uses of the coolant, their shortcomings, different types of cooling strategies, lubricant waste disposal and cost of waste disposal were discussed. According to the author, until 2003, minimum quantity cooling (MQC) was not taken seriously.

P. S. Sreejith et al. [18] gave more emphasis on dry machining i.e. machining without cutting fluid. In dry machining, there was more friction and adhesion between the tool and the workpiece. They stated that more than 16% to 20% of the manufacturing cost occurred only due coolant and lubricant. They also focused on basic and recent advancement in dry machining like under cooling, intercooler, thermoelectric cooling and cryogenic system.

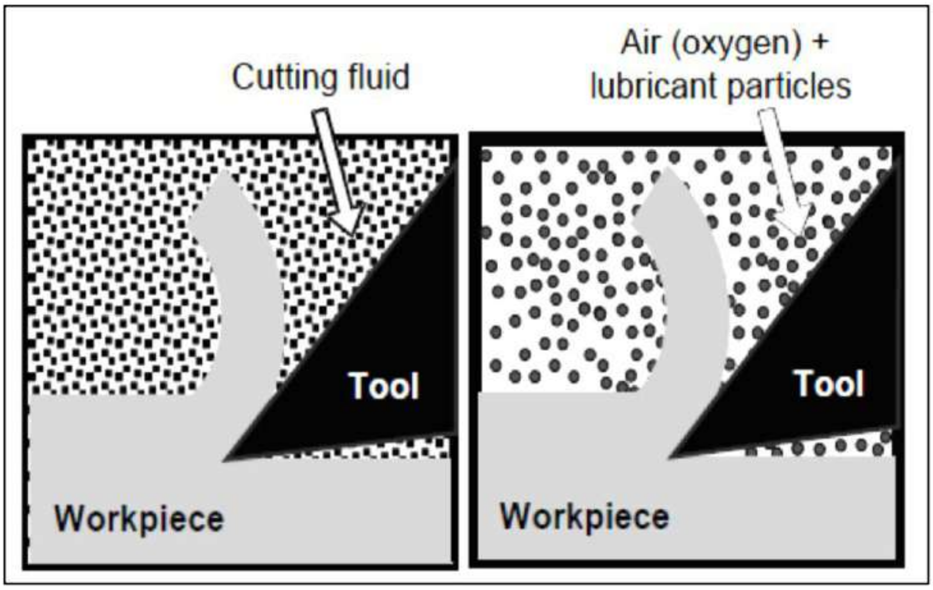
Anselmo Eduardo Diniz et al. [19] determined that feed, tool nose radius and cutting speed had a major impact on tool life and surface roughness. During dry cutting increased feed rate, nose radius and decreasing cutting speed improved tool life and surface roughness. They specified that without using any cutting fluid performance could be increased by proper selection of parameters.

A. Bordin, S. Brachial et al. [20] investigated the surface integrity of a CoCrMo alloy during dry turning. The effect of the cutting parameters was evaluated for a fixed turning length. They conducted experimental trials at 40 m/min and 60 m/min with two feed rate, 0.1 mm/rev and 0.15 mm/rev. The depth of cut was taken as 0.25 mm; no lubricants have been applied for all trials. Their work resulted in interesting outcomes for difficult-to-cut metal in dry conditions, without affecting its surface integrity.

Though dry cutting was considered as an alternative to eliminate the cutting fluid, it has several limitations like higher temperature, tool wear and worsened product quality. Therefore, minimum quantity lubrication (MQL) was developed as a compromise between flood cutting and dry cutting. The financial and ecological worries on the use of cutting fluids lead to the research in minimum quantity lubrication (MQL).

2.3 Minimum Quantity Lubrication (MQL)

In Minimum quantity lubrication, a mixture of compressed air and oil is sprayed at the interface of the tool and workpiece. Due to high-pressure air, oil particles are converted into small droplets. This increases the contact area. The increase in contact area results in more heat dissipation. Studies showed that oxygen enhanced the adsorption ability of the lubricant. The lubricant particles are surrounded by a large amount of air containing oxygen, leading to the formation of a robust and tribologically effective lubricating film. The difference between the lubricating film formed around the tool and work surface is shown in figure 2.1



a) Conventional supply b) MQL supply

Figure 2.1 Schematic difference between conventional supply and MQL supply [21]

According to K. Weinert and I. Inasaki et al. [21] 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. Research activities in the field of MQL would be helpful for small and medium-scaled industry. Author presented a detailed analysis of the dry cutting and minimum quantity lubrication. Minimum quantity lubrication is a strategy that could offer technological and economic advantages over traditional fluid applications.

The tool manufacturing engineers handbook (SME, 1983) explained four mechanisms of cutting fluid flow. They are capillary action, diffusion mechanism, volatilization and rehbinder effect. Two surfaces in contact with each other has gap between them. This gap creates channels like capillary for the flow of the cutting fluid. The capillary action aids to flow the fluids between two vicinity surfaces. Diffusion means to penetration of the cutting fluid through the metal matrix. The fluid particles intrude to form bonds with the workpiece metallurgical structure. Vaporization of fluid changes the viscosity and convert fluid into vapor. The vapor phase penetrates efficiently. Rehbinder effect represents chemical reaction of content of cutting fluid with work surface. Chemical present in the cutting fluid, soften the work material, reduces its shear strength in the primary cutting zone. In MQL application, the capillary action and volatilization are more contributing factor. [22]

Uwe Heisel et al. [23] described the results of MQL in turning, broaching and milling. He had applied MQL technology in machining with geometrically defined edges. Author gave a brief idea about applications of minimum quantity cooling systems in machining.

Varadarajan et al. [24] investigated the hard turning with minimal fluid application and compared it with dry and wet turning. Results showed that MQL had superior performance than dry, wet cutting. Result exhibited that there were decrease in cutting temperature and cutting forces while tool life, surface finish were improved as compared to wet and dry cutting.

Ronan Autret et al. [25] compared the mechanical performance of minimum quantity lubrication to dry lubrication for the turning for bearing grade steel. The results showed that the use of minimum quantity lubrication leads to reduced surface roughness, late tool flank wear and lower cutting temperature but less effect on cutting forces.

Ju. et al. [26] determined that MQL application was not as effective as flood application in reducing the workpiece temperature but it was more effective than dry cutting. Cutting forces were almost equal for flood lubrication, dry and MQL. Rise in fluid flow rate and air pressure resulted in reduction of temperature and improved surface finish.

A. Attanasio et al. [27] acknowledged the results obtained from turning tests and SEM analysis of tools, at two feed rates and two cutting lengths, using MQL on the rake and flank of the tool. The results obtained showed that when MQL was applied to the tool rake, tool life was same as that of dry conditions, but when MQL was applied to the tool flank, it resulted in increased tool life.

McClure et al. [28] 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 liter to 4 liter per hr. There was extensive saving of cutting fluid.

N. Dhar et al. [29] 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. Use of MQL resulted into decrease in cutting temperature and increase in dimensional correctness. The chip formation and chip–tool interaction became more acceptable under MQL condition. MQL reduced the cutting forces by about 5%–15%. MQL provides environment friendliness as well as improve the machinability characteristics.

N.R. Dhar, Kamruzzaman et al. [30] conducted an experimental investigation on the role of MQL on tool wear and surface roughness in turning AISI-4340 steel. Speed was varied from 60 m/min to 110 m/min. Feed was taken at 0.10 mm/rev, 0.13 mm/rev, 0.16 mm/rev and 0.20 mm/rev. Depth of cut is kept constant. MQL system cutting fluid flow rate was 60 ml/hr. Results showed that there was a substantial reduction in tool wear rate and surface roughness by MQL. Machining with soluble oil did not provide any substantial enhancement in tool life, rather surface finish deteriorated.

D.K. Sarma, U.S. Dixit et al. [31] performed a comparative study of dry and air-cooled training for gray cast iron. According to study, tool life was greatly reduced in dry turning. At higher cutting speed, performance of dry cutting was very poor. The air-cooled turning provided an improved surface finish, reduction in tool wear. In all the cases, the cutting and feed forces are reduced in air-cooling.

Y.S. Liao et al. [32] studied the viability of MQL in high-speed milling. Tool life and surface roughness under various cutting conditions including dry, flood cooling and MQL were calculated. For both lower speed cutting and the higher speed cutting conditions tool life was more for MQL cutting. The authors performed a study of MQL in high speed machining of hardened steel. It was concluded that the tool life could be successfully improved by MQL in high speed machining of hardened steel. Scanning electron microscope (SEM) micrograph and energy dissipative X-ray spectroscopy (EDX) analysis were used to inspect the cutting behaviors of MQL. There was lots of improvement in tool life and surface roughness using MQL. The cutting under flood cooling condition resulted in the shortest tool life due to severe thermal cracks while the use of MQL lead to the best performance for all three cutting speeds.

P. S. Sreejith et al. [33] reported the effect of different lubricant environment when 6061 aluminum alloy was machined with diamond-coated carbide tools. The effect of dry machining, minimum quantity of lubricant (MQL) and flooded coolant conditions was analyzed with respect to the cutting forces, surface roughness of the machined work-piece and tool wear. Cutting speed used was 400 m/min. Depth of cut and Feed rate were 1.0 mm and 0.15 mm/rev respectively. Two-flow rate were applied for minimum quantity of lubricant (50 ml/hr and 100 ml/hr).Increasing the flow rate did not affect the tool wear and surface roughness. Results indicated that MQL condition would be a very good substitute to flooded coolant/lubricant conditions.

Michel Roegiers et al. [34] focused on applications of friction additives in the formulation of metalworking lubricants. These friction additives were used to enhance lubricity of the metalworking fluids. Elektrionization of vegetable oils produced lubricity and oiliness additives. Elektrionized vegetable oils were highly efficient. These additives facilitated the transportation of chips from the cutting zone, prevented reading, stabilized oil against oxidation, reduced misting and extend tool life.

B. Tasdelen, T. Wikblom et al. [35] investigated the effect of oil droplets and air in the aerosol at MQL cutting. The experiments were carried out at 155 m/min and 0.11 mm/rev as feed. Test were performed using three environment, i.e., dry, compressed air and emulsion. The results were discussed in terms of wear, chip contact, forces/torques and surface finish. The surface finish values have shown that cutting with compressed air gave a bad surface finish.

M.Alves et al. [36] analyzed the influence of minimum quantity lubrication (MQL), optimized and conventional cooling at different cutting fluid volumes and flow rates for grinding application. The evaluation of work piece was based on specific energy, tangential cutting force, surface roughness, roundness errors, acoustic emission, residual stresses, scanning electron microscopy (SEM) micrographs, and micro hardness. The optimized and MQL processes gave better hardness and surface integrity. MQL with a flow rate of 40 ml/hr resulted into cracking and quenching of the workpiece surface.

Hadad,Sadeghi et al. [37] 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.

Kedare S. B.et al. [38] varied input parameters like speed, feed and depth of cut and their effect on surface finish and other performance parameters. The end milling was performed under the minimum quantity lubrication condition (900 ml/hr) using end mill cutter. It was compared with conventional flooded lubrication (2 liter/min). The surface finish was improved by 27%. MQL offered the benefits mostly by reducing the cutting temperature, which enhanced cooling outcome and results in a better surface finish.

Minimal quantity lubrication offers eco-friendly atmosphere by keeping neat, clean, dry working area, thus minimizes the inconvenience and health hazards. However, it cannot eliminate the use of cutting fluid completely.

Many research activities are carried out for MQL, 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. Cost effective MQL system and awareness in the factory owner about the toxic effect of cutting fluid should escalate the use of MQL.

2.4 Vegetable Oils as a Cutting Fluid

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.

R. B. Brown et al. [39] determined thermal properties like thermal conductivity and convective heat transfer coefficient for soyabean and white bean seeds. The thermal conductivity values for soyabean seeds were 0.211W/m$^{\circ}$C to 0.221 W/m$^{\circ}$C. The average fluid-particle convective heat transfer coefficient was 131 W/m$^{2\circ}$C for soybean seeds and 106 W/m$^{2\circ}$C for white beans.

McCabe and Ostaraff et al. [40] determined environmental compatibility of vegetable-based oil by their biodegradability in comparison with synthetic and polyol esters. Vegetable oils have been used in MQL cutting because of their beneficial biodegradability features.

Khan, Dhar et al. [41] elaborated the investigation results of MQL using vegetable oil on cutting temperature, tool wear, surface roughness and dimensional deviation during turning AISI-1060 steel. Various industrial speed-feed combinations were used. Author listed the various characteristics of the vegetable oil.Non-toxicity, biodegradability, environment friendliness were the advantage over mineral-based oil. Testing was carried out at different velocity (72 m/min, 94 m/min, 139 m/min and 164 m/min).The feed rate was changed as 0.10 mm/rev, 0.13 mm/rev, 0.16 mm/rev and 0.20 mm/rev. Depth of cut was kept constant, 1.5 mm. The results included significant reduction in tool wear rate, dimensional inaccuracy and surface roughness by MQL.

Sunday Albert Lawal et al. [42] evaluated the performance of cutting fluid from fixed oil (groundnut oil, palm kernel oil, palm oil and mineral oil based cutting fluid.) The major test parameter to investigate performance was temperature and heat conducted by cutting fluid. They observed that groundnut oil performs better than other samples.

Babatunde Lawal A et al. [43] assessed lubricants like black soap, groundnut oil, palm kernel oil, red palm oil and shea butter oil. It was observed that red palm oil gave better result for coefficient of friction when tested experimentally by ring compression test.

M.A. Islam, N.R. Dhar et al. [44] 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. [45] conducted a comparative study of the pure coconut oil and SAE 40 oil along with nano boric acid powder suspension. Solid lubricant particles of 50 nm size were mixed in SAE-40 oil and coconut oil in different weight proportions at room temperature. Heat transfer coefficient increased slightly with an increase in percentage of nano boric acid in base oil and cutting speed. Experiments were conducted at 60 m/min, 80 m/min and 100 m/min Feed was 0.14 mm/rev, 0.16 mm/rev, 0.20 mm/rev while the depth of cut is 1.00 mm. The lubricant flow rate was 10 ml per min. They observed that cutting temperature, tool flank wear and surface roughness decreased significantly with coconut oil as cutting fluid.

M. Anthony Xavier et al. [46] 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. In case of coconut oil, the tool wear was significantly reduced as compared to soluble oil and straight cutting oil at lower cutting speed. The viscosity of coconut oil was more than that of soluble oil and less than that of straight cutting oil. This favored easy flow of cutting fluid at minimal oil condition. The performance of coconut oil was compared with an emulsion and neat cutting oil (immiscible with water). The results showed that coconut oil performed better than the other two cutting fluids in reducing the tool wear and improving the surface finish. It was also found that feed rate was a major influencing factor for surface roughness while speed affects tool wear substantially.

Khan, Mithu, Dhar et al. [47] stated that as cutting speed and feed rate increases, temperature increases. Experiments were conducted during turning process of AISI

9310 low alloy steel using uncoated carbide tool. The authors conducted an experiment for MQL with vegetable oil lubricant, wet and complete dry cutting. Significant reduction in surface roughness was obtained for MQL with vegetable oil. The electrochemical interaction between tool and workpiece, resulted in more roughness values for wet cutting. The authors observed that brighter and smoother chip were produced when machining with MQL.

Sultana, N.Dhar et al. [48] investigated the role of different cutting fluid like water-soluble cutting fluid, vegetable oil -VG68 cutting oil on cutting force, surface roughness in turning 42CrMo4 steel. At high cutting speed, VG68 oil gave the best performance due to better cooling and lubrication. MQL by VG68 oil reduced temperature by 6% to 12.5%, chip thickness ratio increased by 14% to 17%.

Abhang L.B et al. [49] investigated the performance of MQL machining of alloy steel with 10 % boric acid with SAE 40 based oil during turning of EN 31 steel using tungsten carbide tool. The Chip tool interface temperature was lowered by 20% to 30 %. Chip thickness was reduced by 12% to 17 % in comparison to dry cutting. Minimum quantity lubricant reduced the cutting forces by about 5% to 12%. Addition of boric acid improved the performance.

E. Kuram et al. [50] 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. Performances of five cutting fluids were examined for cutting force and surface roughness during drilling of AISI 304 with HSS-E tool. Spindle speed, feed rate and drilling depth were considered as machining parameters. L9 orthogonal array was used for the trial plan. Results were assessed by means of regression analysis and analysis of variance.

S.A. Lawal et al. [51] reviewed the use of vegetable oil-based metalworking fluids in machining of ferrous metals. Effect of metalworking fluids and its performances with respect to the cutting force, surface finish of work piece, tool wear and temperature at the cutting zone have been investigated. Author reviewed performance of A304 austenitic stainless steel, AISI 1040 steel, AISI 9310 alloy steel, mild steel, AISI 316L austenitic stainless steel, 100Cr6 Alloy, AISI 4340 steel. The performance of vegetable oil was different for different type of steel.

Arumugan S.G et al. [52] synthesized methyl ester of sunflower oil, palm oil, rapeseed oil. Raw rapeseed oil was chemically modified by oxidation and hydration process. Epoxidised rapeseed oil showed superior oxidation stability, lower pour point and friction.

A. Shokrani et al. [53] studied the materials difficult to machine. Hard materials, ductile materials and non-homogeneous materials were the three groups of material reviewed by the author. Difficult to cut material like titanium, composite ceramics elastomer, cobalt alloy was studied. Various types of coolant/lubricant study were conducted. Health issues related to coolant were studied. Different techniques of reducing cutting fluid like dry cutting, MQL, cryogenic and air-cooling were investigated.

E. A. Rahim et al. [54] studied the effect of the palm oil as a MQL lubricant on high speed drilling of titanium. It was perceived that MQL palm oil gave similar performance with flood lubrication.

S. D. Supekar et al. [55] suggested supercritical carbon dioxide as a new substitute for metal working fluid. They examined the cooling and lubrication properties of supercritical carbon dioxide sprays. Experiments were carried out almost for all machining process like turning, milling, drilling, and threading operation. Comparative study of supercritical carbon dioxide sprays and other metal working fluids showed that heat removed by CO_2sc was more.

According to S. Syahrullaila et al. [56] vegetable oil might be oxidized and undergo changes in their chemical and physical composition. Hence, they tested different vegetable oil for their properties using a four-ball tribometer under extreme pressure conditions. The results indicated that vegetable oils have a high friction coefficient and low wear scars than those produced by mineral oil.

J. P. Davim [57] focused on environmental conscious machining such as dry cutting, machining with minimum quantity lubricant and especially machining with vegetable-based cutting fluids including other types of cutting fluids.

Gurpreet Singh et al. [58] conducted experimental investigations to determine effect on surface roughness using vegetable based minimum quantity lubrication. Cutting velocity was increased from 1.20 m/s to 2.88 m/s. Three feed were chosen. (0.088

mm/rev, 0.112 mm/rev and 0.168 mm/rev) Depth of cut were 0.5 mm and 1.00 mm. Experiments were conducted for dry and MQL environment. For MQL cutting, soyabean oil was taken as cutting fluid. The surface roughness values are comparable with that of mineral oil, during turning of EN-31 Steel. Surface roughness values were decreased by 20% to 40%. Effect of nose radius on surface roughness was also studied.

Nilesh Ghuge, Dr. AM. Mahalle et al. [59] evaluated the performance of the MQL technology for the cutting fluid used in keystone grinding. Protoform-70 was used as a coolant. The piston rings used were an AVL piston ring. The surface roughness of the piston ring is decreased using MQL unit. Waviness was also measured and compared to flood lubrication.

Sharafadeen Kunle Kolawole et al. [60] compared the performance of palm oil and groundnut oil with mineral-based oil during machining of mild steel. Vitamin-C-rich-lemon fruit extract was used as an antioxidant to improve the oxidative stability of the vegetable oils. Work piece temperature, the chip formation rate at different speed, feed and depth of cut combinations were noted. The temperature of the work piece when groundnut oil was used, as cutting fluid was comparable to that of the conventional oil. Palm oil provided highest chip thickness of 0.27 mm probably because of its better oiling property. The result showed that groundnut oil had a better fluidity and rapid cooling ability than other oil samples.

Mohd Saad Saleem, M. Zafaruddin Khan et al. [61] performed trials on a cylindrical workpiece of mild steel. The cutting speed was 250 rpm. HSS single point-cutting tool used during turning. Mustard oil was used as a coolant during the machining. Results on tool life and tool wear were compared with traditional coolants such as (10% Boric acid +SAE-40 Base oil) and (10% MoS_2 +SAE-40 Base Oil). Experimental results indicated the Mustard oil easily removed heat and gives good lubrication. Tool life and surface finish were improved. Mustard oil gave comparable results as compared to coolant (Boric acid +SAE-40 Base oil).

M. Shashidhara, S. R. Jayaram et al. [62] compared the performance of Pongam and Jatropha and a commercially available branded mineral oil. Cutting forces were measured during turning AA 6061. Cutting power was determined for various cutting speeds, depth of cut and feed rate. Performance of vegetable oils was compared to mineral oil. Substantial reduction in cutting forces was observed under the Jatropha family of oils. According to the authors, Jatropha family of oils gave better performance as compared to mineral oil.

Ester C. de Souza et al. [63] studied quenching and heat transfer properties of aged and unaged vegetable oils. Soybean, canola, corn, cottonseed and sunflower oils exhibit very poor thermal-oxidative stability, relative to petroleum oil while peanut oil and coconut oil have improved properties due to their more favorable molecular structure. Numbers of vegetable oils were examined to assess the quenching performance. Cooling curve performance, according to ASTM D6200 for two, bath temperatures (60°C and 90°C) was determined. Effective heat transfer coefficients were calculated.

Sodamade A et al. [64] 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. Palmate acid; (C16: O) Stearic acid (C18:O) and Oleic acid (C18:1) were the main saturated fatty acid present in vegetable oil. Coconut oil consists of 2.09%, 8.584 % of palmate acid, stearic acid respectively. Soyabean oil have 1.496 % of stearic acid. All three acids were found in groundnut- palmate acid, stearic acid and oleic acid (4.76%, 12.75%, and 12.72 %) respectively. Polyunsaturated (essential) fatty acid was also called as linoleic acid (C18:2 Omega-6). The major component of soyabean oil and coconut oil was Myristic acid (C14: O) (41.039% and 33.544% respectively). The highest fatty acid component of groundnut oil is lauric acid (C12: O) at 14.567%.

Manoj Kumar K, Jeewan Sarda, Amitava Ghosh et al. [65] investigated performance of palm oil and sunflower oil based on their wetting capability and lubricity. Sunflower oil outperformed palm oil and synthetic soluble oil in producing good wetting and effective lubrication on alumina and steel surface. Grinding experiments were carried out to assess the performance of the palm oil sunflower and conventional soluble oil. Sunflower oil was found to be the most effective to reduce grinding force.

Carlos Alberto, Schuch Bork et al. [66] collected data on the performance of the jatropha vegetable- oil. It was observed that the jatropha cutting oil gave the best results in relation to requirements for lubrication, superficial mean roughness index and shape errors. Cutting tool life was improved by 30%. The jatropha (vegetable) oil, in relation to its physicochemical properties, appeared to be the best one fit for being used in the machining of aluminum alloys 7050-T7451 because it did not interfere with any of the elements involved in the formation of intergranular corrosion and/or pitting.

K.P. Sodavadia, A.H. Makwana et al. [67] presented research work on performance of nano cutting fluids in machining. Coconut oil with nano particles of boric acid was used as cutting fluid. Work piece for turning was AISI 304 austenitic stainless steel. At different feed and speed, tool flank wear, surface roughness and cutting tool temperature was measured.

Mithun Shah et al. [68] identified the properties of the non-ionic surfactants and formulated a castor oil based cutting fluid. Experimentation has been carried out for different combinations. The machining parameters were cutting velocity, feed rate and depth of cut. Machining had been carried out upon SS 316 L work piece with carbide cutting insert tool. The results showed that castor oil performed better than conventional cutting fluid.

Hasan Mf, Dwivedi et al. [69] presented the influence of minimum quantity lubrication (MQL) using vegetable oil based cutting fluid during turning. The performance of low alloy steel was compared to completely dry and wet machining. Chip–tool interface temperature, chip formation mode, tool wear and surface roughness were measured. Results showed that MQL using vegetable oil gave an improvement in machining performance.

Sachin M. Agrawal, P. K. Brahmankar et al. [70] determined the effect of lubricant to wear and frictional force by using a pin on disc machine with M2HSS tool. The performance of cottonseed oil was evaluated with dry and wet conditions by using SAE-40 oil. Author concluded that cottonseed oil could be proposed as a metal working fluid in the industry as it showed relatively good result in terms of wear and coefficient of friction at various loads and speeds. In addition, it is biodegradable, less pollutant, easily available and cheaper as compared to conventional metal working fluid.

Jagdeep Sharma, Balwinder Singh Sidhu et al. [71] investigated the effects of dry and near dry machining on AISI D2 steel using vegetable oil as lubricant. Observations were made at different speeds-feed combination to determine work tool temperature and surface roughness at dry cutting and near dry machining. Near dry machining showed encouraging outcomes over dry machining in terms of work tool interface temperature and surface roughness.

Vardhaman et al. [72] 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.

Gaurav Arora, Ujjwal Kumar et al. [73] used sunflower oil, coconut oil, castor oil and mineral oil as a cutting fluid. They estimated surface roughness of Aluminum. It was observed that vegetable oil performed well in comparison with conventional oil. A comparative study of turning experiments, between vegetable based cutting fluids and mineral-based cutting fluids were conducted using the same machining parameter. The results showed that vegetable oils, especially non-edible have potential to replace the mineral oils.

Mohamed Hindawi, M.Y. Noordin et al. [74] verified the performance of MQL using castor oil as cutting fluid. HRC48C steel was turned using coated carbide tool at 0.24 mm/rev and cutting speed up to 170 m/min. They compared the results of castor oil with dry cutting. It was found that using MQL with castor oil produces superior results in terms of long tool life. There were improvements in surface roughness as well as cutting forces.

I. Shyhaa et al. [75] stated that vegetable oil offers a combination of good biodegradability, lubricity, co-friendliness, compatibility with additives, low toxicity, volatility, high flash points and high viscosity indices. They carried out initial experimentation when turning Ti-6Al-4V. Statistical analysis exhibited the main contributing factor for roughness was feed rate.

A. Hosseini Tazehkandi et al. [76] investigated the impacts of machining parameters on forces, surface roughness and tool tip temperature in flood cutting and spraying for hard cutting. It was discovered that spray mode of cutting fluid in combination with compressed air improved heat transfer.

According to Fox, Stachowaik et al. [77] the triglyceride structure of vegetable oils is one of the distinguishing features of the vegetable oil needed to be lubricant. Long, polar fatty acid chains results in high strength lubricant films. The strong intermolecular interactions were resilient to changes in temperature providing a more stable viscosity, or high viscosity co-efficient, But VBCFs have low oxidation and thermal stability. Formulated VBCFs with chemical additives displayed a lower co-efficient of friction, equivalent scuffing load capacity and better pitting resistance in the cutting zone.

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.

2.5 Optimization of Cutting Parameters

There are a number of combinations of input parameter in any machining process. Input parameters should be changed to find the best output. This is known as trial and error method. However, it is time consuming and costly. There is a need to obtain optimum parameter, which will give maximum or minimum response as per requirement. 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. This result in saving in time and cost.

Pearson et al. [78] 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. [79] used Taguchi DOE for optimization of cutting speed, feed rate and depth of cut for turning operations. Cutting speed and feed rate were the most contributing parameter, which affect tool life. The S/N ratio and ANOVA result showed that cutting speed, feed rate and depth of cut were considered as significant cutting parameters for affecting surface roughness. However, as per contribution, the sequence of the cutting parameters for surface roughness is the feed rate, depth of cut and cutting speed.

Nian et al. [80] proposed Taguchi method with multiple performance characteristics to optimize of turning operations. To study the performance characteristics in turning operations, the orthogonal array, multi-response signal-to-noise ratio and analysis of variance were used.

W.S. Lin, B. Y. Lee et al. [81] 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. Regression analysis was used to verify the results. Comparison of the two models showed that the prediction model developed by the abductive network was more accurate than that by regression analysis. Experimental results provided, to confirm effectiveness of this approach.

Davim et al [82-83] developed linear regression models to predict surface roughness and tool wear. Predicted values from regression model were compared with the experimental results. Taguchi method and ANOVA were used for the study. Results showed that error related to the power required was less than that of tool wear and surface roughness.

Noordin et al. [84] used response surface methodology for evaluating the performance of coated carbide tools during turning AISI-1045 steel. The parameters considered for the study were cutting speed, feed and side edge angle. The response variables were surface finish and tangential force. Analysis of variance technique used to find most significant parameter. The result showed that feed was the most significant factor influencing the response variables investigated. Mathematical models developed to predict cutting force produced comprehensive results.

Tugral Ozel et al. [85] developed a predictive model of tool wear and surface roughness in hard turning by CBN tool using neural network and regression method. Regression models were also established to find the interrelated parameters. A set of experimental data for finish turning of hardened AISI 52100 steel obtained from literature and the experimental data obtained from trials in finish turning of hardened AISI H-13 steel had been utilized. Trained neural network models were used in predicting tool flank wear and surface roughness for other cutting conditions.

Sahin et al. [86] projected a surface roughness model in the turning of AISI 1040 carbon steel. Response surface methodology was used to develop models in terms of cutting speed, feed rate and depth of cut. Experiments conducted using PVD-coated ceramic tools under different cutting conditions. The developed equation showed that the feed rate found to be a main influencing factor on the surface roughness.

Amman et al. [87] used statistical methods and Taguchi's technique for examining machinability and minimizing power consumption.

Faleh [88] observed that power consumption was one of the most important parameters for condition monitoring. The study revealed that the cryogenic environment was the most significant factor in minimizing power consumption. The effects of feed rate and tool nose radius were not significant compared cutting fluid.

Nalbant et al. [89] examined the influence of cutting speed and cutting tool geometry on cutting forces. Inconel 718 was machined with dry cutting conditions Machining was conducted at four different cutting speeds, such as 150 m/min, 200 m/min, 250 m/min, and 300 m/min. Depth of cut of 2 mm and the feed rate of 0.20 mm/rev was kept constant. It was found from the experimental result that, the lowest main cutting force, which mainly depends on tool geometry and the maximum cutting force was determined as 1346 N.

Ahmed et al. [90] used response surface methodology to establish tool life prediction model for turning medium carbon steel. To study the effects of cutting speed and depth of cut on tool life, Factorial design techniques were used. The trial performed using uncoated carbide inserts under high-pressure coolant condition. The results showed that response surface methodology carried with factorial design of experiments was a better alternative to the traditional one-variable-at-a-time approach for reviewing the effect of cutting variables on surface roughness and tool life.

Kalos et al. [91] used response surface methodology for minimizing the roundness and cylindricity of cylindrical components of EN-8 alloy steel with carbide tool during turning. Cutting speed, feed rate and bar diameter were selected as input parameters. The response variables were roundness and cylindricity. ANOVA results showed that the cutting speed was the main influencing parameter on roundness and feed rate was the main influencing parameter on cylindricity. Roundness was directly proportional to cutting speed, but inversely proportional to feed rate. To simulate the process for combining error, Monte Carlo simulation was used.

Anirban et al. [92] investigated the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI irons steel using Taguchi design and ANOVA. The surface roughness and power consumption were studied as a response factor in different metal cutting conditions. The results showed a significant effect of cutting speed on surface roughness and power consumption, while the other parameters have not substantially affected the response.

Brahmankar et al. [93] combined response surface method and gray relational analysis. This combination was used to optimize electro-discharge machining parameters with multi-performance characteristics. Numerous combinations of machining parameters such as pulse on time, developed to predict the cutting rate, surface roughness, and kerf width of the machined composite material by RSM method. The result showed that improvement in cutting rate was more than 100% compared to the initial level experiments with reasonably smooth surfaces and narrow kerf width.

Bouacha et al. [94] performed experimentation in hard turning of AISI 52100 with CBN tool to find effect of cutting parameters like cutting speed, feed rate and depth of cut on cutting force and surface roughness. He employed response surface methodology (RSM) to examine the influence of cutting parameters on surface roughness and cutting force components. The results gave optimized values and most contributing factors for the required response.

Neseli et al. [95] studied to find the effect of tool geometry parameters on surface roughness during hard turning of AISI 1040 with P25 tool. He employed response surface methodology (RSM) to optimize the effect of tool geometry parameters on surface roughness.

R Suresh, S. Basavrajjapa et al. [96] examined the effect of cutting parameter on cutting forces and tool wear during hard turning of AISI H13 tool steel. The central composite design was used for performing experimentation. Regression models for cutting forces and tool wear was developed. ANOVA was used to analyze the contributing factors. Cutting speed and depth of cut have been more contribution in influencing feed force while the thrust force was mainly affected by the depth of cut. Feed rate was a major contributing factor for tool wear.

Dadapeer, Umesh et al. [97] 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. Taguchi design was used for selecting process parameter. The results indicated that the selected process parameters significantly affected the mean & variance of feed force, tangential force. Depth of cut had a major contribution of feed force, tangential force and surface roughness. Predicted results and experimental results were within range of the values.

DiptiKanta Das et al. [98] dealt with studies on surface roughness during hard machining of EN 24 steel machined with coated carbide insert. The experimentation has been carried under dry conditions. Prediction models have been developed using regression analysis for surface roughness and adequacy has been verified. Good surface quality of roughness about 0.42 microns was obtained in hard machining. Feed was considered as an utmost important parameter for surface roughness parameter. High correlation coefficient (R^2-0.993 and 0.934) was the evidence to be better fitting of the model and found to be highly significant.

Nexus Qehaja et al. [99] 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. According to the authors, the results showed that feed rate had more impact on surface roughness than nose radius and cutting time.

Guillot et al. [100] studied the viability of a neural network technique to evaluate the surface roughness and dimensional deviations during machining. This study concluded that depth of cut, feed rate, radial and cutting forces are the required information that should be fed into neural network models to predict the surface roughness success.

Rangwala et al. [101] developed a theoretical model for machining processes. Shortcomings of the theoretical models were discussed and compared with neural network models.

Azouzi, Guillot et al. [102] formulated a neural network model for surface finish prediction including cutting speed, feed, depth of cut and vibration as various input parameters.

Benardos et al. [103] reviewed different techniques for predicting surface roughness. He concluded that a neural network was the most effective tool in predictive ability.

Feng et al. [104] analyzed experimental data using artificial neural network. Their results indicated that back-propagation neural network modelling provided better predictions. Nevertheless, the authors concluded that proper design of experiment would result into better regression outcomes.

Different techniques are available for modeling and optimization. The literature suggested that the response surface method of desirability analysis gave accurate and valid results. It is a very convenient technique for modeling and analysis of the problem. Response surface methodology (RSM) is the most preferred method for modeling and optimization of cutting parameters. In the last two decades, artificial neural network (ANN) has come up as one of the most efficient methods for empirical modeling and optimization.

2.6 Concluding Remark of Literature Review

In Maharashtra, 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 required to develop low-cost. MQL system so that small domestic units can afford.

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 minimum quantity lubrication. The research work available concentrates on one or two parameters for comparison of performance of vegetable oil. The performance of the MQL uses vegetable oil need to be checked to decide the best cutting oil. This research work will give study of various vegetable oils based on cutting forces, temperature, surface roughness, power consumption, tool wear and tool life. Sunflower oil, coconut oil, groundnut oil and soyabean oil are comparatively cheap, easily available, hence considered as a cutting fluid.

CHAPTER 3

EXPERIMENTAL METHODOLOGY

3.1 Introduction

Based on the literature study, it was decided to conduct an investigation on dry cutting, flood cutting and minimum quantity lubrication to evaluate the performance of cutting fluid. This chapter provides details of the experimental setup to perform experiments. It also includes the study of work material, cutting tool, cutting parameters, cutting conditions and design of an experiment. Details of the experimental facilities for performance measurement has been added to this section.

3.2 Selection of Workpiece Material

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. Figure 3.1 shows the specimen used for experimentation.

Figure 3.1 Specimen of AISI 4130 Steel

The chemical composition and mechanical properties of AISI 4130 steel are determined at Subodh Technologies, Mumbai. These properties are given in the table 3.1 and 3.2 respectively.

Table 3.1 Chemical Composition of AISI 4130 Steel

C (%)	Mn (%)	Si (%)	P (%)	S (%)	Cr (%)	Ni (%)	N (%)
0.30	0.52	0.24	0.017	0.011	1.06	0.017	0.22

Table 3.2 Mechanical Properties of AISI 4130 Steel

Yield Strength Mpa	Tensile Strength Mpa	Elongation (%)	Vickers Hardness (HV)
365	363	24	261

3.3 Cutting Tool Selection

While selecting the cutting tool, it is decided to select a tool, which is used in small-scale industries. Carbide tipped brazed single point cutting tool is used for the investigation. These tools are easily available and less costly. They can be sharpened by grinding. There is no need to replace the insert after failure.

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. The cutting tool is fixed on a dynamometer. The cutting tool used for the experimentation is shown in figure 3.2.

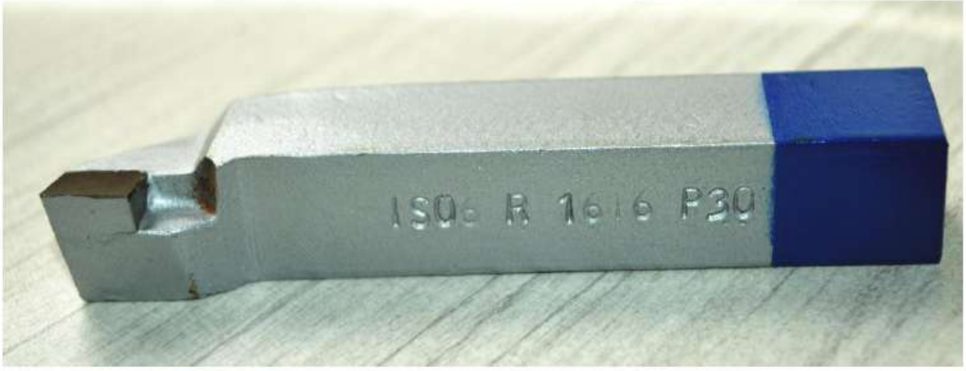


Figure 3.2 Single Point Cutting Tool

3.4 Lathe Machine

Medium duty Lathe machine of Dhara make manufactured by Tirupati Hydraulics, Rajkot is used for experimentation. Table 3.3 gives the detail specification of the lathe machine used.

Table 3.3 Lathe Machine Specifications

S.N.	Parameter	Dimensions	S.N.	Parameter	Dimensions
1	Height of center	225 mm	7	Width of bed	275 mm
2	Swing over cross slide	250 mm	8	Taper of spindle nose	M.T.- 6
3	Swing over bed	425 mm	9	Pitches metric threads	1 to 7 mm
4	Swing in gap	700 mm	10	Threads	4 to 28 TPI
5	Admit between center	500 mm	11	Lead screw diameter	38 mm
6	Length of bed	1370 mm	12	Electrical Motor	2 HP

3.5 Selection of Cutting Parameter

While visiting various industries in Satpur (MIDC) at Nashik, it is observed that smaller units use the medium duty lathe machine for turning. Based on industry practice as well as the capacity and limitation of the lathe machine used for turning operation, the values of the input parameter, i.e. speed, depth of cut and feed are selected. During the experiment, tool height, tool geometry was kept constant. The operating parameters such as speed, feed and depth of cut and mode of machining which are generally controllable in any turning situation are selected as factors for the study.

From the workpiece diameter and machine spindle speed, cutting speed is calculated. 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. Trials are to be conducted for dry, flood and MQL cutting. The flow rate for flood cutting is one liter per minute while for MQL; the flow rate is adjusted at 60 ml/hr.

3.6 Machining Environment

Dry machining and flood machining are the conventional methods generally used in industry. Now a days minimum quantity lubrication is gaining the attention of the industry as it reduces the quantity of cutting fluid used during machining.

3.6.1 Dry Machining

Dry machining is a complete elimination of cutting fluid. Dry machining is low cost, safe and environment friendly. In dry machining higher friction between tool and work can lead to high temperature. This high temperature causes dimensional inaccuracy, rapid tool wear and poor surface finish [17-18]. Figure 3.3 (a) represents dry machining.

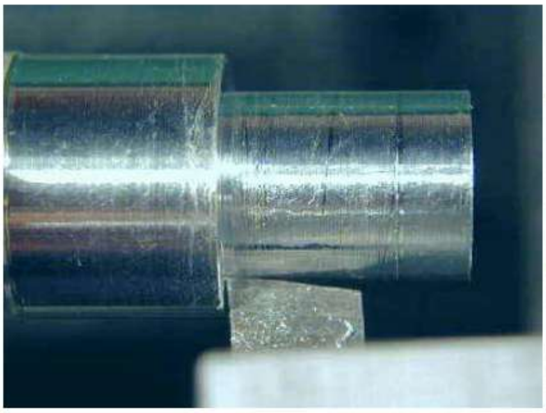


Figure 3.3 (a) Dry Machining

Figure 3.3 (b) Flood Machining

3.6.2 Flood Machining

In flood machining, both the tool and the workpiece are cooled using large amounts of cutting fluid. The coolant is recycled. Coolant flows at the rate of 1-2 liter per minute. Figure 3.3 (b) shows flood machining. Flood cutting reduces temperature but involves more exposure to cutting fluids.

3.6.3 Minimum Quantity Lubrication

Due to the increasing burden of costs related to the protection of the environment, as well as recently introduced regulations, the last few years were seen the manufacturing industry increasingly employing machines with lubrication systems that optimize the performance and reduce the use of lubricants. The aim of minimum quantity lubrication is to replace the traditional flood lubrication system with a precisely controlled compressed air stream that carries oil droplets in the form of aerosol [108]. Cutting fluid is transported to the cutting surface in two ways,

External Lubrication: Cutting fluid is delivered through an external nozzle to the cutting surface placed near the tool and the workpiece.

Internal Lubrication: Cutting fluid is delivered through internal holes in the cutting tool.

Minimum quantity lubrication (MQL) is the process of applying very small quantities (50-500 ml/hr) of cutting fluid, mixed with air, at the point of precise contact between the tool and the workpiece [28].

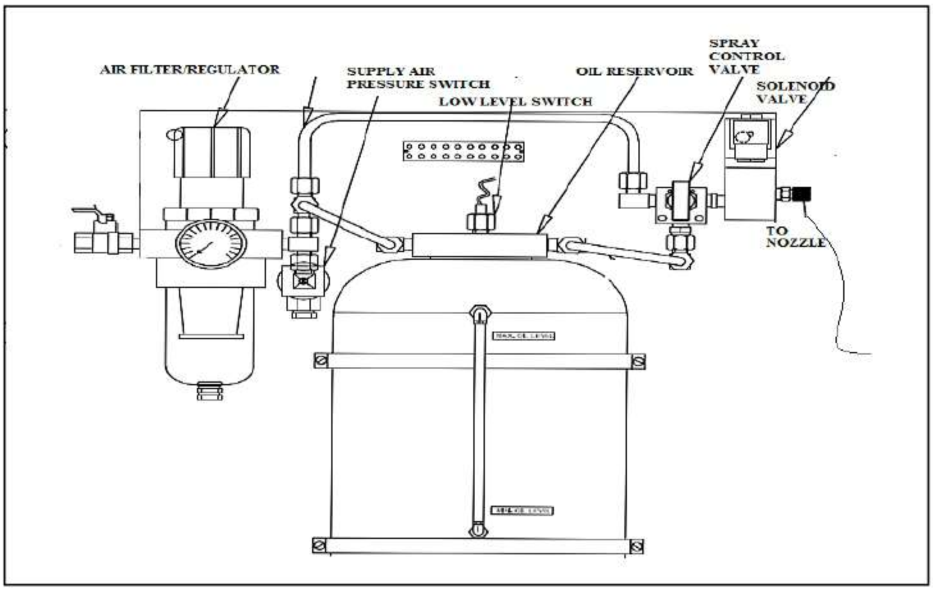


Figure 3.4 MQL System

For this research work, simple design 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 3.4.

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.

The oil tank is the oil reservoir with a refilling plug capacity of 5 liter. A nozzle is often a pipe or tube of the varying cross sectional area and it can be used to direct or modify the flow of a fluid. Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them. The nozzle is used for the spray the coolant at the application. The air compressor is used to compress the air and compressed air can be supplied to the pipe at the required pressure.

MQL system works on siphonage principle. Compressed air and oil mixed and the high jet of oil is sprayed through a nozzle. Highly compressed air with the typical air pressure of two to four bar is supplied to the air filter. The air filter removes any impurity or contaminations to keep the equipment clean and dirt free. A high velocity jet passes through spray unit. Oil in the reservoir is sucked up due to the pressure difference and mixes with air. The high velocity air pushes the oil breaking it into the small droplet. The oil then passes through the nozzle to from a spray of the oil.

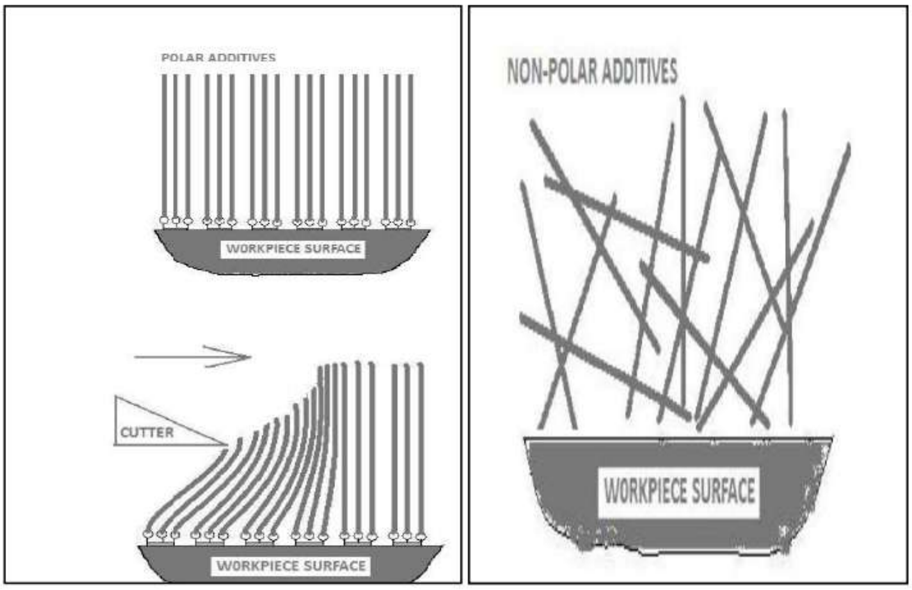
3.7 Selection of Cutting Fluid

Researchers are trying to find out the most suitable substitute to mineral-based cutting fluid. The cutting fluid must be biodegradable, nontoxic, environment friendly, easily available, less costly and renewable. It should have better cooling and lubricity properties. The reasons for selecting vegetable oil as an alternative to the mineral-based fluid is given below.

- Vegetable oils consist of triglycerides (TAG). Triglycerides are glycerol molecules with three long chain fatty acids attached to the hydroxyl groups. The fatty acids in vegetable oil triglycerides have similar length, between 14 and 22 carbons. They are polyunsaturated, monounsaturated and saturated. The triglyceride structure of vegetable oils provides desirable properties of lubricant [111].

- Vegetable oil molecules are long, heavy and dipolar in nature. The ends of the molecules have opposite electrical charges. This charge acts as a magnet. Vegetable oils stick to a metal surface more tightly than mineral oils.

- Figure 3.5 (a) shows the homogeneous arrangement of the vegetable oil molecule. This dense arrangement of vegetable oil molecules creates a thick, strong and a durable film layer of lubricant. This film is stubborn to resist being easily wiped off. This lubricating film gives the vegetable oil a greater capacity to absorb the load. On the contrary, the molecules of mineral oils are non-polar [50].
- Figure 3.5 (b) shows non-polar, random molecule arrangement of mineral oil. They form a random arrangement along a metal surface, which provides a weaker film of lubricant.



(a) Vegetable Oil (b) Mineral Oil

Figure 3.5 Difference Between Polarity and Affinity towards the Metal Surface [50]

- Vegetable oils have a higher flash point, which reduces smoke formation and fire hazard. Higher flash point value permits using the cutting fluid in high temperature situations.
- Vegetable oils have a high natural viscosity. As the machining temperature increases, the viscosity of vegetable oils drops more gradually than that of mineral oil. As the temperature falls, vegetable oils continue to be more fluid than mineral oils. The high viscosity index of vegetable oils ensures that vegetable oils will provide more stable lubricity across the operating temperature range.

- Vegetable oil molecules are homogeneous in size, but mineral oil molecules vary in size, thus, the properties of mineral oil such as viscosity, boiling temperature are more likely to vary at high temperature.
- Vegetable oil has a higher boiling point and greater molecular weight and this result in less loss of vaporization and misting [41].
- Thermal and oxidation stability of vegetable oils is limited; however, it can be increased by adding an antioxidant. Vitamin-C- rich-lemon fruit extract was used as an antioxidant to improve the oxidative stability of the vegetable oils [60].

Numbers of vegetable oils are available in the market. i.e. soyabean oil, groundnut oil, sunflower oil, coconut, palm oil, mustard oil. In Maharashtra the production of mustard oil, palm oil and coconut oil is less however, coconut oils are easily available. Soyabean, groundnut and sunflower are cultivated at large scale; hence, oils, from these seeds can be easily available. Blasocut is a water miscible, mineral oil-based, high performance cutting fluid, shows good properties and performance. It is used in medium, small-scale industry in large amount; therefore, it is selected to compare against vegetable oil.

Properties of the vegetable oil are determined at Ashwamedh Engineers and Consultant in Nashik. Table 3.4 shows the properties of the vegetable oil. Flash point indicates the risk of fire hazard. High flash point, density describes molecular weight while the acid value represents the acidic nature of oil.

Vegetable oils contain 80%-90% fatty acid. The fatty acid composition of the vegetable oil is shown in table 3.5. It shows the percentage of miristic, palmitic, stearic, oleic, linoleic, linolenic, archidic and erucic acid. Stearic acid is saturated fatty acid. Stearic acid molecule aligns itself in a straight chain and loosely packed on the surface. Linoleic and oleic acids are unsaturated fatty acid. They are double bond acid. Unsaturated fatty acid forms thick film of lubricant. Mineral oils contain saturated aliphatic compounds paraffinic, naphthenic and small amount of aromatic. They provide a weaker chemical bond [110-111].

From various references, the common value of thermal properties of selected cutting fluids like specific heat, thermal conductivity and heat transfer coefficient are presented in table 3.6

Table 3.4 Properties of Cutting Fluid

S.N.	Properties	Sunflower oil	Soyabean oil	Groundnut oil	Coconut oil	Blasocut 4000
1	Flashpoint (°C)	320	325	318	290	144
2	Density (m/cm^3)	0.915	0.919	0.909	0.920	0.845
3	Viscosity (cst)	29.7	38.3	30.1	25.8	48.00
4	Acid Value	0.043	0.040	1.18	0.359	0.98

Table 3.5 Fatty Acid Composition of Vegetable Oil [111]

S.N.	Vegetable Oil	C14:0	C16:0	C18:0	C18:1	C18:2	C18:3	C20:1
		Miristic	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Archidic
1	Coconut oil	47	9	3	7.45	1.80	----	0.06
2	Groundnut oil	---	13	2	48.71	31.06	0.23	1.43
3	Soyabean oil	0.12	11	4	23.44	52.92	7.60	0.36
4	Sunflower oil	0.5	6/7	4	15.26	71.17	0.45	0.22

Table 3.6 Thermal Properties of Vegetable Oil [63,112]

S.N.	Properties	Sunflower oil	Soyabean oil	Groundnut oil	Coconut oil
1	Specific Heat (KJ/Kg.K)	2.257	1.692	2.055	1.71
2	Thermal Conductivity (W/m K)	0.168	0.154	0.161	0.147
3	Heat Transfer Coefficient, (W/m^2 °C)	660	859	312	318

3.8 Measurement of Output Parameters

To evaluate the performance of the vegetable oil different parameter like cutting forces, surface roughness, tool wear and temperature are measured. The instruments used for the measurement and their specification are described

3.8.1 Cutting Force Measurement

Cutting forces were measured using strain gauge type three component lathe tool dynamometer as shown in figure 3.6. The unit consists of a mechanical sensing unit or tool holder and digital force indicator. The strain gauge with tungsten carbide tool was attached to the tool post of the lathe machine with this dynamometer. The readings for cutting forces were logged after output stabilization. Readings are converted into Newton. The specifications of lathe tool dynamometer are,

a) Strain gauges - Quantity- 12 Nos. Resistance: 350 Ω, Gauge factor: 2 ±1

b) Digital Force Indicator - three channel, Range - 0 to 500 Kg, least count - 1 Kg

c) Balancing Potentiometer for initial balancing

Figure 3.6 Lathe Tool Dynamometer

3.8.2 Surface Roughness Measurement

The surface roughness (Ra) was measured by using TR110 portable surface roughness tester. It operates on surfaces like flat and cylindrical parts. The piezoelectric pickup stylus with diamond tip assures reliable measurement with tolerances in conformance with ISO Class-3. It can measure surface roughness value from 0.05 µm to 10.00 µm with an accuracy of ±15%. Figure 3.7 shows Qualitest -TR110 surface roughness tester.

Figure 3.7 Stylus Surface Roughness Tester   Figure 3.8 Infrared Thermometer

3.8.3 Temperature Measurement

Temperature is measured by using a non-contact type infrared thermometer. Kusum-Meco make IRL-550 infrared thermometer is used for measurement of temperature. Temperature range is -25 ^{0}C to 560 ^{0}C. Accuracy ±1.5% +1°C, The response time is 500 ms. Figure 3.8 shows photo of IRL-550 model of thermometer.

3.8.4 Tool Wear (VB) Measurement

Different types of wear occur during turning operation like crater wear, flank wear, thermal crack, brittle crack, fatigue crack, plastic distortion and build-up edge. Flank wear affects the surface finish, dimensional precision of the tool and an increased cutting force, heat and vibration. Flank wear occurs due to more the friction between the work piece surface and the tool flank face. The width of the flank wear land "VB" is generally taken as a measure of the amount of wear [85, 96]. Toolmaker's microscope is used for measurement of tool wear is shown in figure 3.9 and its specification are,

Make-Metzer, measuring Range-25x25 mm, scale unit of micrometer-0.01mm, swivel center-±10°, magnification of objective-5 x and 10 x, magnification of eyepiece-x, 10x, 5 x, total magnification-25 x to 150 x.

Figure 3.9 Toolmakers Microscope

3.8.5 Tool life and Tool Failure Criteria

Tool life is the amount of satisfactory performance or service offered by a fresh tool or cutting point until it is failed. The tool life is expressed in terms of machining time (T) in minutes. From an experimental point of view, measuring tool life is a destructive test. The wear of the face and flank of the cutting tool is not uniform. To decide the failure of the cutting tool edge, it is necessary to designate the locations and the certain value of wear [85]. The criteria suggested by the International Standards Organization (ISO) to decide the tool life according to the tool wear [119].

- High-speed steel or ceramic tool-VB-0.4 mm
- Worn out flank.VB max -0.6 mm
- Sintered carbide tools- VB -0.3 mm.

3.8.6 Power Consumption

In machining processes, saving money and improving productivity can be achieved by reducing power consumption. The constant increase in electricity prices is a major concern of manufacturing companies. There are two methods to determine the power consumed. It can be measured by using wattmeter connected to the motor of the lathe tool. The shortcoming of this method that is that it does not consider the mechanical losses, transmission losses. The second method for determining power consumption is to measure the cutting forces acting on the tool during turning operation. Power consumption is calculated as a product of main cutting forces and velocity [62]. The equation for the power is,

$$P = Fc * V \qquad \text{… Eq. 3.1}$$

where P is the power in watt, V is the cutting speed (m/min) and Fc is the main cutting force (N)

3.9 Design of Experiments

In every industry, it is expected that experiments should be properly designed to study the process variables that influence product quality. As resources are limited, it is necessary to get the maximum outcomes from the minimum experiments performed. Well-designed experimentations provide more information, require less number of trials than haphazard or unplanned experiments and saves cost. The design of the experiment process is divided into three key phases as planning, conduction and analysis [106]. Different techniques are used for the design of experiments like Taguchi approach, factorial design and response surface analysis.

Factorial design is a systematic method for formulating the steps needed to implement the experiments. In the factorial plan, each complete trial or replicate of the experiment are taken into account to get all possible combination of varying levels of the factor.

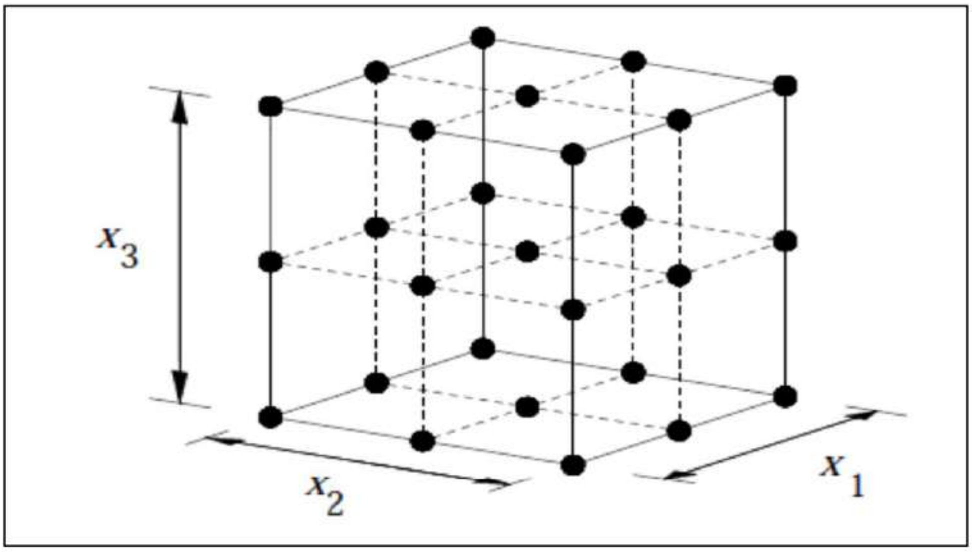


Figure 3.10 Full Factorial Design (3^3)

A factorial design is an experimental plan in which design variables are varied together, instead of one at a time. The lower and upper limits of each of N design variables need to be defined. If each of the variables is defined at only the lower and upper limits (two levels), the experimental design is called 2^N full factorial [115-118]. Similarly, if the midpoints are included, the design is called 3^N full factorial, as shown in figure 3.10.X_1 $X_{,2}$ and X_3 represents the design variables.

Table 3.7 Machining Parameters and Their Levels

Level	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	34.27	0.30	0.5
2	53	0.35	1.00
3	79.73	0.40	1.5

In the present work, Minitab-17 is used to plan the design of experiments. Full Factorial design for three levels and three factors (3^3) with single replication is used which is shown in table 3.7. For the each cutting environment, twenty-seven trials were performed

Table 3.8 shows the design matrix and the combination of the independent variable as per full factorial design. A, B, C signifies the cutting parameter. These are represented as v, f and dp respectively. Run order shows the sequence of the experiment. Minitab stores the standard order, run order, center point indicator, block assignment, and each factor in separate columns. Each row in the worksheet contains data that correspond to one run of the experiment [116].

Table 3.8 Design Matrix

Std Order	Run Order	Pt Type	Blocks	A	B	C	v (m/min)	f (mm/rev)	dp (mm)
1	1	1	1	1	1	1	34.27	0.35	0.5
2	2	1	1	1	1	2	34.27	0.35	1
3	3	1	1	1	1	3	34.27	0.35	1.5
4	4	1	1	1	2	1	34.27	0.4	0.5
5	5	1	1	1	2	2	34.27	0.4	1
6	6	1	1	1	2	3	34.27	0.4	1.5
7	7	1	1	1	3	1	34.27	0.45	0.5
8	8	1	1	1	3	2	34.27	0.45	1
9	9	1	1	1	3	3	34.27	0.45	1.5
10	10	1	1	2	1	1	53	0.35	0.5
11	11	1	1	2	1	2	53	0.35	1
12	12	1	1	2	1	3	53	0.35	1.5
13	13	1	1	2	2	1	53	0.4	0.5
14	14	1	1	2	2	2	53	0.4	1
15	15	1	1	2	2	3	53	0.4	1.5
16	16	1	1	2	3	1	53	0.45	0.5
17	17	1	1	2	3	2	53	0.45	1
18	18	1	1	2	3	3	53	0.45	1.5
19	19	1	1	3	1	1	79.73	0.35	0.5
20	20	1	1	3	1	2	79.73	0.35	1
21	21	1	1	3	1	3	79.73	0.35	1.5
22	22	1	1	3	2	1	79.73	0.4	0.5
23	23	1	1	3	2	2	79.73	0.4	1
24	24	1	1	3	2	3	79.73	0.4	1.5
25	25	1	1	3	3	1	79.73	0.45	0.5
26	26	1	1	3	3	2	79.73	0.45	1
27	27	1	1	3	3	3	79.73	0.45	1.5

3.10 Experimental Setup

Experimental set up consist of medium duty lathe machine and the MQL system as shown in figure 3.11 Experimentation is carried out on a conventional lathe machine as per the design of experiments. The experiment is conducted on an AISI 4130 steel bar using P-30 uncoated brazed carbide tool.

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Figure 3.11 Experimental Setup

Experimentation is 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. For measuring tool wear, toolmakers microscope is used.

Tool wear measured with respect to machining time. To determine the tool life, the tool wear was measured at cutting speed i.e. 34.27 m/min, 53 m/min and 79.73 m/min at fixed feed, 0.45 mm/rev and depth of cut 1.5 mm at intervals of 5 minutes. 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. Tool life was determined, taking 0.4 mm flank wear as tool life criterion.

The experimental observations for different cutting condition and cutting fluid are given in Appendix A. Table A.1 to A.7 represents the observations for dry cutting, flood cutting,blascout,soyabean oil, sunflower oil, coconut oil and groundnut oil respectively. Table A.8 to A.10 shows tool wear for different cutting fluid while table A.11 shows tool life calculated during all machining environment.

It is apparent from observation tables that performance of the soyabean oil seems to be better than other vegetable oil in terms of cutting forces, temperature, surface roughness, tool wear and tool life.

CHAPTER 4

MATHEMATICAL MODELING

4.1 Introduction

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.

Experiments were conducted for dry, flood and minimum quantity lubrication. Vegetable oils like blasocut, soyabean oil, sunflower, groundnut oil and coconut oil are used as cutting fluid during MQL turning. From experimental observation, it is seen that soyabean oil gives better performance in term of the response. Hence in this section, mathematical modeling for MQL with soyabean oil is analyzed. The analysis for other cutting fluids are given in appendix B.

4.2 Response Surface Methodology

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes. RSM is one of the important tool to examine the complex nature of the interrelationship between input and output [106,113]

The important steps in response surface methodology are, [114]

- Identification of predominant factors, which affects the response.
- Developing the experimental design matrix.
- Conducting the experiments as per the design matrix.
- Developing the mathematical model.
- Determination of constant coefficients of the developed model.
- Testing the significance of the coefficients.
- Adequacy test for the developed model by using analysis of variance (ANOVA).
- Analyzing the effect of input machining parameters on output responses.

4.3 Mathematical Modeling

The word model means the mathematical explanation of how the response performs as a function of the input parameters. It gives a systematic representation of the experimental data. These models may be experimental or based on first principles depends on the requirement of the researchers. The most common forms are first or second-order polynomial. Multiple regression is used for building the empirical models required in response surface methodology.

To develop an empirical model relating the response Y for input variable X_1 and X_2. A first-order response surface model to describe this relationship as below

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \qquad \text{…Eq.4.1}$$

Where,$\beta_{0,}$ β_1 and β_2 are regression coefficient ε is termed as the difference between input and output parameter or residual. Second order response surface model is given by the following equation,

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} X_1^2 + \beta_{22} X_2 + \beta_{12} X_1 X_2 + \varepsilon \qquad \text{…Eq.4.2}$$

The second-order model is flexible and gives a good estimation of the true response surface. The method of least squares is used to estimate the regression coefficients. Minitab 17 is used for estimating the regression coefficient and formulating the regression equation. ANOVA checks the acceptability of the mathematical model.

4.4 ANOVA Test

Ronald Fisher developed a statistical method that stands for analysis of variance (ANOVA) in 1918. ANOVA employs a single statistical test to compare all possible pairs of means to see if there are variances between them simultaneously. This technique uses the F test to examine the variability among three or more treatment means in a clever and safe way. Two-way and multi-way ANOVA is used for complex problems involving more levels and more variable [106].

4.4.1 Adequacy Test of the Model by ANOVA

To validate the use of the ANOVA method, sampled populations should be normally distributed and independent. The typical method of testing the data is to assess the various plots of the residuals. The residuals are the difference between the experimental response and the predicted response.

The purpose of the histogram is to evaluate the assumption that the sample populations are normally distributed. For normality, the histogram data should approximate the bell-shaped curve of the normal distribution or approximately symmetric.

Normal plots are more sensitive to abnormalities. If the model is adequate, the points on the normal probability plots of the residuals should form a straight-line the errors are normally distributed.

The residual vs. fits plot used to verify the assumptions that residuals are randomly distributed and have constant variance. When residuals bounce randomly around the zero line, this suggests that the relationship is linear and reasonable.

The residual versus order plot is used to verify the assumption that the residuals are independent from one another. Independent residual show no trend or no pattern when displayed in time order [106].

When these conditions are satisfied, the hypotheses can be stated as,

H_0: All samples come from essentially the same population (Null Hypothesis)

H_A: One or more pairs of treatments have population means that are different from each other. (Alternative Hypothesis)

4.4.2 Significance of F Value

The F value tells us how much we are deviating from hypothesis. The low F value suggests that factors are not relevant according to our data. A big F value implies that the effect of the factor is relevant. It is given by the following equation,

$$F=\frac{\mathrm{MS(Factor)}}{\mathrm{MS(Error)}} \qquad \text{...Eq.4.3}$$

The statistic F is compared to the critical Fcrit = F (α, fterm, f_{error}), where α is the significance level (generally it is 0.05). Degree of freedom can be calculated as below

f_{term} = number of level- 1,

f_{total} = number of run -1

$f_{error} = f_{total} - f_{term}$

If F-value is greater than the critical F, model is acceptable and accurate. The value of Fcrit is taken from statistical table. For, F (0.05, 2, 24), Fcrit value is 3.40. Critical values taken from standard tables (Appendix B.9). If the observed F-value is greater than the critical F, then H_o will be rejected [116-117].

4.4.3 Significance of P Value

The term of P value is the probability value, which is associated with the F value. The values of P less than 0.0500 indicates that model terms are significant. H_0 is rejected when the P value less than significant level α.

4.4.4 Significance of R^2, R^2- Adjusted and R^2- Predicted

The coefficient of determination R^2 measures percentage of the variation of response, as per regression equation. R^2 gives information about how well the predicted model fits the experimental data. For the better assessment of the regression equation to fit the trial data, R^2 should be closer to one (80% to 100%). The variation may occur due to uncontrollable factors.

The formula of coefficient of determination, R^2 is,

$$R^2 = 1 - \frac{SS(Error)}{SS(Total)} \qquad \text{...Eq.4.4}$$

Due to the addition of variable, the value of R^2 is always increased. It does not matter whether a variable is insignificant or not. To overcome this adjusted-R^2 values are measured. The predicted R^2 is a measure of how good the model predicts a response value and the adjusted R^2 is the amount of variation about the mean. Adjusted R^2, is useful for comparing models with different numbers of predictors. Larger values of predicted R^2 suggest that the predictive ability of the model is greater. Adjusted R^2 is given by the following equation,

$$\mathrm{Adj.R^2} = 1 - \frac{\mathrm{MS\ (Error)}}{\mathrm{SS\,Total/DF\,Total}} \qquad \text{...Eq.4.5}$$

The calculations for the mean square of the factor and error are

$$\mathrm{MS(Factor)} = \frac{\mathrm{SS\ (Factor)}}{\mathrm{DF\,(Factor)}} \qquad \text{...Eq.4.6}$$

$$\mathrm{MS(Error)} = \frac{\mathrm{SS\ (Error)}}{\mathrm{DF(Error)}} \qquad \text{...Eq.4.7}$$

The model will be adequate when it satisfies the following condition.

- Normal probability plot should be a straight line.
- Residual vs. predicted response plot should not follow a fixed pattern.
- R^2 values should approach one.
- R^2 adjusted and R^2 predicted values should be in good agreement.
- F value should be larger. It should be greater that F critical.
- P Value should be more than the significance level.

4.4.5 Influence of Input Parameters on Output Responses

Analysis of variance technique is used to find out the significant parameters influencing the performance measure. F-test value at 95 % confidence level is used to decide the significant factors affecting the process. Percentage contribution of F term for each term and P value indicates which factor is more influential.

4.5 Development of Regression Equation from Experimental Data

Before formulating mathematical models to verify the adequacy of the model, hypothesis is developed.

4.5.1 Hypothesis

For the development of the model, null hypothesis and alternate hypothesis are decided.

Null Hypothesis: There is no significant difference between the responses obtained by varying the individual input variables .i.e. Variation of the depth of cut, speed and feed do not have any effect on responses like cutting forces, temperature, surface roughness and power consumption.

Alternate Hypothesis: There is a significant difference between the responses obtained by varying the individual input variables. The input cutting parameter affects responses like cutting forces, temperature, surface roughness and power consumption.

4.5.2 Model Formulation

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 while cutting force (Fc), radial force (Fr), feed force (Ff), temperature (T), surface roughness (Ra) and power consumption (P) are the dependent parameter.

Second order quadratic models developed for each response for each cutting condition. ANOVA test is carried out to test the hypothesis as well as to check the adequacy of the model. ANOVA table gives the contribution percentage (C %) of each term. The contribution will be helpful for deciding the most significant factor. Residual plots are plotted. Surface graphs plotted to decide the significant parameter.

4.6 Regression Equations for Soyabean Oil

Equation 4.8 to 4.13 represents mathematical models developed with the help of Minitab-17 when soyabean oil is used as cutting fluid. Figure 4.1 to 4.6 shows the residual plots plotted for different responses. Summary of the ANOVA is recorded in table 4.1, 4.2 and 4.3.

Regression Equations for other cutting fluids are given (B1 to B.7) in appendix B. Summary of ANOVA for other cutting fluids are also added in appendix B from table B 1.1 to table B.7.3.

Regression Equations for Soyabean Oil- Cutting Force (Fc)

$$Fc_{Soyabean} = 565 - 1.99\ v - 1782\ f + 289.3\ dp + 0.00751\ v*v + 2404\ f*f - 45.9\ dp*dp + 2.32\ v*f - 0.147\ v*dp - 219.3\ f*dp \quad \text{…Eq.4.8}$$

Regression Equations for Soyabean Oil – Radial Force (Fr)

$$Fr_{Soyabean} = -430 - 0.049\ v + 2534\ f + 44.0\ dp + 0.00044\ v*v - 2884\ f*f + 5.01\ dp*dp - 0.12\ v*f - 0.009\ v*dp - 38.3\ f*dp \qquad \text{…Eq.4.9}$$

Regression Equations for Soyabean Oil – Feed Force (Ff)

$$F_{f\ Soyabean} = 986 - 1.23\ v - 4240\ f + 235.0\ dp + 0.00481\ v*v + 5635\ f*f - 53.2\ dp*dp + 1.00\ v*f + 0.107\ v*dp - 119\ f*dp \qquad \text{…Eq.4.10}$$

Regression Equations for Soyabean Oil – Temperature (T)

$$T_{Soyabean} = -132 - 0.581\ v + 850\ f + 21.2\ dp + 0.00633\ v*v - 706\ f*f - 2.75\ dp*dp - 1.35\ v*f + 0.271\ v*dp - 15.9\ f*dp \qquad \text{…Eq.4.11}$$

Regression Equations for Soyabean Oil – Surface Roughness (Ra)

$$Ra_{Soyabean} = -1.76 - 0.0973\ v + 25.1\ f + 0.447\ dp + 0.000863\ v*v - 18.4\ f*f + 0.036\ dp*dp\ 0.0404\ v*f - 0.00196\ v*dp - 0.367\ f*dp \qquad \text{…Eq.4.12}$$

Regression Equations for Soyabean Oil – Power Consumption (P)

$$P_{Soyabean} = 0.421 + 0.00255\ v - 2.31\ f + 0.1632\ dp + 0.000001\ v*v + 2.98\ f*f - 0.0412\ dp*dp + 0.00314\ v*f + 0.001574\ v*dp - 0.1872\ f*dp \qquad \text{…Eq.4.13}$$

4.6.1 Inferences from Residual Plot of MQL-Soyabean Oil

The residual plots for cutting forces, feed forces, radial forces, surface roughness, temperature and power consumption during MQL machining when soyabean oil is used as cutting fluid are shown in figure 4.1 to 4.6 respectively. Residual plots are plotted to verify the assumptions of the ANOVA.The residual plots for other cutting fluids are shown (Figure B.1.1 to B.6.1) in appendix B.

The histogram data shows that the normal distribution is approximately symmetric. Normal probability plot shows that errors are normally distributed from the mean and variance. The residuals for all responses fall on the straight line it indicated that errors are normally distributed. Residual vs. fitted value graphs indicates that the points are scattered within limits. It designate that residuals are randomly distributed and have constant variance Residual vs. observation graph is not forming any pattern. It means variables are independent. This shows that the assumptions for ANOVA test are satisfied, i.e. the sampled populations are normally distributed, as well, the observations are independent. This is commonly a good sign that the model is a reasonable fit to the data [106].

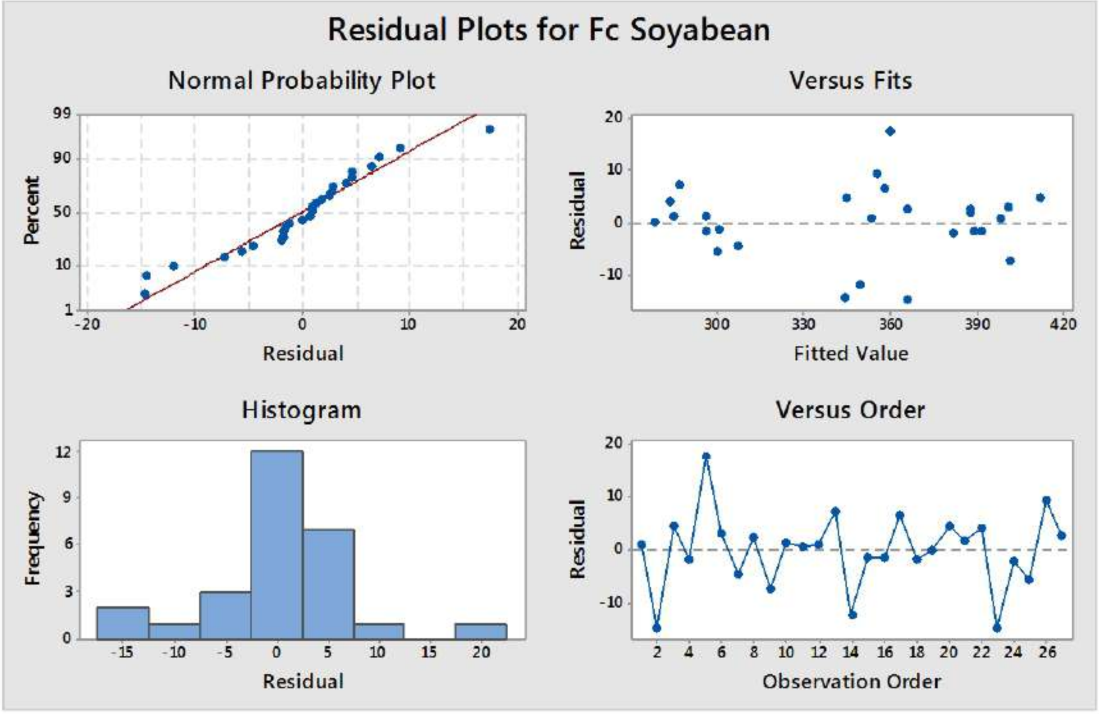

Figure 4.1 Residual Plot for Cutting Forces (MQL-Soyabean Oil)

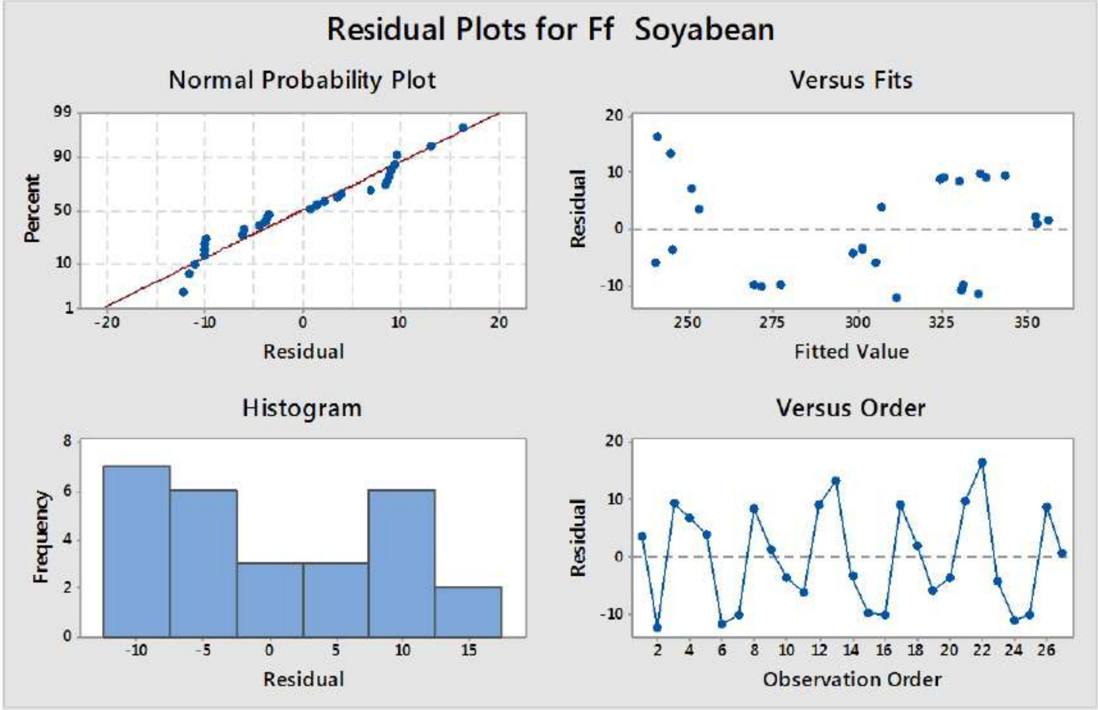

Figure 4.2 Residual Plot for Feed forces (MQL-Soyabean Oil)

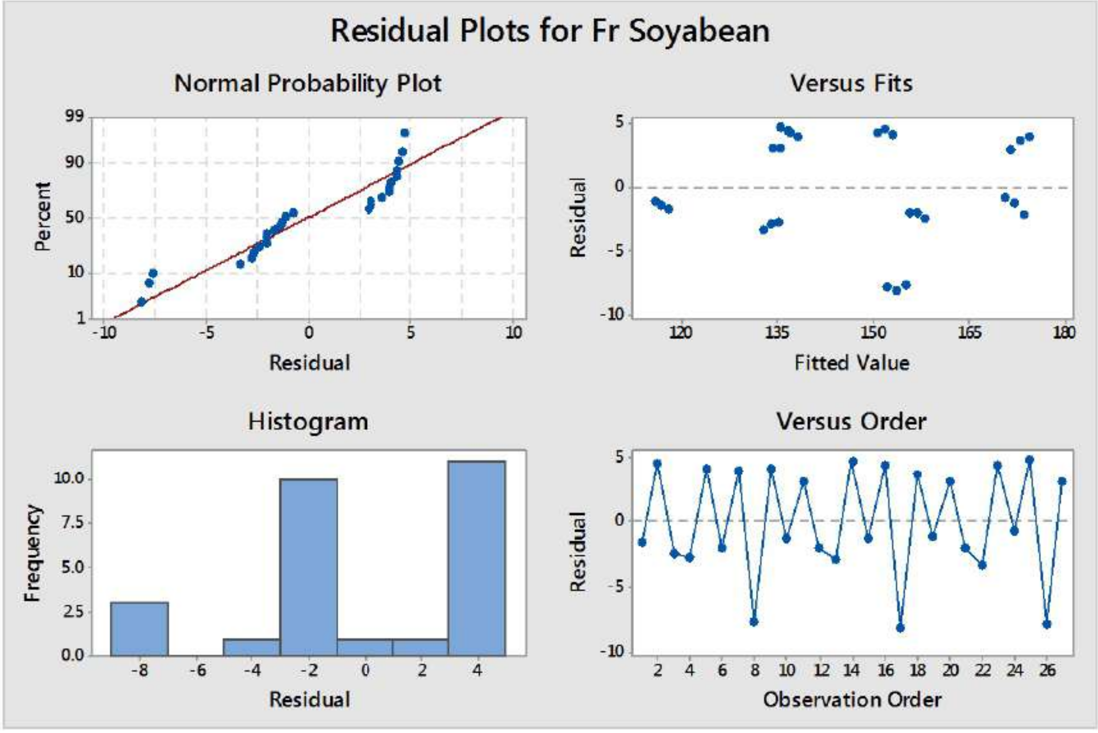

Figure 4.3 Residual Plot for Radial Force (MQL-Soyabean Oil)

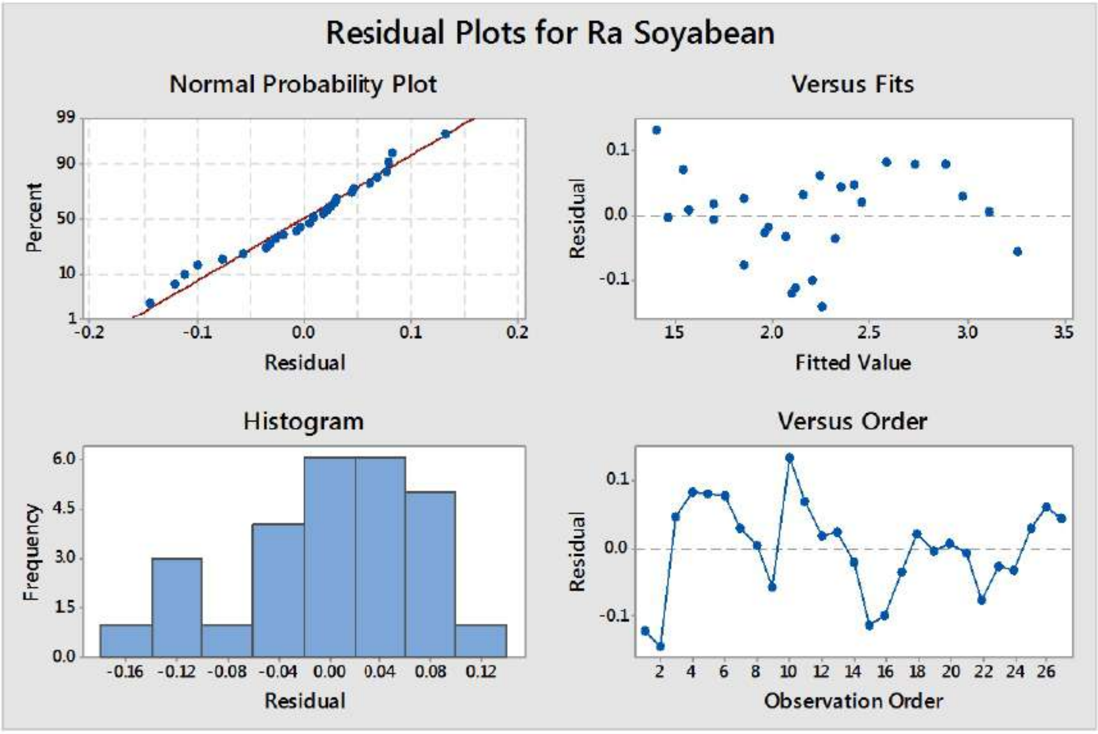

Figure 4.4 Residual Plots for Surface Roughness (MQL-Soyabean Oil)

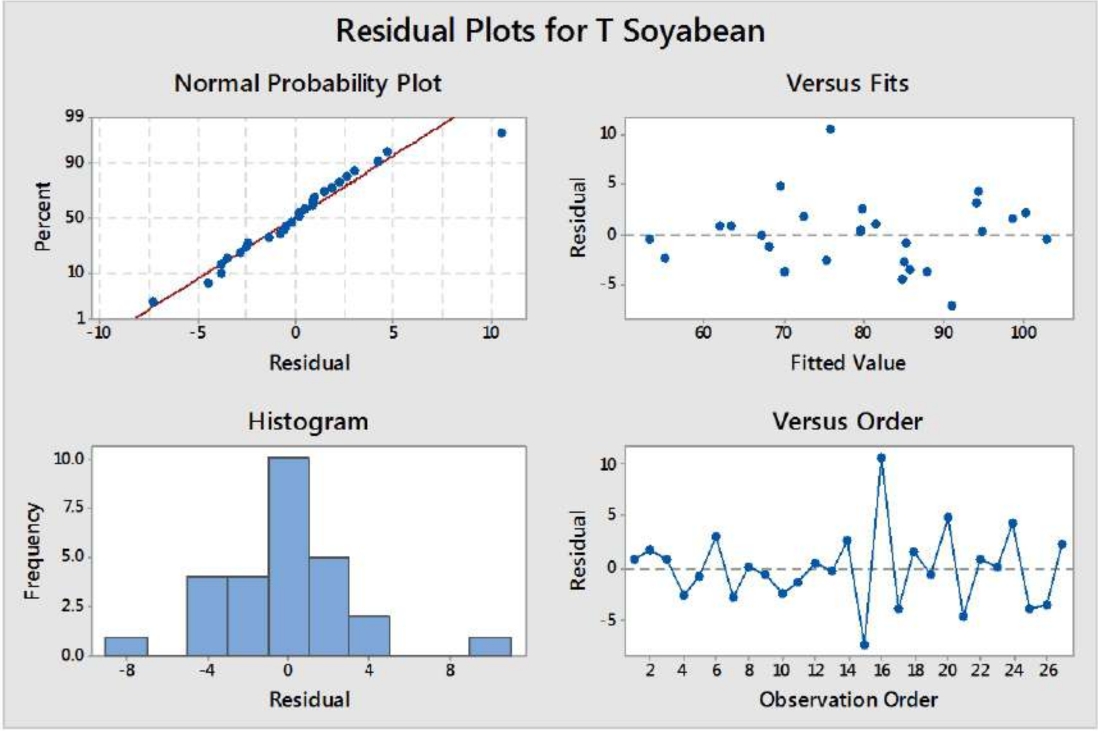

Figure 4.5 Residual Plots for Temperature (MQL-Soyabean Oil)

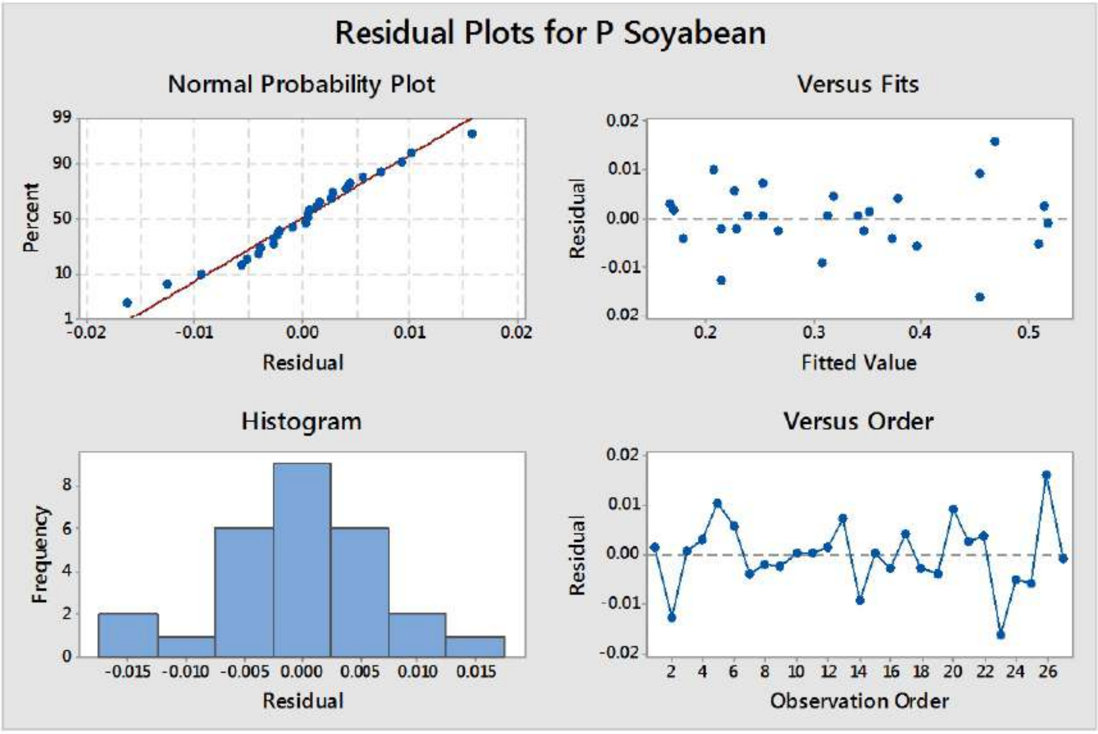

Figure 4.6 Residual Plots for Power Consumption (MQL-Soyabean Oil)

4.6.2 Cutting Force Model for MQL-Soyabean Oil

The multiple regression coefficients of the second order quadratic models are shown in table 4.1. R^2 for cutting forces during MQL using soyabean oil is 97.50%., which shows that only 3.5 % variation occurred due to uncontrollable factors. Adj. R^2 and Pre.R^2 are in respectable agreement (96.18% and 94.50%, respectively), as shown in table 4.1.

The F value of cutting force model is 73.76 as shown in table 4.2, which is larger than the F critical value 3.40. This evidences that model is significant. Fcritcal values are determined from F-Distribution table which is added as B.9 in appendix B.

The P value for the cutting force model for soyabean oil as mentioned in table 4.3 is 0.000, which indicates that null hypothesis should be rejected; it means the input parameter has an influence on the cutting force. The alternative hypothesis that cutting speed, feed and depth of cut has a significant effect on cutting forces should be accepted. This states that regression equations are satisfactory to characterize the machining process.

4.6.2.1 Influence of the Cutting Parameter on Cutting Force

ANOVA table 4.2 shows cutting forces are greatly influenced by the depth of cut (nearly 94% contribution), feed and speed have least effect on main cutting forces. The linear term v, deep and square terms dp*dp are significant terms in the model

4.6.3 Feed Force Model for MQL-Soyabean Oil

The R^2 value for feed force 95.16%. The error term is 4.84% only which is due to machine vibration, measurement error, etc. Table 4.1 shows that the regression model for feed force is 95% true. Adj.R^2 is 92.60% and Pre.R^2 is 87.29%. Both the values are reasonably in agreement with each other. This shows that the model is fitted and competent to predict the response.

The model value is 37.13, which shows that the model is substantial. Table 4.3 shows that the P value for the feed force model is 0.000.It specifies that input parameter has an influence on the feed force.

4.6.3.1 Influence of the Cutting Parameter on Feed Force

The depth of cut (88% contribution) has more impact on the feed force during machining as compared to feed and speed. Speed is an insignificant parameter. Table 4.3 shows that, higher order term as well as an interaction effect of the parameter is insignificant.

4.6.4 Radial Force Model for MQL - Soyabean Oil

The R^2 value for radial force is 95.13% as shown in table 4.10. It means that there is only 4.87 % variation. Adj.R^2 is 92.53% and Pre.R^2 is 87.93%. Adj.R^2 and Pre.R^2 values are close to each other.

The model implies that there is a relation between input parameter and output parameter. The model value is 36.87 as shown in table 4.2. Larger F value depicts that model is significant.

P value for the model is 0.000 hence null hypothesis must be rejected. The alternative hypothesis is that the cutting parameter has an impact on radial forces.

4.6.4.1 Influence of the Cutting Parameter on Radial Force

The most influential factor is the depth of cut having 77.99 % contribution. Feed contribute to radial forces by 17.68 %. The P value for the speed term is 0.298, which is more than 0.005. This shows that speed term insignificant. The linear term f, dp, square term of f, dp are more significant terms in the model as shown in table 4.3.

4.6.5 Temperature Model for MQL-Soyabean Oil

Table 4.1 shows that adjusted and predicted R^2 values are in good agreement. Adj.R^2 is 90.39%; Pre.R^2 is 84.16%. The difference between them is 0.06, which is less than the limit value. This advocates that regression model fit accurately into the experimental observations. The R^2 for temperature is 93.72%.

The model value for temperature model is 28.18. This value is more than 3.40, Critical value. This shows that model is significant. P value is 0.000, which implies that null hypothesis is rejected. Alternative hypothesis i.e. temperature is affected by input turning parameters is accepted.

Table 4.1 R^2 for MQL-Soyabean Oil

Factor	Cutting Force	Feed Force	Radial Force	Temperature	Surface Roughness	Power
R^2 (%)	97.50	95.16	95.13	93.72	98.14	99.63
Adj.R^2 (%)	96.18	92.60	92.55	90.39	97.16	99.44
Pre.R^2 (%)	94.508	87.29	87.93	84.16	95.35	99.18

Table 4.2 F-Value and % Contribution for MQL-Soyabean oil

Factor	Cutting Force		Feed Force		Radial Force		Temperature		Surface Roughness		Power	
	F	% C	F	% C	F	% C	F	% C	F	% C	F	% C
Model	73.76	--	37.13	--	36.87	--	28.18	--	99.91	--	510.1	--
V	15.42	2.34	2.47	0.74	1.15	0.35	8.26	3.23	370.6	**39.67**	3924.3	**85.73**
f	1.77	0.27	16.49	4.94	58.33	17.68	88.76	**34.67**	363.6	**38.92**	2.67	0.06
dp	620.5	**94.2**	294.0	**88.06**	257.3	**77.99**	146.8	**57.37**	41.55	4.45	576.3	**12.59**
v*v	1.13	0.17	0.3	0.09	0.01	0.00	3.19	1.25	152.2	16.29	0.01	0.00
f*f	2.92	0.44	10.26	3.07	12.31	3.73	1	0.39	1.75	0.19	4.71	0.10
dp*dp	10.6	1.61	9.14	2.74	0.37	0.11	0.15	0.06	0.07	0.01	8.98	0.20
v*f	1.14	0.17	0.13	0.04	0.01	0.00	1.52	0.59	3.51	0.38	2.18	0.05
v*dp	0.46	0.07	0.15	0.04	0	0.00	6.15	2.40	0.82	0.09	54.65	1.19
f*dp	4.85	0.74	0.91	0.27	0.43	0.13	0.1	0.04	0.14	0.01	3.7	0.08

Table 4.3 P-Value for MQL-Soyabean oil

Facto	Cutting Force	Feed Force	Radial Force	Temperature	Surface Roughness	Power
Model	0.000	0.000	0.000	0.000	0.000	0.000
V	0.001	0.135	0.298	0.011	0.000	0.000
f	0.216	0.001	0.000	0.000	0.000	0.120
dp	0.000	0.000	0.000	0.000	0.000	0.000
v*v	0.303	0.593	0.916	0.092	0.000	0.911
f*f	0.106	0.005	0.003	0.332	0.203	0.045
dp*dp	0.005	0.008	0.550	0.702	0.802	0.008
v*f	0.301	0.718	0.924	0.234	0.078	0.158
v*dp	0.508	0.700	0.947	0.024	0.377	0.000
f*dp	0.042	0.354	0.518	0.755	0.714	0.071

4.6.5.1 Influence of the Cutting Parameter on Temperature

The depth of cut (57.37 %) and feed (34.67%) are the most influencing factor affecting the temperature as shown in table 4.3. Speed has little effect on temperature. Linear term v,dp,f, square term v*v, f*f interaction term v*dp, and v*f are significant parameter in the regression equation because the P value for all this term is less than 0.005. Remaining square term and interaction terms are negligible, should be neglected.

4.6.6 Surface Roughness Model for MQL-Soyabean Oil

R^2, F and P value for surface roughness during soyabean oil cutting are shown in table 4.1, 4.2 and 4.3 respectively. R^2 is 98.14 %. Adj. R^2 value is 97.16 % and Pre.R^2 value is 95.35%. Both are in good agreement. Regression equations are adequate to predict the surface roughness. F critical (3.40) is very less than F value for model (F-99.91).

Low values of P reject the null hypothesis. i.e factors have no effect on the surface roughness. Table 4.3 shows that P value (0.0000) is less than 0.05 that guides the established regression equations are appropriate and adequate to predict the precise response.

4.6.6.1 Influence of the Cutting Parameter on Surface Roughness

Table 4.2 shows that surface roughness is mostly affected by speed (39.67%).The depth of cut has a negligible effect (4.44%) on surface roughness. Feed (38.92%) has second impact on roughness value. Linear term v, f, dp, square term v*v are significant term as for this term P value is less than 0.000.

4.6.7 Power Consumption Model for MQL-Soyabean Oil

The R^2 value for power consumption is 99.63%, which represents 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. Model F value (510) as shown in table 4.2, is very large as compared to Fcritical.

P value is 0.000, indicates that developed regression equation for power consumption is statistically significant and describes the true relation between input and output

4.6.7.1 Influence of the Cutting Parameter on Power Consumption

Power consumption is mostly affected by speed (85.73%) and depth of cut (12.59%). There is negligible effect of feed on power consumption. According to table 4.3, the feed is an insignificant parameter as P is 0.120. The most significance terms in the regression equation are v, dp, f*f, v*dp and dp*dp. Other terms are less significant as P values for these terms is more than 0.05.

4.7 Tool Wear Model for MQL-Soyabean Oil

Tool wear goes on increasing with machining time; hence, it is necessary to find the amount of wear with respect to time. This will also help to determine the tool life. Tool wear is higher at maximum feed and depth of cut, so in the present work, the maximum value of the depth of cut (1.5 mm) and feed (0.45mm) are considered for trial. Since cutting parameters were kept constant during measurement of wear, tool wear is function of the machining time (t) and speed (V). Regression equations for other cutting fluids are given as B.7.1 in appendix B.

Regression equations for Tool Wear –MQL-Soyabean Oil Cutting

$$VB_{\text{Soyabean}} = 0.0415 + 0.000644\,V + 0.000318\,t - 0.000001\,V*V + 0.000034\,t*t + 0.000001\,V*t \qquad \ldots\text{Eq.4.14}$$

4.7.1 Adequacy of Regression Model

It is essential to inspect the fitted model to confirm that it provides a right approximation to the true system and proves that none of the least squares regression assumptions is violated. Residual plot are used to verify the assumptions. The residual plot for tool wear is represented by figure 4.7, which shows that all the residual are along straight line. Predicted vs residual plot indicate that residual slightly varies from mean position. Residual vs observation pattern does not follow any pattern. This indicate that developed model for tool wear is valid and accurately represents the experimental data.

Analysis of variance is used to check the model accuracy. Table 4.4 represent the correlation coefficient, P value and F value for tool wear during machining while using soyabean oil as cutting fluid. Summary of ANOVA of other cutting fluids for tool wear is given as table B.7.1 in appendix B.

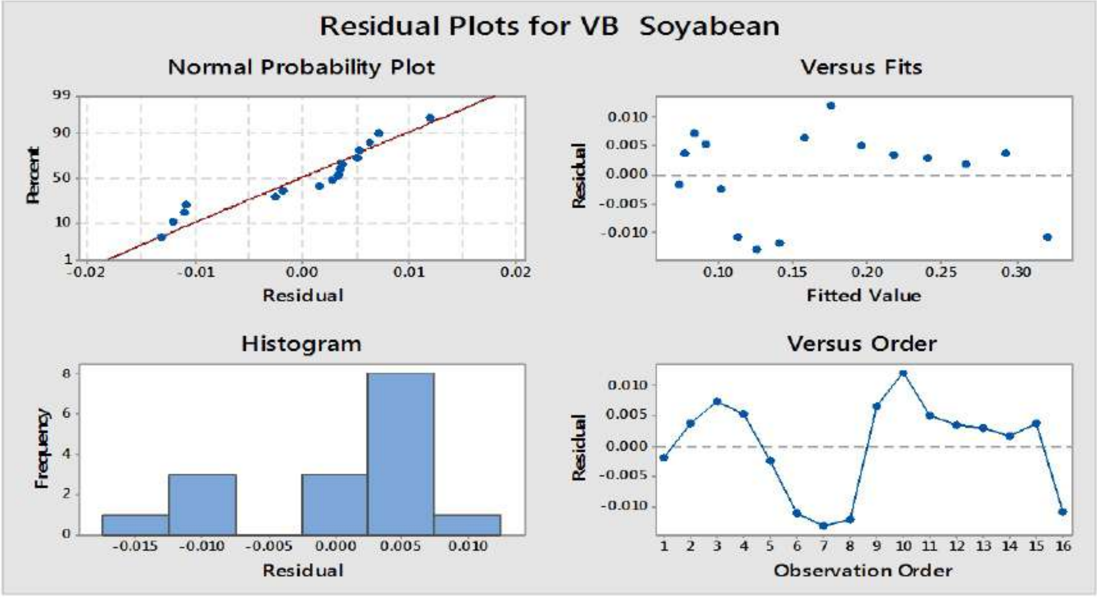

Figure 4.7 Residual Plots for Tool Wear -Soyabean Oil

Table 4.4 ANOVA Summary for Tool Wear-Soyabean Oil

R^2 (%)	97.99
Adj.R^2 (%)	97.75
Pre.R^2 (%)	97.34
P value	0.00
F(Model)	760.85

As shown in table 4.4, the correlation coefficient of soybean oil, R^2 is 94.99%. It indicates that the regression equations developed from tool wear are statistically significant. It is observed that adjusted R^2 and Predicted R^2 are in good agreement. The regression equations truly represent the wear of the cutting tool.

4.8 Validation of Experimental Results

A mathematical model of the response was developed using response surface methodology. Using the regression equation predicted values of different performance parameter like cutting force, temperature, surface roughness, power and tool wear were computed and theses predicted values are compared with experimental values. The comparison between predicted model and actual model for different vegetable oils are shown in appendix B. Figure B.8.1 to B.8.6 shows comparison of experimental and predicted RSM results for dry cutting, flood cutting, blasocut, soyabean oil, sunflower oil, coconut oil and groundnut oil respectively. Tool wear is represented in figure B.8.7. The experimental results and predicted results are in close agreement, which shows that regression equations developed are true and accurate.

4.9 Artificial Neural Network

An Artificial Neural Network (ANN) is an information processing system that has performance features in common with biological neural networks. A typical neural network has an input layer, one or more hidden layer and an output layer as shown in figure 4.8. 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 [100-101].

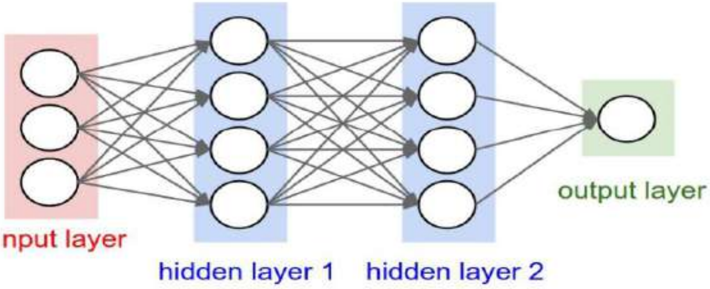

Figure 4.8 Typical Neural network

In the case of complex phenomenon involving non-linear function, Artificial Neural Network (ANN) simulation is used to validate the experimental data.

In the present study, mathematical models are developed using response surface methodology for feed forces, radial forces, cutting forces, temperature, surface roughness and power consumption during MQL-soyabean oil turning operation. To validate the results obtained by response surface methodology, ANN prediction model is used. The multilayer feed forward topology is used for the network.

From experimental observation, it is observed that soyabean oil gives the better performance hence to validate the response surface model; artificial network analysis was done for soyabean oil only.

4.9.1 Steps in formulation of ANN Simulation

The various steps followed in developing the algorithm to form ANN are as under.

1. The experimental data is divided into two groups i.e. Input data or the data of independent pi terms and the output data or the data of dependent pi terms. The input data and output data are imported to the program respectively. The cutting speed, feed and depth of cut are the input design parameter.
2. The input and output data are read by prestd function and appropriately sized. The function prestd is preprocesses the data so that the mean is 0 and the standard deviation is 1.
3. In preprocessing step the input and output data is normalized using mean and standard deviation.
4. The input and output data are then categorized into three categories viz. Testing, validation and training. From the observations of each response, initial 75% of the observations is selected for training, last 75% data for validation and middle overlapping 50% data for testing.
5. The data is then stored in structures for training, testing and validation.
6. Looking at the pattern of the data, feed forward back propagation type neural network is chosen.
7. This network is then trained using the training data. The computation errors in the actual and target data are computed and then the network is simulated.
8. The regression analysis and the representation are done through the standard functions. The values of regression coefficient and the equation of regression lines are represented on the one different graph plotted for the one dependent pi terms.

4.9.2 ANN Program - Feed Force for MQL-Soyabean oil

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 cutting forces, surface roughness, temperature etc. The program executed for feed forces during soyabean oil cutting for different input parameters is explained here.

```
clear all;
close all;
Inputs=3 [
```

34.27	0.35	0.5
34.27	0.35	1
34.27	0.35	1.5
34.27	0.4	0.5
34.27	0.4	1
34.27	0.4	1.5
34.27	0.45	0.5
34.27	0.45	1
34.27	0.45	1.5
53	0.35	0.5
53	0.35	1
53	0.35	1.5
53	0.4	0.5
53	0.4	1
53	0.4	1.5
53	0.45	0.5
53	0.45	1
53	0.45	1.5
79.73	0.35	0.5
79.73	0.35	1
79.73	0.35	1.5
79.73	0.4	0.5
79.73	0.4	1
79.73	0.4	1.5
79.73	0.45	0.5
79.73	0.45	1
79.73	0.45	1.5

```
]
 a1=inputs3
 a2=a1
 input_data=a2;
output3=[
```

256.47
299.41
353.24
258
310.67
324.21
267.21
338.54
357.64
241.54
298.87
347.24
257.54
297.62
321.24
261.32
334.21
354.54
234.24

297.54
345.64
257.00
294.32
319.24
258.98
332.97
353.65

```
]
 y1=output3
 y2=y1
size(a2);
size(y2);
p=a2';
sizep=size(p);
t=y2';
sizet=size(t);
[S Q]=size(t)
[pn,meanp,stdp,tn,meant,stdt] = prestd(p,t);
 net = newff(minmax(pn),[27 1],{'logsig' 'purelin'},'trainlm');
 net.performFcn='mse';
net.trainParam.goal=.99;
net.trainParam.show=200;
net.trainParam.epochs=50;
net.trainParam.mc=0.05;
net = train(net,pn,tn);
an=sim(net.pn) ;
[a] = poststd(an,meant,stdt);
error=t-a;
x1=1:27;
plot(x1,t,'rs-',x1,a,'b-')
legend('Experimental','Neural');
title('Output (Red) and Neural Network Prediction (Blue) Plot');
xlabel('Experiment No.');
ylabel('Output');
grid on;
figure
error_percentage=100*error./t
plot(x1,error_percentage)
legend('percentage error');
axis([0 27 -100 100]);
title('Percentage Error Plot in Neural Network Prediction');
xlabel('Experiment No.');
ylabel('Error in %');
grid on;
yy_practical(ii)=(y2(ii,1));
yy_neur(ii)=(a(1,ii))
yy_practical_abs(ii)=(y2(ii,1));
yy_neur_abs(ii)=(a(1,ii));
```

```
pause
end
figure;
plot(x1,yy_practical_abs,'r-',x1,yy_neur_abs,'k-');
legend('Practical','Neural');
title('Comparision between practical data, equation based data and neural based data');
xlabel('Experimental');
grid on;
meanexp=mean(output3)
meanann=mean(a)
```

4.9.3 Development of ANN Model for Feed Force (Soyabean Oil)

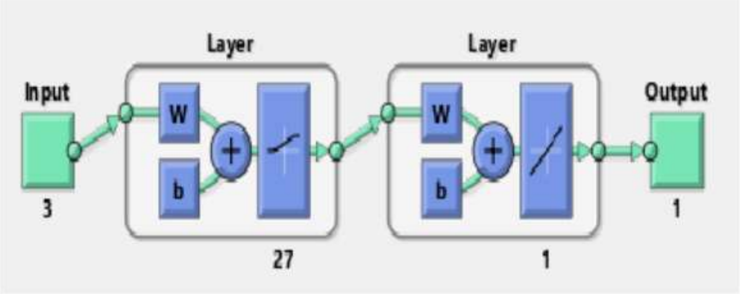

Figure 4.9 Architecture of ANN Model for Feed Force (Soyabean Oil)

After repeated trials, it was found that a network with 27 hidden neurons produced the best performance. The architecture of ANN model for feed force is shown in figure 4.9. It has three-layer ANN, with tangent sigmoid transfer function (tansig) at hidden layer with 27 neurons and linear transfer function (purelin) at the output layer.

The first step in ANN is training the data. Figure 4.10 represents training of network for feed force prediction during turning with soyabean oil.

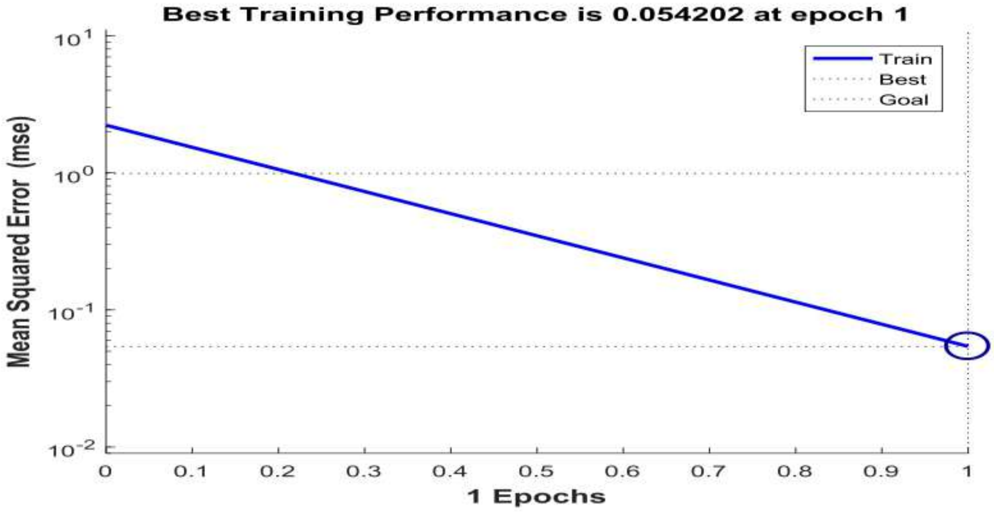

Figure 4.10 Training Performance of the ANN for Feed Force

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.

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. If the training were perfect, the network outputs and the targets would be exactly equal.

The regression plots represent the training, validation, and testing of data. The dashed line in figure 4.11, 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. Figure 4.11 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.

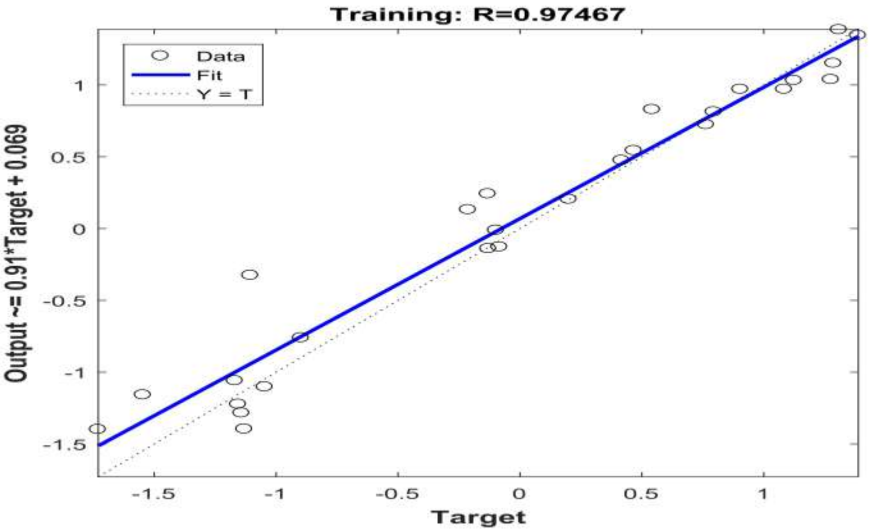

Figure 4.11 Regression Plot for the ANN for Feed Force

The percentage error between the experimental results and ANN predicted values for feed force is shown in figure 4.12. The error percentage is very less which reveals that the models can be effectively used for predicting the feed forces for soyabean oil. Figure 4.13 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.

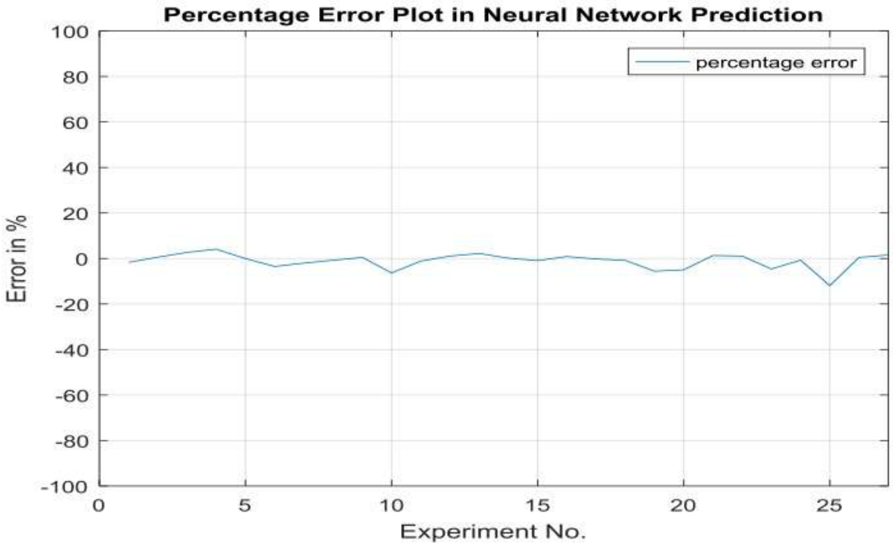

Figure 4.12 Percentage Error in ANN for Feed Force

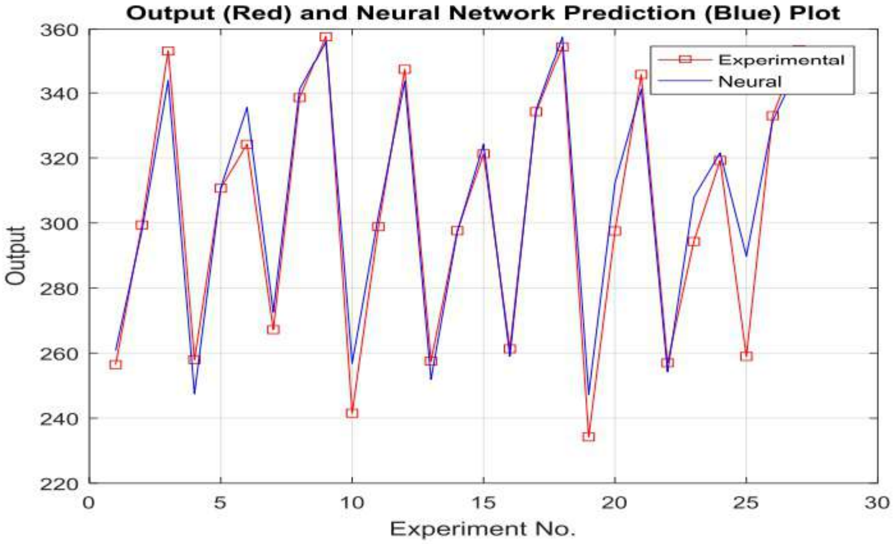

Figure 4.13 Comparison of Feed Force (Expt. vs. ANN)

4.9.4 Comparison of Experimental and ANN Predicted 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 radial force, cutting force, temperature, tool power consumption and tool wear with respect to soyabean oil.

Figure 4.14 and figure 4.15 shows the comparison between the experimental output and neural network prediction for radial forces and 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.

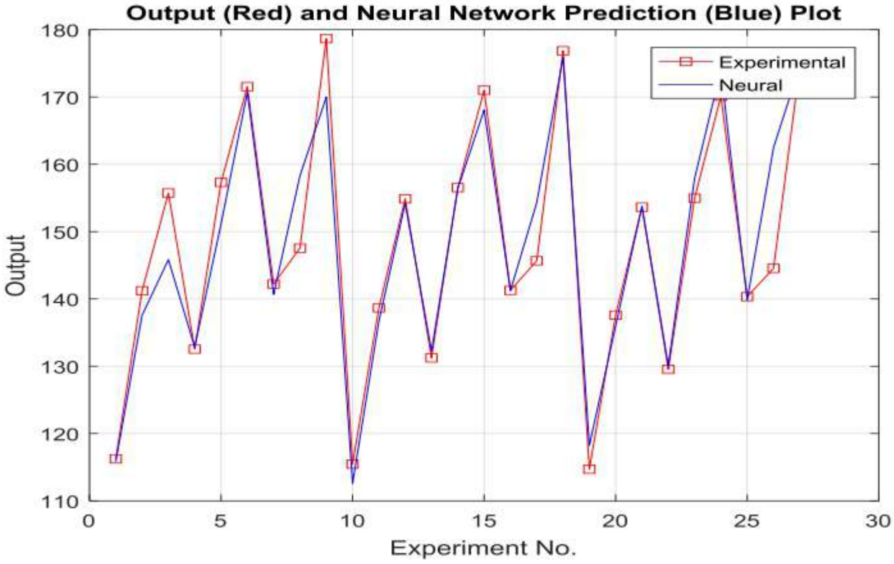

Figure 4.14 Comparison of Radial Force (Expt. Vs ANN)

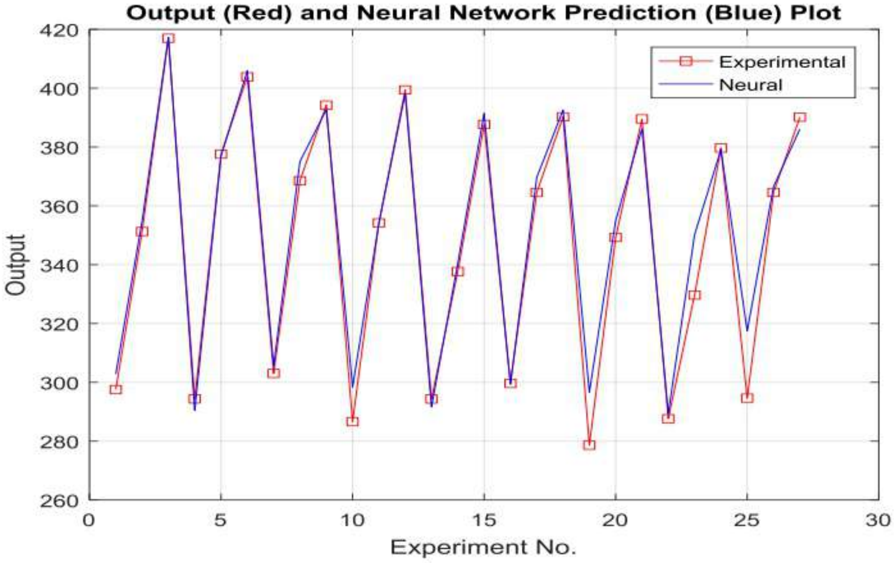

Figure 4.15 Comparison of Cutting Force (Expt. Vs ANN)

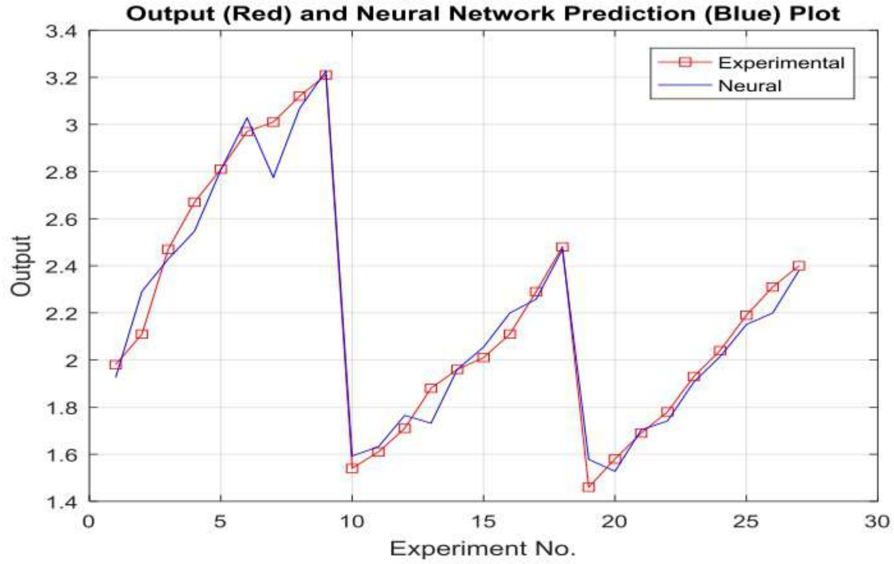

Figure 4.16 Comparison of Surface Roughness (Expt. Vs ANN)

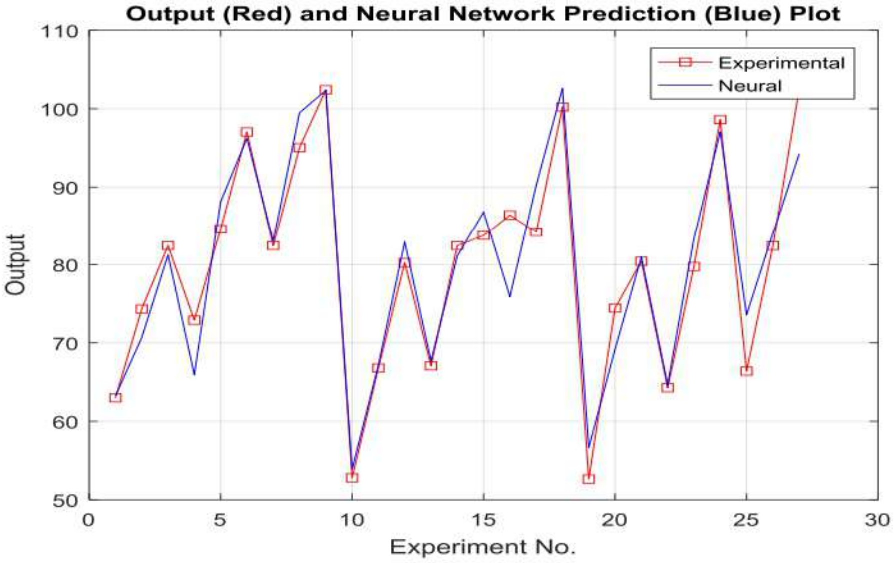

Figure 4.17 Comparison of Temperature (Expt. Vs ANN)

The comparison between experimental and ANN predicted results for surface roughness and temperature is given by figure 4.16 and figure 4.17 respectively.

Figure 4.18 and 4.19 shows comparison between experimental and neural network predicted results for power consumption and tool wear respectively.

The results of the neural network model shows good agreement between the model output and the measured responses with very marginal error.

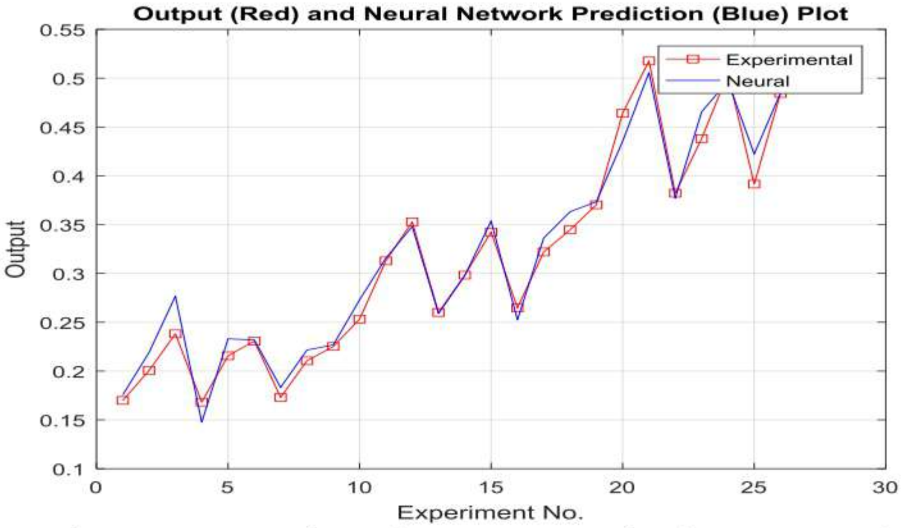

Figure 4.18 Comparison of Power Consumption (Expt. Vs. ANN)

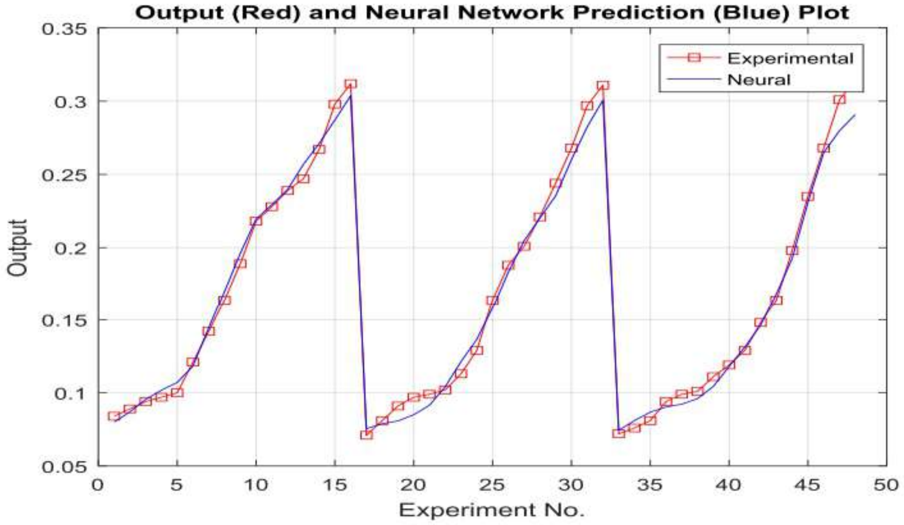

Figure 4.19 Comparison of Tool Wear (Expt. Vs ANN)

The percentage error between the experimental results, RSM and ANN predicted values of the different responses during turning with soyabean oil are represented in table 4.5 to table 4.11.

Table 4.5 represents the feed forces predicted by an artificial neural network and RSM. The comparison between experimental data and predicted values for radial forces and cutting forces is shown in table 4.6 and table 4.7. The variation between experiential value and results obtained by RSM and ANN for temperature and surface roughness respectively as shown in table 4.8 and 4.9, while table 4.10 and 4.11 shows error for power consumption and tool wear respectively. For all the responses, the variation between predicted results and experimental results is within the acceptable range. The results of ANN, RSM are in agreement with the measured responses. This indicates that both the model truly represent the experimental results.

Table 4.5 Percentage Error between the Experimental, RSM and ANN for Feed Forces (Soyabean Oil)

Total runs	V	f	dp	$F_{f\ Expt}$	$F_{f\ ANN}$	$F_{f\ RSM}$	Error Expt Vs RSM	Error Expt. Vs ANN
	m/min	mm/rev	mm	N	N	N	%	%
1	34.27	0.35	0.5	256.47	260.773	252.931	1.379	1.677
2	34.27	0.35	1	299.41	297.657	311.625	4.079	0.5855
3	34.27	0.35	1.5	353.24	343.781	343.723	2.694	2.677
4	34.27	0.4	0.5	258	247.459	251.008	2.710	4.0858
5	34.27	0.4	1	310.67	310.788	306.739	1.265	0.037
6	34.27	0.4	1.5	324.21	335.523	335.875	3.598	3.489
7	34.27	0.45	0.5	267.21	272.602	277.259	3.760	2.017
8	34.27	0.45	1	338.54	341.107	330.028	2.514	0.758
9	34.27	0.45	1.5	357.64	355.984	356.201	0.402	0.4629
10	53	0.35	0.5	241.54	256.863	245.3	1.556	6.343
11	53	0.35	1	298.87	302.264	304.993	2.048	1.135
12	53	0.35	1.5	347.24	343.541	338.089	2.635	1.065
13	53	0.4	0.5	257.54	251.891	244.313	5.136	2.193
14	53	0.4	1	297.62	297.182	301.043	1.15	0.147
15	53	0.4	1.5	321.24	324.219	331.177	3.093	0.927
16	53	0.45	0.5	261.32	259.069	271.5	3.895	0.8614
17	53	0.45	1	334.21	334.879	325.267	2.675	0.200
18	53	0.45	1.5	354.54	357.519	352.439	0.5925	0.840
19	79.73	0.35	0.5	234.24	247.336	240.257	2.568	5.590
20	79.73	0.35	1	297.54	312.277	301.375	1.288	4.952
21	79.73	0.35	1.5	345.64	341.115	335.897	2.818	1.3092
22	79.73	0.4	0.5	257	254.296	240.605	6.379	1.0522
23	79.73	0.4	1	294.32	307.917	298.76	1.508	4.619
24	79.73	0.4	1.5	319.24	321.52	330.32	3.470	0.714
25	79.73	0.45	0.5	258.98	289.823	269.128	3.918	11.90
26	79.73	0.45	1	332.97	331.361	324.321	2.597	0.4831
27	79.73	0.45	1.5	353.65	348.278	352.918	0.207	1.5190

Table 4.6 Percentage Error between the Experimental, RSM and ANN for Radial Force (Soyabean Oil)

Total runs	V	f	dp	Fr $_{Expt}$	Fr $_{ANN}$	Fr $_{RSM}$	Error Expt Vs RSM	Error Expt. Vs ANN
	m/min	mm/rev	mm	N	N	N	%	%
1	34.27	0.35	0.5	116.24	117.90	117.874	1.4061	1.431
2	34.27	0.35	1	141.21	140.41	136.759	3.1517	0.564
3	34.27	0.35	1.5	155.74	155.11	158.15	1.5474	0.018
4	34.27	0.4	0.5	132.54	131.61	135.267	2.0578	0.695
5	34.27	0.4	1	157.31	159.63	153.194	2.616	1.475
6	34.27	0.4	1.5	171.54	172.42	173.626	1.216	0.517
7	34.27	0.45	0.5	142.21	144.04	138.239	2.792	1.287
8	34.27	0.45	1	147.54	153.11	155.208	5.197	3.780
9	34.27	0.45	1.5	178.67	177.39	174.681	2.232	0.711
10	53	0.35	0.5	115.45	116.04	116.799	1.168	0.513
11	53	0.35	1	138.64	138.46	135.603	2.190	0.126
12	53	0.35	1.5	154.87	157.33	156.913	1.3192	1.594
13	53	0.4	0.5	131.24	131.46	134.077	2.161	0.169
14	53	0.4	1	156.54	156.73	151.923	2.949	0.125
15	53	0.4	1.5	171.01	172.13	172.274	0.7394	0.659
16	53	0.45	0.5	141.27	133.89	136.934	3.069	5.224
17	53	0.45	1	145.67	152.88	153.822	5.595	4.950
18	53	0.45	1.5	176.87	177.91	173.215	2.066	0.591
19	79.73	0.35	0.5	114.69	122.83	115.799	0.967	7.103
20	79.73	0.35	1	137.59	134.49	134.488	2.254	2.246
21	79.73	0.35	1.5	153.64	154.32	155.683	1.329	0.444
22	79.73	0.4	0.5	129.54	130.64	132.913	2.604	0.850
23	79.73	0.4	1	154.98	161.27	150.644	2.797	4.063
24	79.73	0.4	1.5	170.1	168.90	170.88	0.458	0.702
25	79.73	0.45	0.5	140.33	147.75	135.606	3.366	5.291
26	79.73	0.45	1	144.54	147.20	152.379	5.423	1.840
27	79.73	0.45	1.5	174.64	164.26	171.657	1.708	5.940

Table 4.7 Percentage Error between the Experimental, RSM and ANN for Cutting Force (Soyabean Oil)

Total runs	V	f	dp	Fc_{Expt}	Fc_{ANN}	Fc_{RSM}	Error Expt Vs RSM	Error Expt. Vs ANN
	m/min	mm/rev	mm	N	N	N	%	%
1	34.27	0.35	0.5	297.54	302.8	296.588	0.3200	1.767
2	34.27	0.35	1	351.27	354.758	365.956	4.1807	0.993
3	34.27	0.35	1.5	416.97	417.261	412.391	1.0981	0.069
4	34.27	0.4	0.5	294.37	290.496	296.13	0.597	1.316
5	34.27	0.4	1	377.58	376.895	360.016	4.6517	0.1815
6	34.27	0.4	1.5	403.87	405.963	400.97	0.7180	0.518
7	34.27	0.45	0.5	303.03	305.599	307.693	1.538	0.847
8	34.27	0.45	1	368.54	375.074	366.097	0.6628	1.7731
9	34.27	0.45	1.5	394.24	392.66	401.57	1.859	0.400
10	53	0.35	0.5	286.65	298.349	285.454	0.4171	4.081
11	53	0.35	1	354.21	354.072	353.443	0.2164	0.038
12	53	0.35	1.5	399.41	398.146	398.5	0.2277	0.316
13	53	0.4	0.5	294.34	291.625	287.172	2.4353	0.922
14	53	0.4	1	337.68	340.49	349.679	3.553	0.832
15	53	0.4	1.5	387.67	391.447	389.254	0.408	0.974
16	53	0.45	0.5	299.64	299.381	300.91	0.423	0.086
17	53	0.45	1	364.54	369.611	357.936	1.811	1.391
18	53	0.45	1.5	390.24	392.564	392.03	0.4586	0.59
19	79.73	0.35	0.5	278.65	296.587	278.695	0.0161	6.43
20	79.73	0.35	1	349.31	354.917	344.716	1.3150	1.60
21	79.73	0.35	1.5	389.54	386.19	387.806	0.4452	0.859
22	79.73	0.4	0.5	287.65	289.477	283.517	1.436	0.635
23	79.73	0.4	1	329.65	350.188	344.057	4.370	6.23
24	79.73	0.4	1.5	379.65	379.1	381.665	0.530	0.144
25	79.73	0.45	0.5	294.65	317.486	300.361	1.938	7.75
26	79.73	0.45	1	364.54	366.484	355.419	2.502	0.53
27	79.73	0.45	1.5	390.14	386.107	387.545	0.665	1.033

Table 4.8 Percentage Error between the Experimental, RSM and ANN for Temperature (Soyabean Oil)

Total runs	V	f	dp	T_{Expt}	T_{ANN}	T_{RSM}	Error Expt Vs RSM	Error Expt Vs ANN
	m/min	mm/rev	mm	0^0C	0^0C	0°C	%	%
1	34.27	0.35	0.5	63	63.242	62.1156	1.40384	0.384
2	34.27	0.35	1	74.32	70.681	72.5045	2.44286	4.8961
3	34.27	0.35	1.5	82.42	81.243	81.5178	1.094	1.4270
4	34.27	0.4	0.5	72.9	65.941	75.4382	3.481	9.5456
5	34.27	0.4	1	84.6	88.135	85.4304	0.9815	4.1788
6	34.27	0.4	1.5	97.04	96.233	94.047	3.084	0.8311
7	34.27	0.45	0.5	82.42	83.035	85.2318	3.4116	0.7470
8	34.27	0.45	1	95.04	99.490	94.8274	0.223	4.682
9	34.27	0.45	1.5	102.4	102.33	103.047	0.6126	0.0873
10	53	0.35	0.5	52.8	53.866	55.2595	4.65	2.019
11	53	0.35	1	66.8	67.182	68.186	2.074	0.571
12	53	0.35	1.5	80.24	82.893	79.7369	0.626	3.307
13	53	0.4	0.5	67.08	67.690	67.3183	0.3553	0.909
14	53	0.4	1	82.42	81.109	79.8481	3.120	1.5905
15	53	0.4	1.5	83.74	86.826	91.0024	8.676	3.685
16	53	0.45	0.5	86.42	75.894	75.8483	12.233	12.179
17	53	0.45	1	84.2	90.213	87.9814	4.491	7.142
18	53	0.45	1.5	100.2	102.62	98.739	1.477	2.396
19	79.73	0.35	0.5	52.64	56.640	53.1638	0.995	7.599
20	79.73	0.35	1	74.44	69.195	69.7118	6.351	7.0450
21	79.73	0.35	1.5	80.42	80.971	84.8842	5.551	0.685
22	79.73	0.4	0.5	64.28	64.662	63.4191	1.339	0.594
23	79.73	0.4	1	79.74	83.341	79.5704	0.2127	4.515
24	79.73	0.4	1.5	98.62	97.085	94.3461	4.33369	1.556
25	79.73	0.45	0.5	66.4	73.578	70.1455	5.6	10.810
26	79.73	0.45	1	82.4	84.025	85.9001	4.247	1.972
27	79.73	0.45	1.5	102.4	94.236	100.279	2.147	8.0443

Table 4.9 Percentage Error between the Experimental, RSM and ANN for Surface Roughness (Soyabean Oil)

Total runs	V	f	dp	Ra_{Expt}	Ra ANN	Ra RSM	Error Expt Vs RSM	Error Expt. Vs ANN
	m/min	mm/rev	mm	µm	µm	µm	%	%
1	34.27	0.35	0.5	1.98	2.0275	2.10151	6.136	2.401
2	34.27	0.35	1	2.11	2.0638	2.25382	6.816	2.1889
3	34.27	0.35	1.5	2.47	2.4126	2.42391	1.866	2.3235
4	34.27	0.4	0.5	2.67	2.3931	2.58723	3.10016	10.370
5	34.27	0.4	1	2.81	2.8582	2.73037	2.833	1.7178
6	34.27	0.4	1.5	2.97	2.9448	2.89129	2.657	0.8460
7	34.27	0.45	0.5	3.01	2.7940	2.98072	0.9727	7.1733
8	34.27	0.45	1	3.12	3.1685	3.1147	0.169	1.555
9	34.27	0.45	1.5	3.21	3.2041	3.26646	1.7587	0.1817
10	53	0.35	0.5	1.54	1.5751	1.40654	8.666	2.2797
11	53	0.35	1	1.61	1.6121	1.54054	4.314	0.1358
12	53	0.35	1.5	1.71	1.8130	1.69231	1.034	6.027
13	53	0.4	0.5	1.88	1.8906	1.85443	1.360	0.568
14	53	0.4	1	1.96	1.9283	1.97926	0.982	1.613
15	53	0.4	1.5	2.01	2.1363	2.12187	5.565	6.283
16	53	0.45	0.5	2.11	2.1376	2.21009	4.743	1.309
17	53	0.45	1	2.29	2.3686	2.32576	1.5614	3.435
18	53	0.45	1.5	2.48	2.5632	2.4592	0.838	3.354
19	79.73	0.35	0.5	1.46	1.5280	1.46334	0.228	4.660
20	79.73	0.35	1	1.58	1.6077	1.5712	0.557	1.756
21	79.73	0.35	1.5	1.69	1.6411	1.69683	0.404	2.893
22	79.73	0.4	0.5	1.78	1.7660	1.85723	4.339	0.783
23	79.73	0.4	1	1.93	2.0357	1.95593	1.343	5.477
24	79.73	0.4	1.5	2.04	1.9929	2.0724	1.588	2.306
25	79.73	0.45	0.5	2.19	2.2940	2.15891	1.419	4.74
26	79.73	0.45	1	2.31	2.3107	2.24843	2.665	0.033
27	79.73	0.45	1.5	2.4	2.4448	2.35574	1.844	1.868

Table 4.10 Percentage Error between the Experimental, RSM and ANN for Power Consumption (Soyabean Oil)

Total runs	V	f	dp	P E_{xpt}	P_{ANN}	P RSM	Error Expt Vs RSM	Error Expt. Vs ANN
	m/min	mm/rev	mm	KW	KW	KW	%	%
1	34.27	0.35	0.5	0.1699	0.1732	0.16833	0.948657	2.302
2	34.27	0.35	1	0.2006	0.1932	0.21323	6.2776	0.421278
3	34.27	0.35	1.5	0.2381	0.1997	0.23751	0.274697	0.308913
4	34.27	0.4	0.5	0.1681	0.2374	0.16523	1.725012	3.52365
5	34.27	0.4	1	0.2151	0.1740	0.20545	4.734698	1.23812
6	34.27	0.4	1.5	0.2306	0.2183	0.22505	2.440719	1.75676
7	34.27	0.45	0.5	0.1730	0.2347	0.17706	2.29878	0.43549
8	34.27	0.45	1	0.2104	0.1738	0.2126	0.99672	1.63429
9	34.27	0.45	1.5	0.225	0.2139	0.22751	1.03742	5.13435
10	53	0.35	0.5	0.253	0.2367	0.25277	0.173492	3.34271
11	53	0.35	1	0.318	0.2616	0.3124	0.153589	0.414973
12	53	0.35	1.5	0.352	0.3115	0.35142	0.393979	1.717595
13	53	0.4	0.5	0.260	0.3467	0.25261	2.841621	0.79007
14	53	0.4	1	0.298	0.2620	0.30757	3.11284	0.778386
15	53	0.4	1.5	0.342	0.2959	0.34191	0.15631	0.39996
16	53	0.45	0.5	0.264	0.3438	0.26738	1.01939	2.92593
17	53	0.45	1	0.322	0.2724	0.31766	1.351809	2.351597
18	53	0.45	1.5	0.344	0.3144	0.34732	0.75515	2.733465
19	79.73	0.35	0.5	0.370	0.3352	0.37422	1.06493	2.7581
20	79.73	0.35	1	0.464	0.3804	0.4549	1.998931	1.560072
21	79.73	0.35	1.5	0.517	0.4569	0.51495	0.518396	3.27222
22	79.73	0.4	0.5	0.382	0.5007	0.37827	1.039368	0.791785
23	79.73	0.4	1	0.4380	0.3791	0.45426	3.70049	3.28471
24	79.73	0.4	1.5	0.5044	0.4524	0.50963	1.01938	1.2951
25	79.73	0.45	0.5	0.391	0.4979	0.39723	1.45396	2.01133
26	79.73	0.45	1	0.484	0.3994	0.46855	3.27514	2.326749
27	79.73	0.45	1.5	0.5184	0.47314	0.51924	0.15648	2.41985

Table 4.11 Percentage Error between the Experimental, RSM and ANN for Tool Wear (Soyabean Oil)

Sr No	V	Machining Time	$VB_{Expt.}$	VB_{ANN}	VB_{RSM}	Error Expt Vs RSM	Error Expt. Vs ANN
	m/min	min	mm	mm	mm	%	%
1	79.73	5	0.084	0.080075	0.0814	3.095238	4.672049
2	79.73	10	0.089	0.086955	0.08564	3.775281	2.297418
3	79.73	15	0.094	0.095528	0.09674	2.91489	1.62589
4	79.73	20	0.097	0.101828	0.0967	0.309278	4.97761
5	79.73	25	0.1	0.107053	0.0987	1.30	7.05287
6	79.73	30	0.121	0.118276	0.1154	4.628099	2.251614
7	79.73	35	0.142	0.144496	0.146	2.8169	1.75753
8	79.73	40	0.164	0.169876	0.1712	4.39024	3.58293
9	79.73	45	0.189	0.19605	0.1975	4.49735	3.73022
10	79.73	50	0.218	0.219432	0.224	2.75229	0.65689
11	79.73	55	0.228	0.22937	0.234	2.63158	0.60092
12	79.73	60	0.239	0.239664	0.241	0.83682	0.27779
13	79.73	65	0.247	0.256792	0.255	3.23887	3.96425
14	79.73	70	0.267	0.271118	0.2731	2.28464	1.54245
15	79.73	75	0.298	0.287107	0.289	3.020134	3.65532
16	79.73	80	0.312	0.303767	0.31	0.641026	2.638843
17	53	5	0.071	0.075555	0.07497	5.59155	6.41611
18	53	10	0.081	0.078927	0.07984	1.432099	2.558861
19	53	15	0.091	0.080781	0.08421	7.461538	11.22921
20	53	20	0.097	0.085028	0.094	3.092784	12.34264
21	53	25	0.099	0.091527	0.0927	6.363636	7.548174
22	53	30	0.102	0.104199	0.109	6.86275	2.15567
23	53	35	0.113	0.121335	0.123	8.84956	7.37642
24	53	40	0.129	0.136497	0.1378	6.82171	5.81143
25	53	45	0.164	0.158247	0.162	1.219512	3.507961
26	53	50	0.188	0.183246	0.184	2.12766	2.528667
27	53	55	0.201	0.204677	0.219	8.95522	1.82917
28	53	60	0.221	0.22021	0.229	3.61991	0.357434

Sr No	V	Machining Time	VB $_{\text{Expt.}}$	VB$_{\text{ANN}}$	VB$_{\text{RSM}}$	Error Expt Vs RSM	Error Expt. Vs ANN
	m/min	min	mm	mm	mm	%	%
29	53	65	0.244	0.23536	0.241	1.229508	3.541051
30	53	70	0.268	0.260027	0.264	1.492537	2.975145
31	53	70	0.268	0.260027	0.264	1.492537	2.975145
32	53	75	0.297	0.28247	0.286	3.703704	4.892347
33	53	80	0.311	0.300695	0.312	0.32154	3.313563
34	34.27	5	0.072	0.074435	0.0789	9.58333	3.38148
35	34.27	10	0.076	0.081038	0.0845	11.1842	6.62888
36	34.27	15	0.081	0.086788	0.0894	10.3704	7.1453
37	34.27	20	0.094	0.090307	0.0945	0.53191	3.928386
38	34.27	25	0.099	0.092266	0.0934	5.656566	6.801983
39	34.27	30	0.101	0.096038	0.0968	4.158416	4.912591
40	34.27	35	0.111	0.104391	0.108	2.702703	5.95367
41	34.27	40	0.119	0.117911	0.145	21.8487	0.915279
42	34.27	45	0.129	0.131303	0.149	0.67568	1.78558
43	34.27	50	0.148	0.146241	0.174	6.09756	1.188284
44	34.27	55	0.164	0.168289	0.196	1.010101	2.61544
45	34.27	60	0.198	0.192611	0.245	4.25532	2.721591
46	34.27	65	0.235	0.230965	0.271	1.1194	1.717126
47	34.27	70	0.268	0.26494	0.284	5.647841	1.141757
48	34.27	75	0.301	0.279827	0.299	4.77707	7.034114

CHAPTER 5

OPTIMIZATION OF MACHINING PARAMETERS

5.1 Introduction

For every machining operation, the selection of optimum machining parameters is very important step to maintain the quality of machined products, to reduce the machining costs and to increase the production rate. The cutting conditions set by practitioners of manufacturing industries are sometimes too far from optimal conditions. Therefore, different mathematical techniques are used for obtaining optimized parameters in machining [118].

In the present study, response surface methodology based desirability approach is used for multi-response optimization. It is used to optimize the machining parameter like cutting speed, depth of cut and feed to accomplish multiple objectives like minimum cutting forces, minimum temperature, minimum roughness and minimum power consumption.

5.2 Optimization and Desirability Analysis

Desirability function method is controlling tools for solving the multiple performance optimization problems, where all the objectives are accomplished a definite goal simultaneously. Individual desirability (d) evaluates how the settings optimize a single response; composite desirability (D) evaluates how the settings optimize a set of responses overall. Desirability has a range of zero to one. One represents the ideal case; zero indicates that one or more responses are outside their acceptable limits. To find the desirability, First step is to convert each response yi into an individual desirability function di. The desirability function varies over the range $0 \leq di \leq 1$. If the response meets the goal or target value, then di = 1, and if the response falls beyond the acceptable limit, then di = 0. The second step is to decide the input parameter combination that will maximize overall desirability. If any response is entirely objectionable then the overall desirability is zero. (D = 0) If the desirability value is greater than 0.9 the values of process parameters was considered to be the optimum for giving maximum performance [116-117].

The overall desirability D is calculated using individual desirability. Geometric mean, of individual desirability gives composite desirability [116-117].

The composite desirability is given by,

$$D= (d1\ (y1)*d2\ (y2)*d3\ (y3)*\ldots*dk\ (yk))\ \hat{}\ (1/k) \qquad \ldots Eq.5.1$$

where, k is the total number of responses.

5.3 Multi Response Optimization of Cutting Parameter

Optimization is a method of finding the best result under given circumstances. It can be defined as the process of finding the conditions that give the maximum or minimum value of a function. Normally optimization of machining parameters can be done by considering a single objective function like desired surface finish, minimum tool-work piece interface temperature, minimum cutting force, minimum tool wear, maximum tool life, and minimum power consumption during machining. For multi-objective response i.e. Optimization with multiple responses simultaneously, the response surface optimizer is used. Desirability is used to verify the feasibility of the optimization process. Value of desirability approaching toward one, specifies that optimization process is realistic and reasonable.

Response optimizer is used to find the optimized values of the input parameter. One of the advantages of response optimizer is that it gives optimized value considering the all the response factor simultaneously. In this study, optimization is carried out to minimize cutting forces, surface roughness, and temperature and power consumption.

Optimization success is measured by the composite desirability. The value of one indicates that the response is in goal and the value of zero means that one or more responses are outside of the acceptable region. RSM optimization results for power consumption, temperature, surface roughness, cutting force radial force and feed force are shown in table 5.1. All the values of desirability are approaching towards one, which indicate that optimization process is feasible. The optimum cutting speed is between 50 m/min-60 m/min. The depth of cut and feed are 0.5 mm and 0.35 mm/rev respectively. Figure 5.1 shows optimum plot for soyabean oil. Optimum plot for all other vegetable oil are added as figure C1 to C3 in Appendix C.

Table 5.1 Optimum Cutting Conditions and Desirability

Cutting condition / parameter	V	f	dp	Fc	Ff	Fr	Ra	T	P	Desirability
	m/min	mm/rev	mm	N	N	N	µm	° C	KW	
Dry Cutting	54	0.35	0.5	367.5	320.1	189.4	3.477	78.4	0.33	0.8819
Flood Cutting	62.28	0.35	0.5	338.6	294.7	166.3	1.81	60.7	0.35	0.8997
Blaso Cut	58.6	0.35	0.5	320	276.2	148.5	1.74	59.1	0.31	0.9114
Soyabean Oil	50.8	0.35	0.5	286.4	246	116.9	1.456	55.8	0.24	0.9200
Sunflower Oil	52.17	0.35	0.5	316.7	270.2	142.7	1.64	60.3	0.27	0.9146
Coconut Oil	59.98	0.35	0.5	338	293.1	167.7	1.78	67.7	0.33	0.9013
Groundnut Oil	55.85	0.35	0.5	358.2	309.1	176.5	1.61	63.1	0.335	0.909

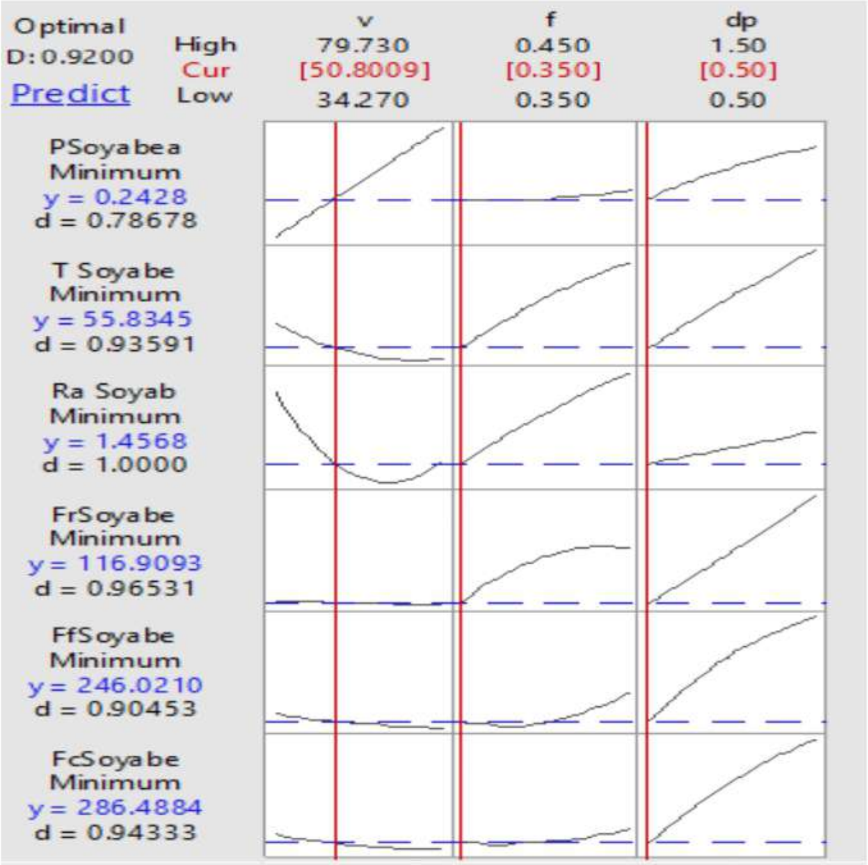

Figure 5.1 Optimum Plot for Soyabean Oil

The optimization plot 5.1 shows the effect of each factor (columns) on the responses and composite desirability (rows). The vertical red lines on the graph represent the optimum factor settings. The numbers displayed at the top of a column show the optimum factor level settings (in red). The horizontal blue lines and numbers represent the responses for the optimum level. It shows how the desired response varies with increase in cutting speed, feed and depth of cut. The values that maximize the desirability give the optimal setting. For soyabean oil, the optimum condition for maximum performance is 50.08 m/min, 0.35 mm/rev and 0.5 mm. The desirability value in all the cases is approaching to 100. This indicates the success or feasibility of the optimization process.

5.4 Confirmation of Experiment to Validate Optimized Parameter

After optimization, it is necessary to perform confirmation experiment to predict and confirm the enhancement in the performance parameters with the chosen optimal machining parameters. It is required to verify closeness of the predicted and experimental value. Performing confirmation experiment is the very crucial, concluding and an important part of every research work.

In order to validate the results obtained from response optimizer, confirmation experiment was conducted at optimal process parameter. The predicted results and the experimental results were compared and the percentage error was calculated. The result of the confirmation experiments at different cutting conditions for various cutting fluids is shown in table 5.2 to table 5.7.

Table 5.2 Cutting Forces – Comparison of Predicted and Experimental Results

Cutting parameter/ condition	Speed (m/min)	dp (mm)	Feed (mm/rev)	Expt.Fc (N)	Pred.Fc (N)	% Error
Dry Cutting	54	0.35	0.5	384.2	367.5	4.346
Flood Cutting	62.28	0.35	0.5	348.31	338.6	2.787
Blaso Cut	58.6	0.35	0.5	334.2	320	4.248
Soyabean Oil	50.8	0.35	0.5	299.5	286.4	4.373
Sunflower Oil	52.17	0.35	0.5	329.4	316.7	3.855
Coconut Oil	59.98	0.35	0.5	349.5	338	3.290
Groundnut Oil	55.85	0.35	0.5	367.5	356.45	3.006

Table 5.3 Feed Force - Comparison of Predicted and Experimental Results

Cutting parameter/ condition	Speed (m/min)	dp (mm)	Feed (mm/rev)	Expt.Ff (N)	Pred.Ff (N)	% Error
Dry Cutting	54	0.35	0.5	337.1	320.2	5.013
Flood Cutting	62.28	0.35	0.5	307.45	294.8	4.114
Blaso Cut	58.6	0.35	0.5	297.4	276.6	6.993
Soyabean Oil	50.8	0.35	0.5	258.4	246	4.7987
Sunflower Oil	52.17	0.35	0.5	287.4	270.2	5.984
Coconut Oil	59.98	0.35	0.5	304.7	293	3.839
Groundnut Oil	55.85	0.35	0.5	327.8	309.1	5.704

Table 5.4 Radial Force - Comparison of Predicted and Experimental Results

Cutting parameter/ condition	Speed (m/min)	dp (mm)	Feed (mm/rev)	Exp.Fr (N)	Pred.Fr (N)	% Error
Dry Cutting	54	0.35	0.5	197.4	189.4	4.052
Flood Cutting	62.28	0.35	0.5	171.2	166.3	2.862
Blaso Cut	58.6	0.35	0.5	157.6	148.5	5.774
Soyabean Oil	50.8	0.35	0.5	122.4	116.9	4.493
Sunflower Oil	52.17	0.35	0.5	149.7	142.7	4.676
Coconut Oil	59.98	0.35	0.5	171.1	167.7	1.987
Groundnut Oil	55.85	0.35	0.5	186.5	176.5	5.361

Table 5.5 Temperature - Comparison of Predicted and Experimental Results

Cutting parameter/ condition	Speed (m/min)	dp (mm)	Feed (mm/rev)	Expt.T	Pred.T	% Error
Dry Cutting	54	0.35	0.5	81.2	78.4	3.448
Flood Cutting	62.28	0.35	0.5	63.74	60.7	4.769
Blaso Cut	58.6	0.35	0.5	61.2	59.1	3.431
Soyabean Oil	50.8	0.35	0.5	53.74	55.8	3.833
Sunflower Oil	52.17	0.35	0.5	63.4	60.3	4.889
Coconut Oil	59.98	0.35	0.5	69.4	67.7	2.449
Groundnut Oil	55.85	0.35	0.5	66.4	63.1	4.969

Table 5.6 Surface Roughness - Comparison of Predicted and Experimental Results

Cutting parameter/ condition	Speed (m/min)	dp (mm)	Feed (mm/rev)	Expt.Ra (μm)	Pred.Ra (μm)	% Error
Dry Cutting	54	0.35	0.5	3.61	3.477	3.684
Flood Cutting	62.28	0.35	0.5	1.92	1.81	5.729
Blaso Cut	58.6	0.35	0.5	1.78	1.74	2.247
Soyabean Oil	50.8	0.35	0.5	1.51	1.456	3.576
Sunflower Oil	52.17	0.35	0.5	1.72	1.64	4.651
Coconut Oil	59.98	0.35	0.5	1.84	1.78	3.2608
Groundnut Oil	55.85	0.35	0.5	66.2	63.16	4.592

Table 5.7 Power Consumption -Comparison of Predicted and Experimental Results

Cutting parameter/ condition	Speed (m/min)	dp (mm)	Feed (mm/rev)	Expt.P (KW)	Pred.P (KW)	% Error
Dry Cutting	54	0.35	0.5	0.34578	0.3389	1.984
Flood Cutting	62.28	0.35	0.5	0.36155	0.3519	2.667
Blaso Cut	58.6	0.35	0.5	0.3264	0.3104	4.902
Soyabean Oil	50.8	0.35	0.5	0.25358	0.2395	5.551
Sunflower Oil	52.17	0.35	0.5	0.28641	0.2771	3.25
Coconut Oil	59.98	0.35	0.5	0.34938	0.3294	5.719
Groundnut Oil	55.85	0.35	0.5	0.34208	0.3314	3.122

It can be seen from table 5.2 to 5.7, experimental results are more than predicted results. This is due to the various uncertainties during experimental operation. It is observed that average error are 3.7%, 5.20%, 4.86%, 3.97%, 3.96% and 3.67% for cutting forces, feed forces, radial forces, temperature, surface roughness and power consumption respectively for various machining environments.

It can be concluded that experimental results and optimum values are in good agreement. The error percentage is within the range of 5% so the response equation for the performance parameter evolved through RSM can be used effectively to predict the performance. The optimum conditions that are determined for minimizing the cutting forces, temperature, surface roughness, power consumption are precise and true. Developed models are valid only for the assumed test conditions and within the specified volatility of machining parameters.

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Introduction

Turning of AISI 4130 steel was performed using carbide tipped cutting tool in different working environment like dry, flood and MQL. MQL cutting was performed with five types of cutting fluid; one is a mineral-based oil (Blasocut-4000) and four vegetable oil (sunflower oil, groundnut oil, coconut oil and soyabean oil). For each machining environment, 27 trials are performed.

Multivariate radar charts are used for representing the variation of responses with respect to the different cutting condition is shown in figure 6.1 to 6.6. Points 1 to 27 in the figures shows the observation number of experiments. Points 1 to 9 indicates the speed at 34.27 m/min while points 10 to 18 shows cutting forces at 53 m/min. Points 19 to 27 indicates the speed at 79.27 m/min.

6.2 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 6.1. 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 workpiece, hence cutting forces seems to be higher at dry cutting. For flood cutting, adhesion between tool and workpiece 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.

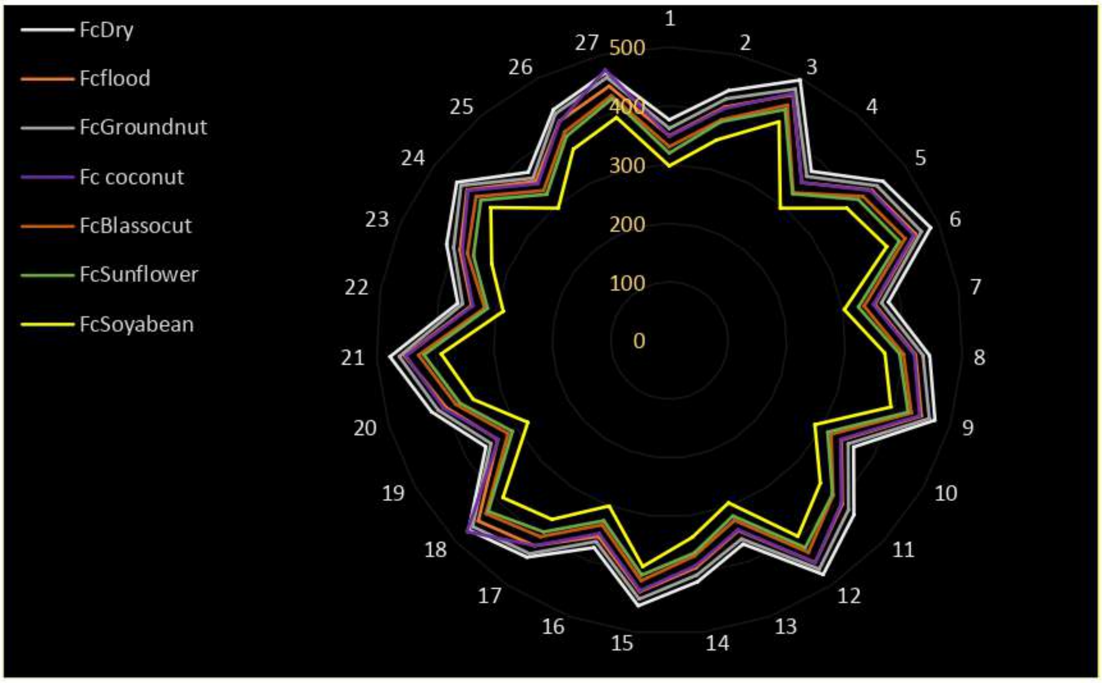

Figure 6.1 Variation of Cutting Force at Different Cutting Conditions

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 [58]. Sunflower oil also shows reduced cutting forces as compared to blasocut.

6.3 Variations of Feed Forces at Different Cutting Conditions

Feed force increases with the increase in feed due to more chip load. Feed forces follow a less increasing trend than the cutting forces. Figure 6.2 shows the increasing pattern for observation 1-3, 4-6 and 7-9, which indicates, that feed forces increases with an increase in depth of cut. As speed increases, the contact surface decreases in the direction of feed. This results in the reduction in coefficient of friction.

MQL shows approximately 5%-6 % and 8%-10% of the reduction in feed forces as compared to dry and flood respectively.

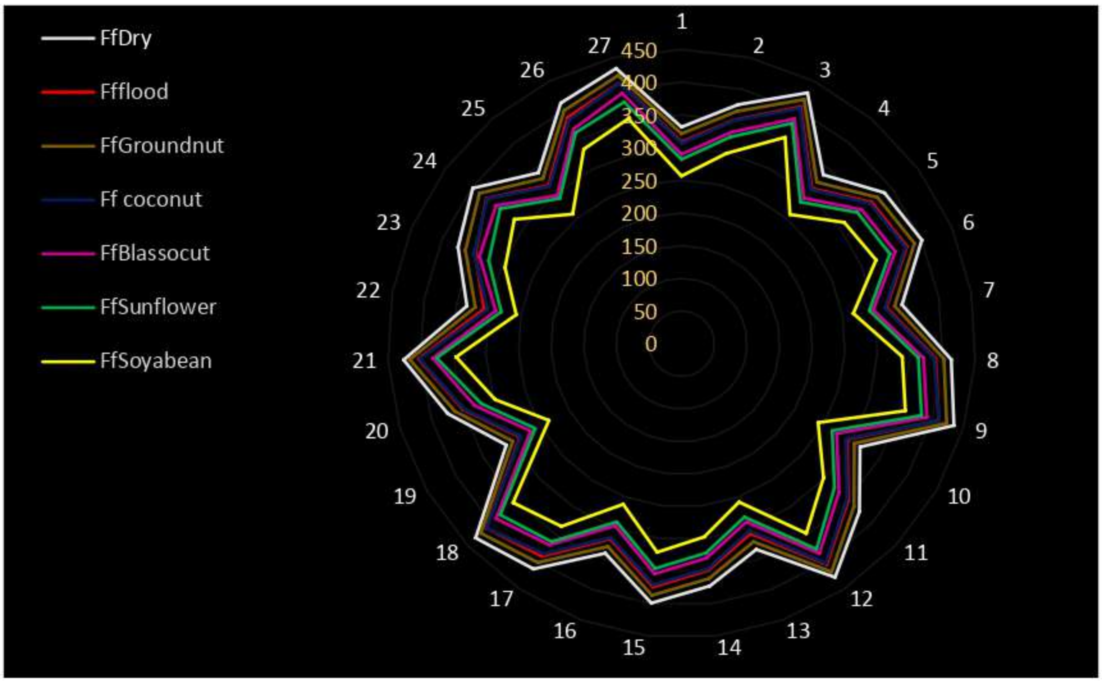

Figure 6.2 Variation of Feed Force at Different Cutting Conditions

Vegetable oils are known to provide excellent lubricity due to their ester functionality. Due to good lubricity properties, friction in machining with soyabean oil is less [118]. There are approximately 6%, 8%, 12%, and 15%, reduction in feed forces as compared to sunflower, coconut oil, blasocut and groundnut respectively. Yellow and green lines in figure 6.2 represent of feed forces for soyabean oil and sunflower oil respectively. Soybean and sunflower have more viscosity index. Higher viscosity index indicates less effect on viscosity at higher temperature, this maintains the constant film thickness [75]. Machining with soyabean oil as cutting fluid shows a substantial reduction in feed forces. The feed forces are more as dry cutting >groundnut oil>flood cutting >coconut oil>blasocut>sunflower oil>soyabean oil.

6.4 Variation of Radial Forces at Different Cutting Conditions

The magnitude of feed force is less as compared to cutting force and feed force. The depth of cut has more impact on the radial force during machining than feed and speed. The white line in figure 6.3 shows the variation of radial force for soyabean oil.

It shows that radial forces are least in case of soyabean oil (110 N to 175 N). For dry cutting, the radial forces are highest (up to 250 N) as indicated by the yellow line. Soyabean oil shows 18% reduction in radial forces as compared to blasocut. The lubricating film provided by vegetable oils is strong, absorbs more pressure resulting in less force in the radial direction.

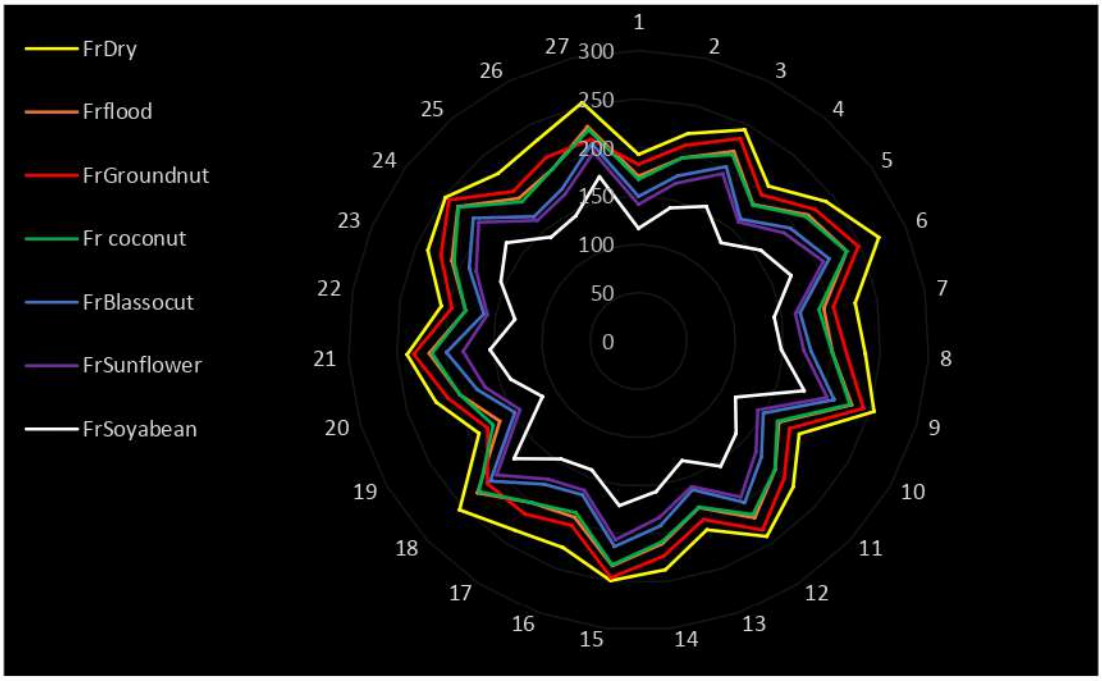

Figure 6.3 Variations of Radial Force at Different Cutting Conditions

6.5 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 6.4. 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. A blue line shows dry cutting. 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 the flood cutting respectively.

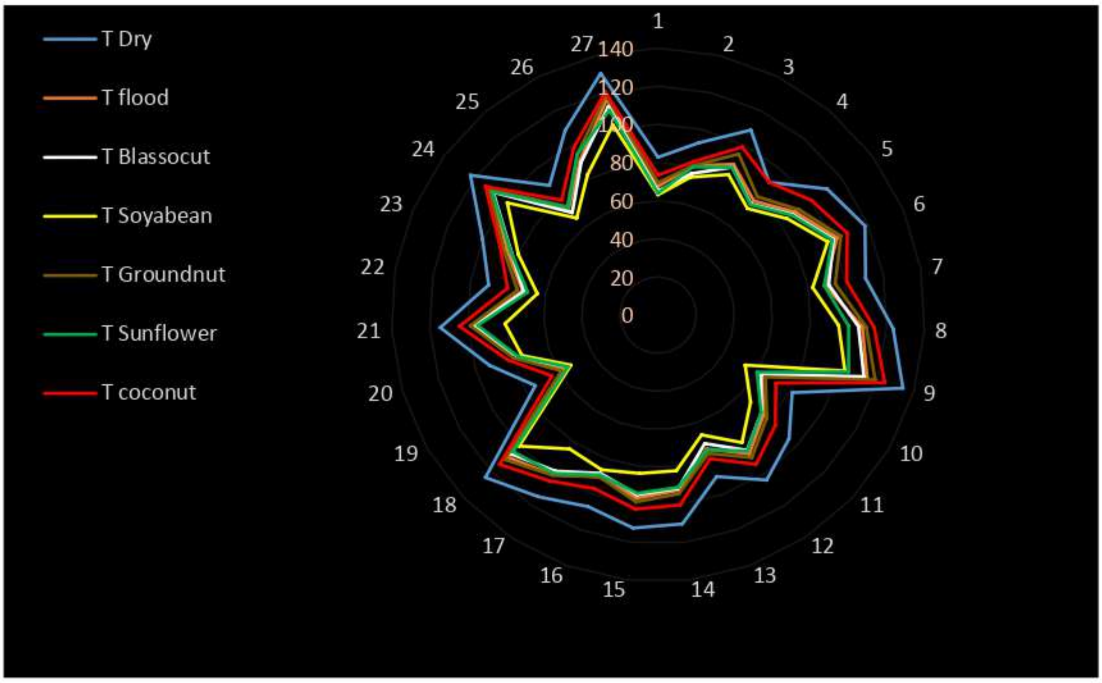

Figure 6.4 Variations of Temperature at Different Cutting Conditions

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^{2}K) higher as compared to sunflower oil (660 W/m^{2}K), groundnut oil (312 W/m^{2}K), coconut (318 W/m^{2}K) [63,112]. 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 6.4, 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 [112]. When the machining temperature increases, the viscosity of vegetable oil drops more slowly than that of mineral oil. 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.

6.6 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. The blue line and orange line in figure 6.5 corresponds to dry cutting and flood cutting. Both the lines are moving radially outward side of the circle. 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.

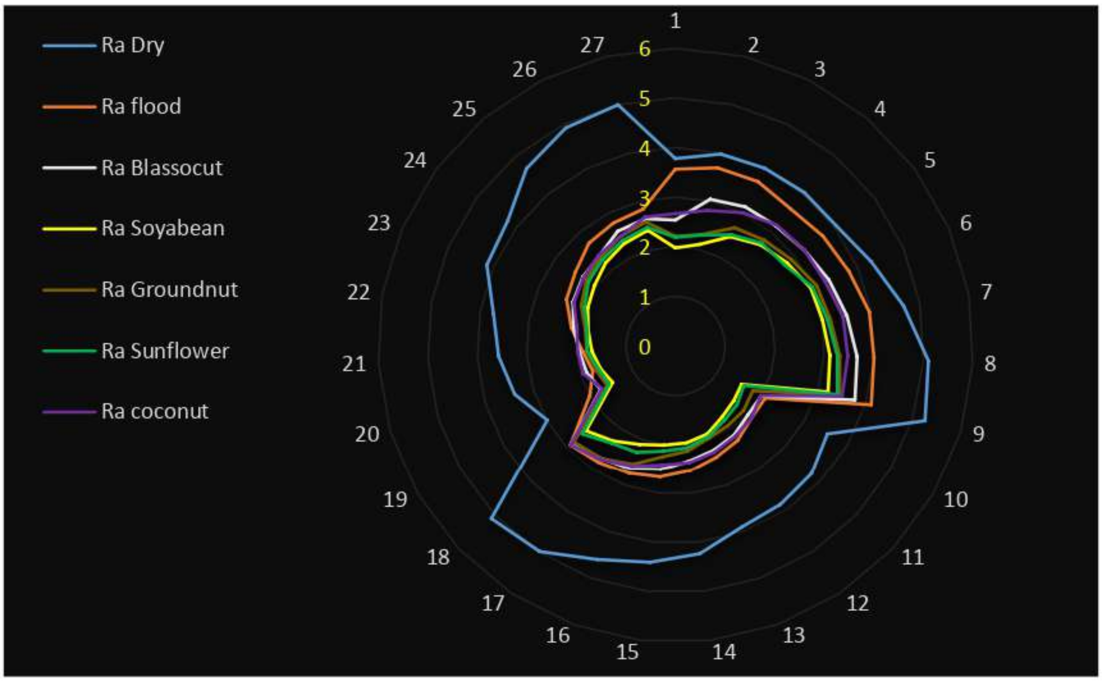

Figure 6.5 Variation of Surface Roughness at Different Cutting Conditions

When vegetable oils are used as a cutting fluid with MQL, the surface roughness is greatly reduced. The yellow and green line in figure 6.5 denotes soyabean oil and sunflower oil.Theses 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 decreases 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.

6.7 Variation of Power Consumption at Different Cutting Conditions

Consumption of power play very important role in any industry, efforts are made to reduce the power consumed during any machining process. Power consumption can be determined as a product of cutting force and speed. Power consumption is proportional speed. As speed, increases power consumption increases. To increase speed, more driving power is required, which results in maximum power consumption. The increase in the feed and depth of cut incurred more power consumption. This is due to the more frictional resistance offered at the contact between tool and work piece increased.

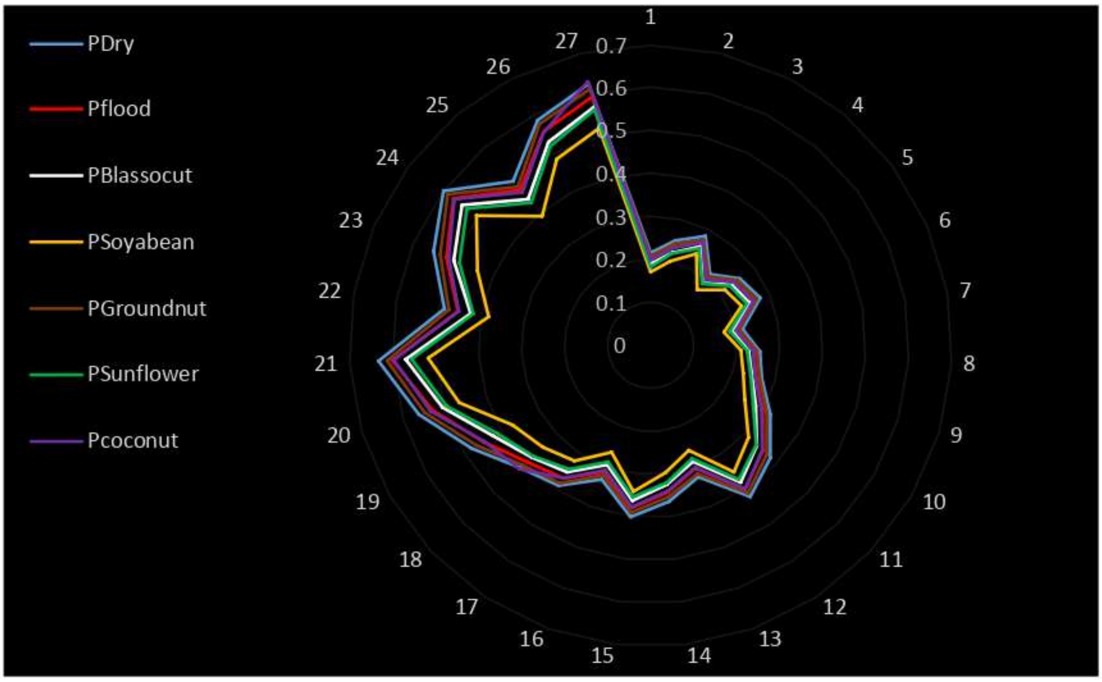

Figure 6.6 Variation of Power Consumption at Different Cutting Conditions

Power consumption is comparatively less at 34.27 m/min and 53 m/min as shown in figure 6.6. There is a sudden increase in power consumption at a speed of 79.27 m/min. At 79.72 m/min, f-0.35 mm/rev and dp -1.5 mm, power consumption is maximum in all cutting environments. The result shows that dry cutting has approximately 5% to 10 % more power consumption, than flood cutting. Using MQL, power consumption is reduced by 10%.

Due to more lubricity, soybean oil offers less resistance for cutting force, hence it shows less power consumption. The blue line and yellow line in figure 6.6 refers to the dry cutting and cutting using soyabean oil. The yellow line is at the innermost part of the circle, which reveals that power consumption is least for soyabean oil. Soyabean oil shows approximately 9% reduction in power consumption as compared to mineral-based blasocut. Sunflower oil also gives similar performance as compared to blasocut.

6.8 Variation of Tool Wear at Different Cutting Conditions

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 three cutting speed (34.2 m/min, 53 m/min and 79.73 m/min) at constant feed (0.45 mm/rev) and constant depth of cut (1.5mm) as shown in figure 6.7, 6.8 and 6.9 respectively. Observations were recorded at 5 minute intervals. Later, tool life was determined, taking a 0.4 mm flank wear as tool life criteria [119].

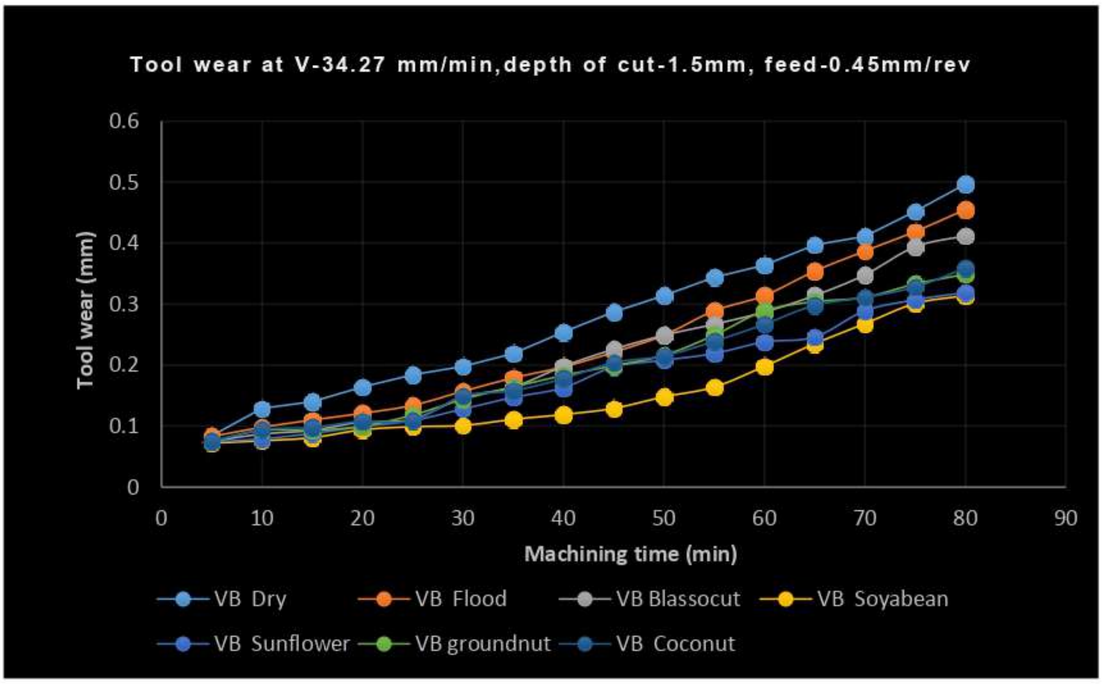

Figure 6.7 Variation of Tool Wear with Machining Time at 34.27m/min

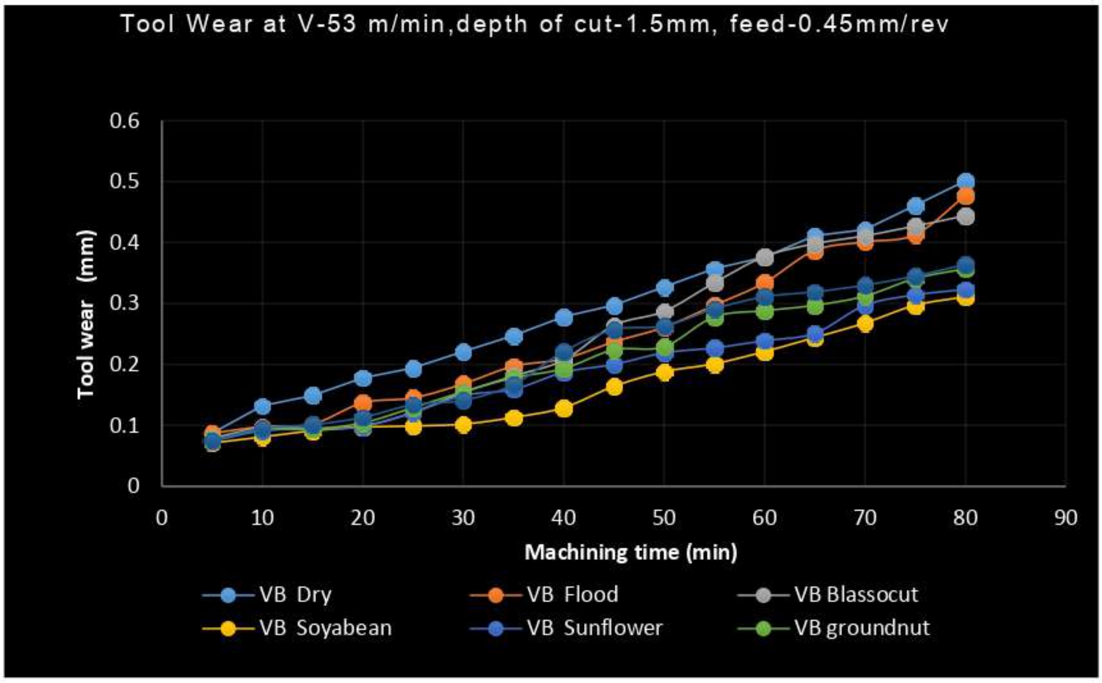

Figure 6.8 Variation of Tool Wear with Machining Time at 53 m/min

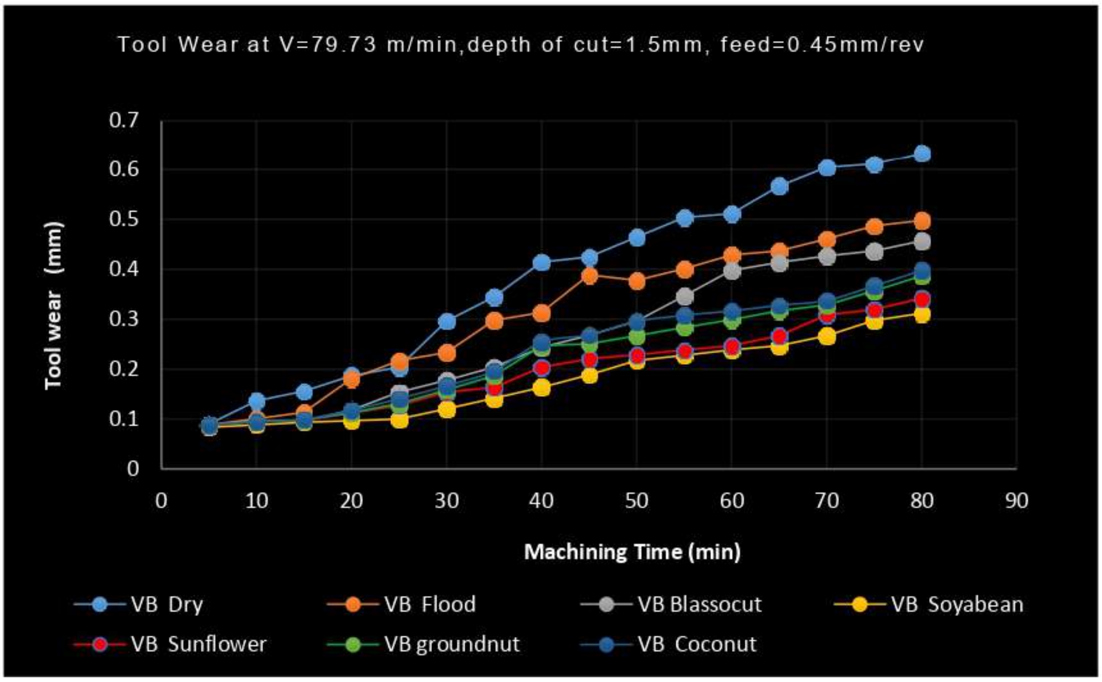

Figure 6.9 Variation of Tool Wear with Machining Time at 79.73 m/min

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. At low cutting speeds, the tool wears by removing the cutting point and then loses sharpness.

Increasing cutting speed, feed and depth of cut increases cutting temperature, which leads to rapid failure of the tool.

From the figure 6.7 to 6.9, it is perceived that wear rate was more rapid at higher cutting speed. 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. Tool wear rate is approximately 16% higher in the case of dry cutting as compared to flood cutting. MQL with blasocut shows 30% decrease in tool wear as compared to dry cutting. 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.

6.9 Variation of Tool Life at Different Cutting Conditions

Tool life for various cutting fluids is shown in figure 6.10. Cutting speed has the greatest impact on tool life. Tool life decreases as speed increases. Tool life is significantly reduced in dry condition as shown in figure 6.10.

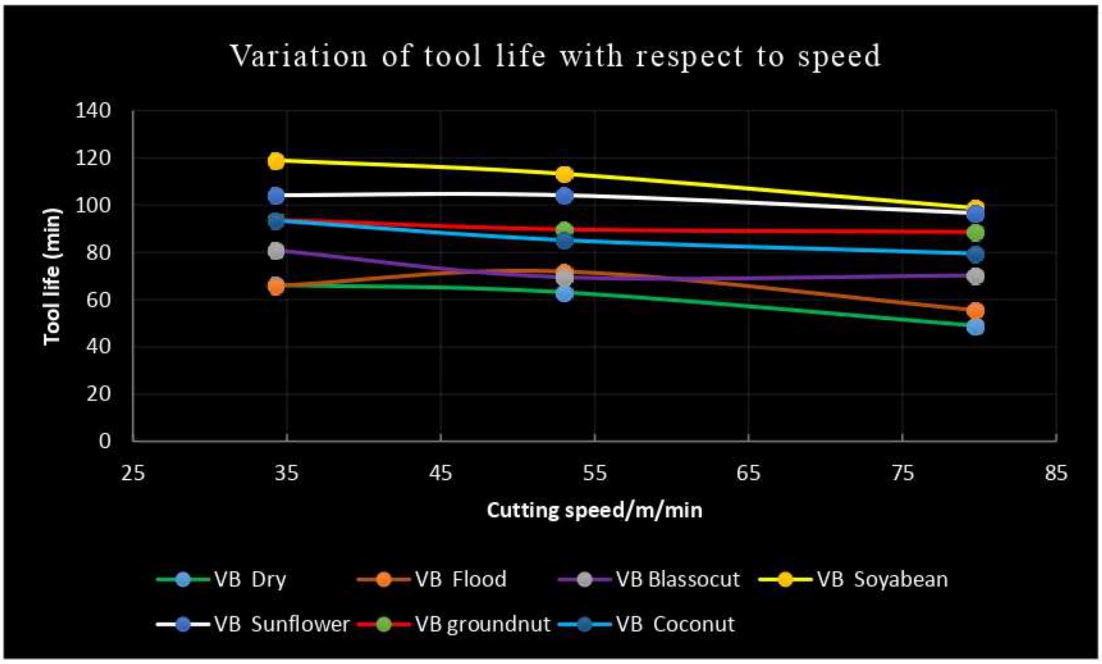

Figure 6.10 Variation of Tool Life at Different Cutting Speed
(f-0.45 mm/rev, dp-1.5 mm)

The mineral-based cutting oil blasocut shows approximately 18% improvement in cutting tool life as compared to dry cutting. Soyabean oil shows 33% increase in tool life as compared to blasocut. The average tool life calculated for dry cutting is at 59 min while for soyabean oil average tool life is 110 min. Machining with soyabean oil and sunflower oil shows less wear and thus has more tool life. Groundnut oil (90 min) as well as coconut oil (87 min) also shows greater tool life as compared to blasocut (73 min) as shown in figure 6.10.

6.10 Influence of the Machining Parameters on Response

3-D surface plots can be used for estimating the performance parameter at any suitable combination of the input parameters namely feed rate, cutting speed and depth of cut. The response surface plots for each response with respect to the machining parameter are drawn, using the developed RSM model by varying the two parameters and keeping the third parameter at the middle level.

From experimentation, it is seen that soyabean oil gives good results as compared to other cutting fluid. This section describes the effect of cutting parameter on response during turning with soyabean oil. The effect of the cutting parameter on performance is represented in the form of surface plot for soyabean oil. Figure 6.11 to 6.16 demonstrates the interaction surface plots with a combination of speed, feed and depth of cut for soyabean oil only. For other cutting fluids, details are given in (D.1–D.6) appendix D.

6.10.1 Effect of Machining Parameters on Cutting Force (Soyabean Oil)

The interaction plots for speed, depth of cut and feed for cutting force for soyabean oil is shown in figure 6.11. It reveals that the depth of cut is the most significant parameter affecting the cutting forces. It has approximately 94% contribution toward cutting force. The cutting force decreases as speed increases when the depth of cut is kept constant at the middle level. Cutting forces increase marginally as feed increases. The interaction plot of speed vs. depth of cut illustrates that speed has no effect on cutting forces while the depth of cut has more impact on cutting forces. The highest value of cutting force for higher depth of cut is up to 450 N. The lowest cutting forces can be obtained at high speed, lower depth of cut and feed.

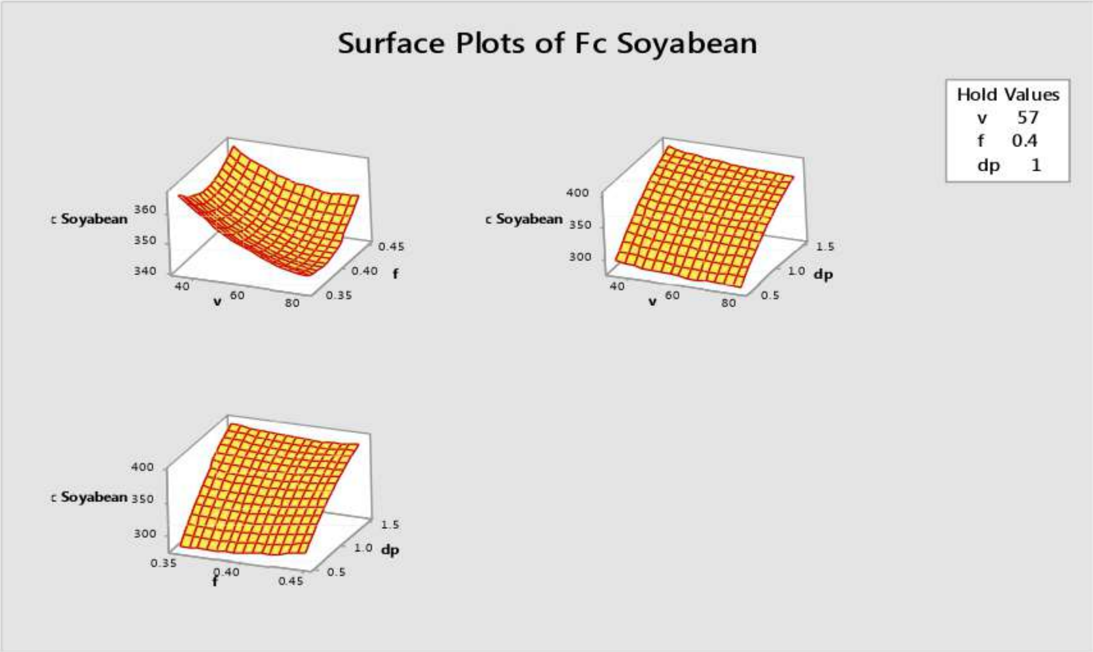

Figure 6.11 Surface Plots of Cutting Force for Soyabean Oil

6.10.2 Effect of Machining Parameters on Feed Force (Soyabean Oil)

The 3-D surface plots for the feed force are shown in figure 6.12. It is clear from figure 6.12 that the feed force decreases marginally with increasing speed. Speed has a minor effect on feed forces. The depth of cut has a significant effect on the feed force. Feed forces are highest at low speed and at a higher feed rate.

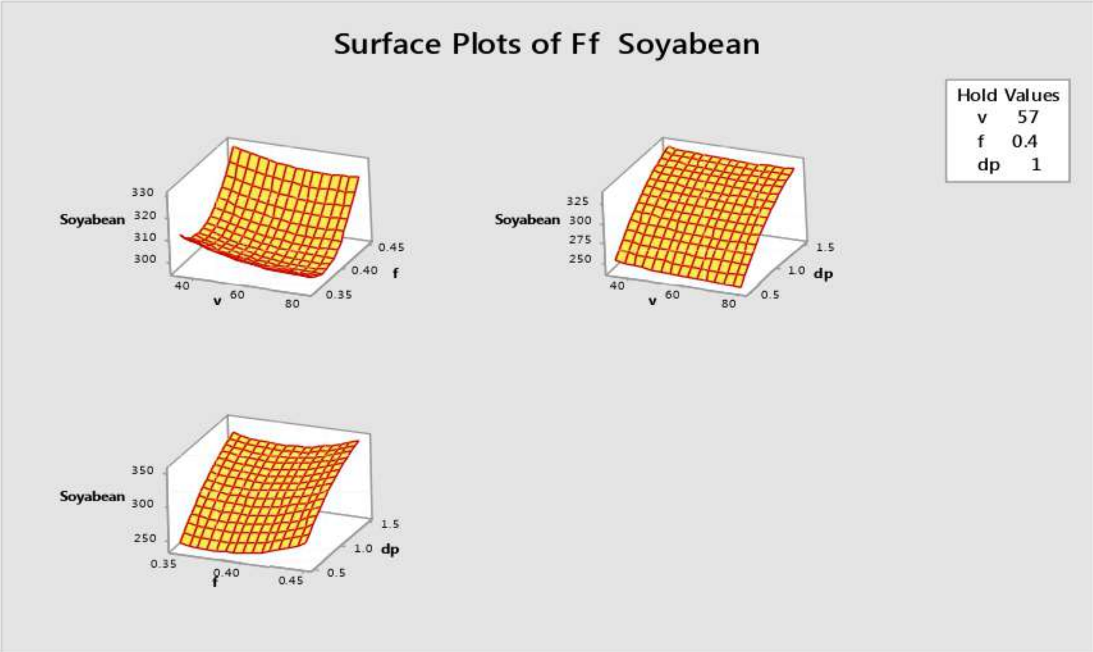

Figure 6.12 Surface Plots of Feed Force for Soyabean Oil

6.10.3 Effect of Machining Parameters on Radial Force (Soyabean Oil)

Surface plot of radial forces for soyabean oil is shown in figure 6.13. It shows that as depth of cut and feed increases the radial force increases. The depth of cut is more sensitive than other parameters.

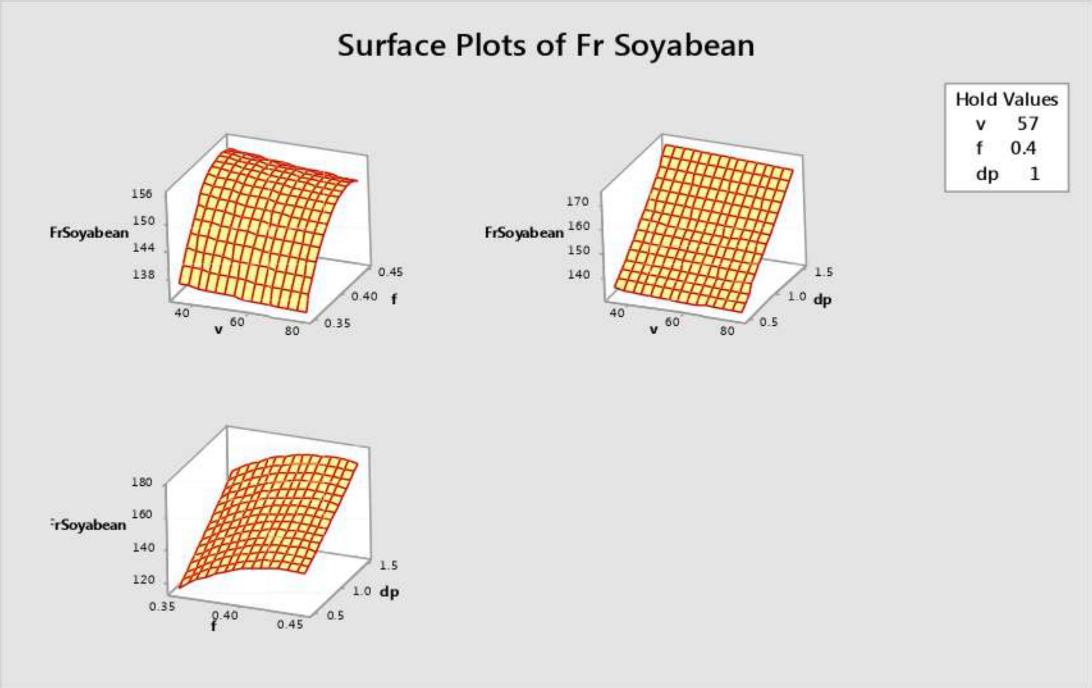

Figure 6.13 Surface Plots of Radial Forces for Soyabean Oil

The radial forces are maximum at higher depth of cut and feed. The approximate value of radial force is 180 N at feed-0.45 mm/rev and depth of cut-1.5. Figure 6.13 shows that speed is insignificant in case of radial force. When depth of cut is kept constant, the large difference in radial, forces is observed after change in feed rate.

6.10.4 Effect of Machining Parameters on Temperature (Soyabean Oil)

The depth of cut and feed are the most substantial factor influencing the temperature of the tool for MQL-soyabean oil. Speed has an insignificant effect on the temperature. The increase in feed increases the temperature. Figure 6.14 shows that with an increase in depth of cut, there is remarkable rise in temperature. Temperature can reach up to 100ºC at a maximum depth of cut (1.5mm) and feed value (0.45 mm/rev).

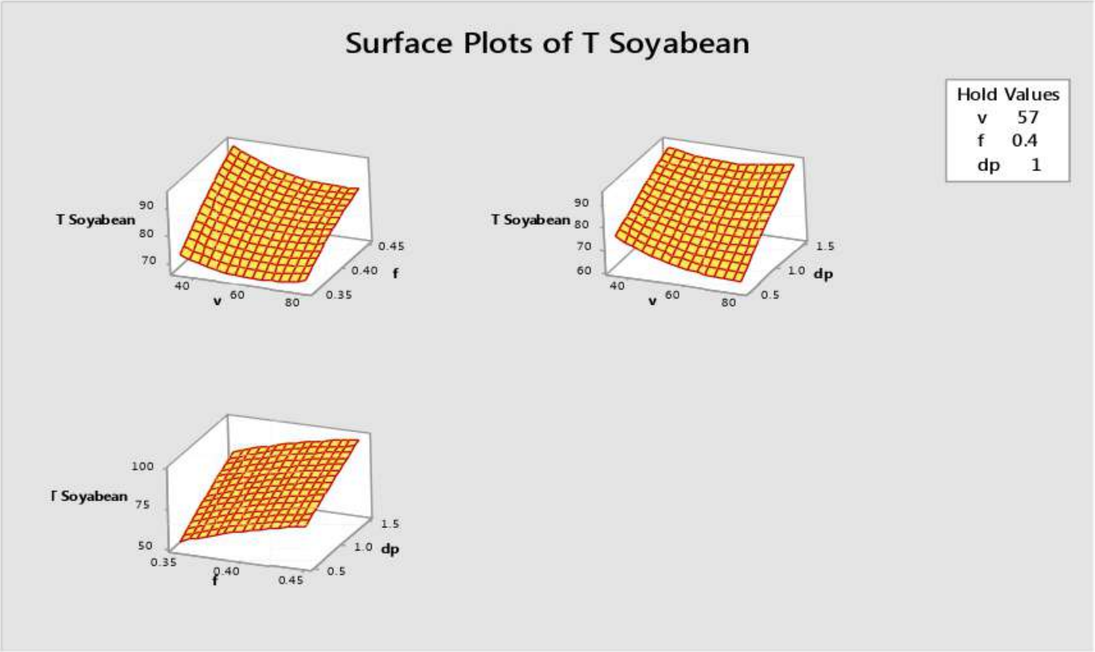

Figure 6.14 Surface Plots of Temperature for Soyabean Oil

6.10.5 Effect of Machining Parameters on Surface Roughness (Soyabean Oil)

Surface roughness is equally affected by cutting speed and feed. The depth of cut has less effect on the surface roughness. The good surface finish can be obtained at lower values of feed and higher value of speed.

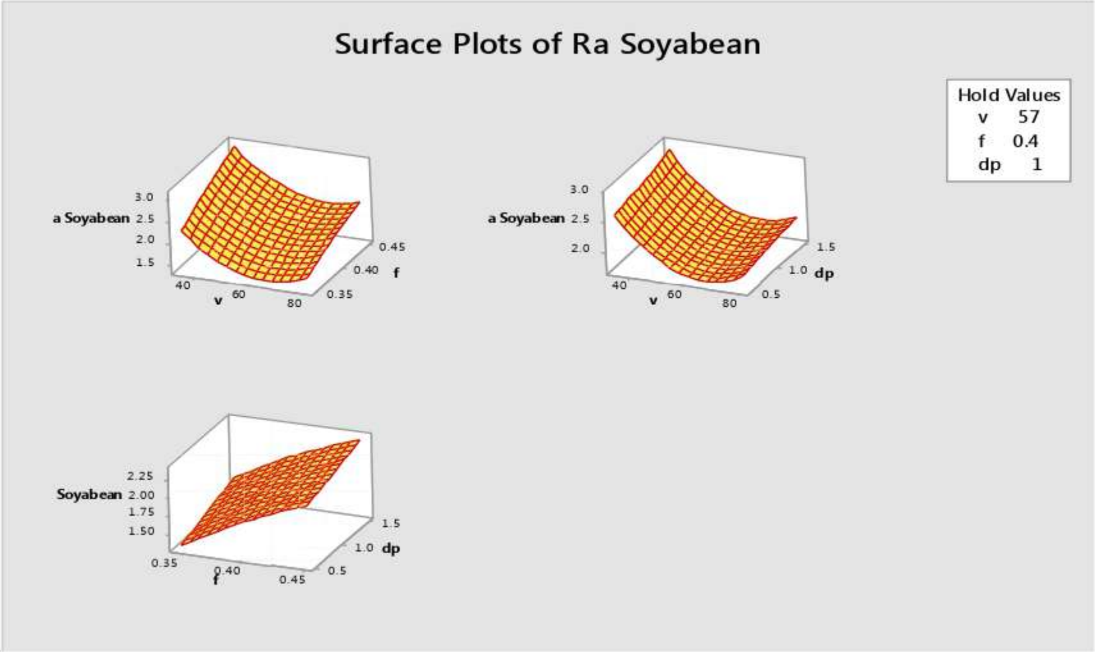

Figure 6.15 Surface Plots of Surface Roughness for Soyabean Oil

Figure 6.15 shows that as speed increases the surface roughness value decreases up to 70 m/min then increases slightly as speed increases. The increase in feed also increases the surface roughness. It also shows that cutting speed is more sensitive than the other parameters. The variation of cutting speed causes more changes in surface roughness. The lowest surface roughness is obtained at a high level of cutting speed and depth of cut and low level of feed rate

6.10.6 Effect of Machining Parameters on Power Consumption (Soyabean Oil)

Speed has approximately 85% contributory influence on power consumption while the depth of cut has only 12% contribution. Figure 6.16 shows that when speed is kept constant, depth of cut is the most significant parameter, which affects the power consumption. Feed has a negligible impact on the power consumption.

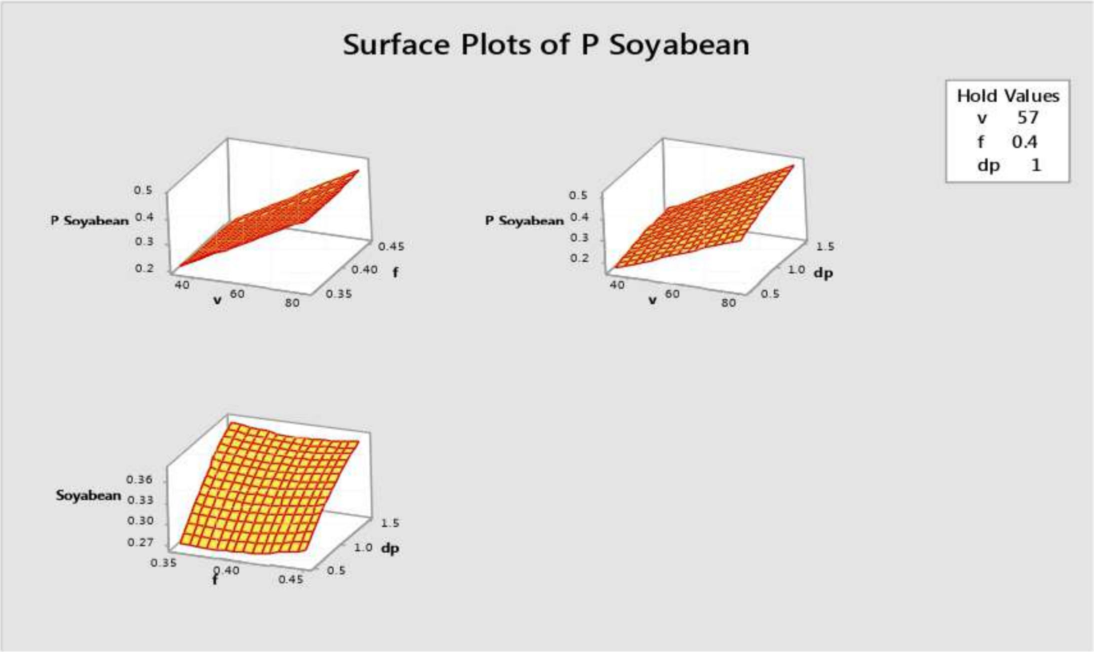

Figure 6.16 Surface Plots of Power Consumption for Soyabean Oil

6.10.7 Effect of Machining Parameters on Tool Wear (Soyabean Oil)

As cutting speed increases, temperature increases that results into decrease in tool life. Cutting speed is the most significant parameter affecting tool life. Similarly, as feed rate is increased, temperature and flank wear increases. However, the effects of feed rate on the tool life are minimum compared to cutting speed. The depth of cut has a negligible effect on tool life.

6.11 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 responses like feed force, radial force, cutting force, temperature, surface roughness and 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.

The coefficient of determination was used to compare the performance of the RSM and ANN models. The R-values for ANN and RSM are represented in table 6.1.

It shows that R-values for both RSM and ANN are close to one, which indicates that both the model are accurate and acceptable.

Table 6.1 R-Value for RSM and ANN

Factor (%)	Cutting Force	Feed Force	Radial Force	Temperature	Surface Roughness	Power	Tool Wear
	N	N	N	°C	µm	KW	mm
R-RSM	97.50	95.16	95.13	93.72	98.14	99.63	99.81
R-ANN	98.53	94.35	95.43	95.50	98.65	99.03	99.87

The percentage error between experimental results and predicted values for response surface methodology, artificial neural network are calculated. Figure 6.17 to 6.23 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.

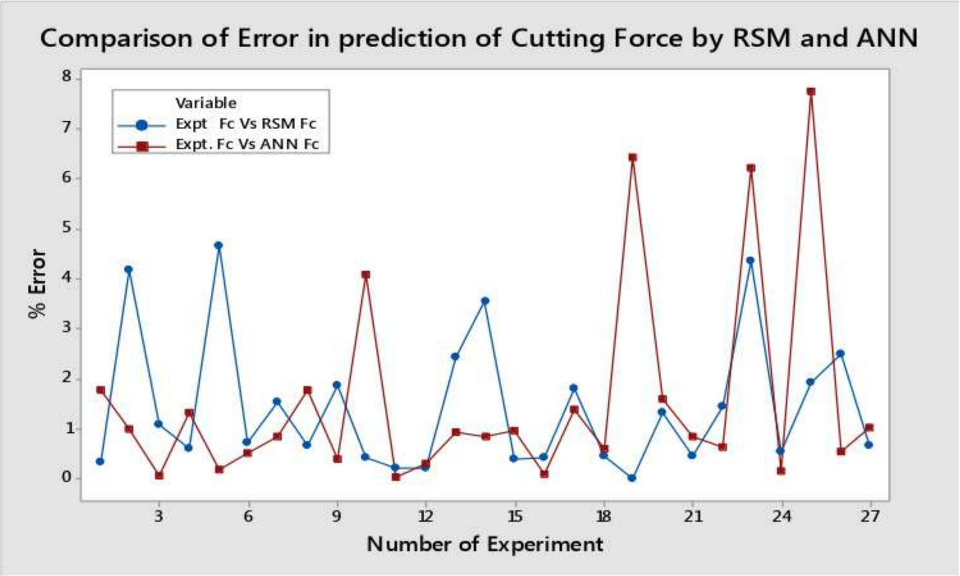

Figure 6.17 Validation of Cutting Force by RSM and ANN

The average error in predicting cutting forces by RSM and ANN is 1.43 % and 1.56% respectively as shown in figure 6.17. This suggests that prediction of cutting forces is equivalent by both the techniques

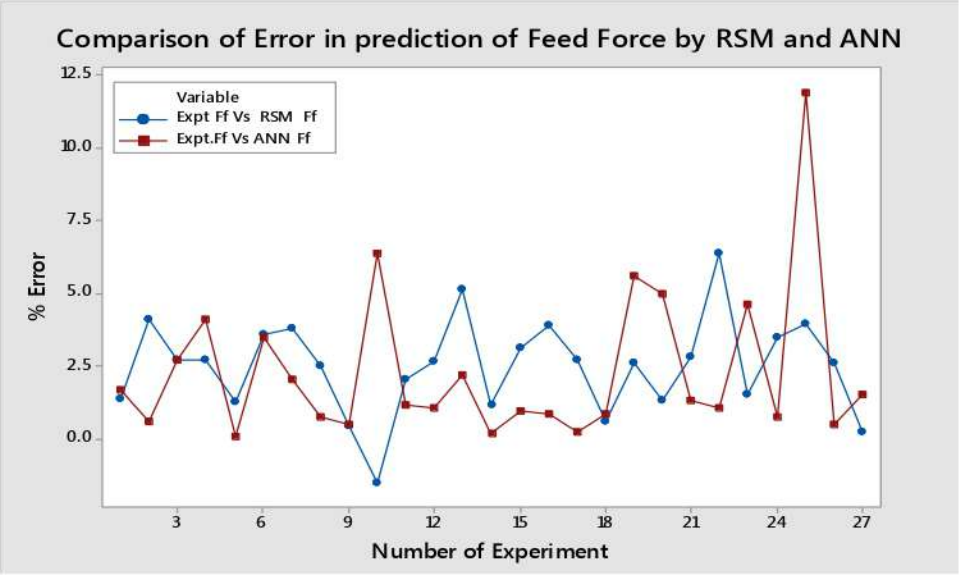

Figure 6.18 Validation of Feed Force by RSM and ANN

The error comparison for feed forces is represented by figure 6.18. It shows that the maximum error in case of ANN is approximately 12.5%, while for RSM maximum error is up to 7.5%. The average error in predicting feed forces for RSM and ANN is 2.47% and 2.28% respectively, which are almost same.

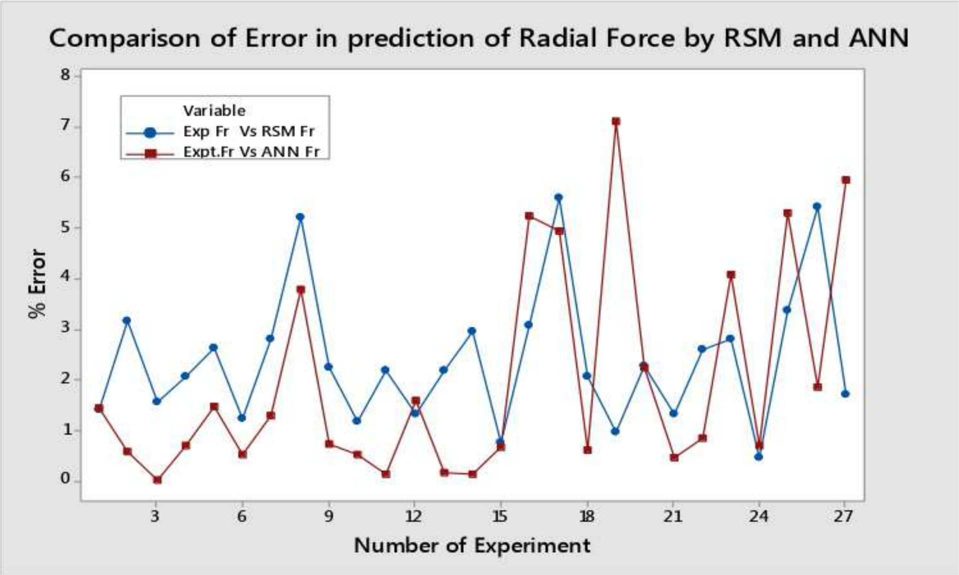

Figure 6.19 Validation of Radial Force by RSM and ANN

Figure 6.19 shows that the average error in predicting radial forces for RSM and ANN is 2.38 % and 1.56 % respectively. This implies that the prediction of radial forces using ANN is more accurate.

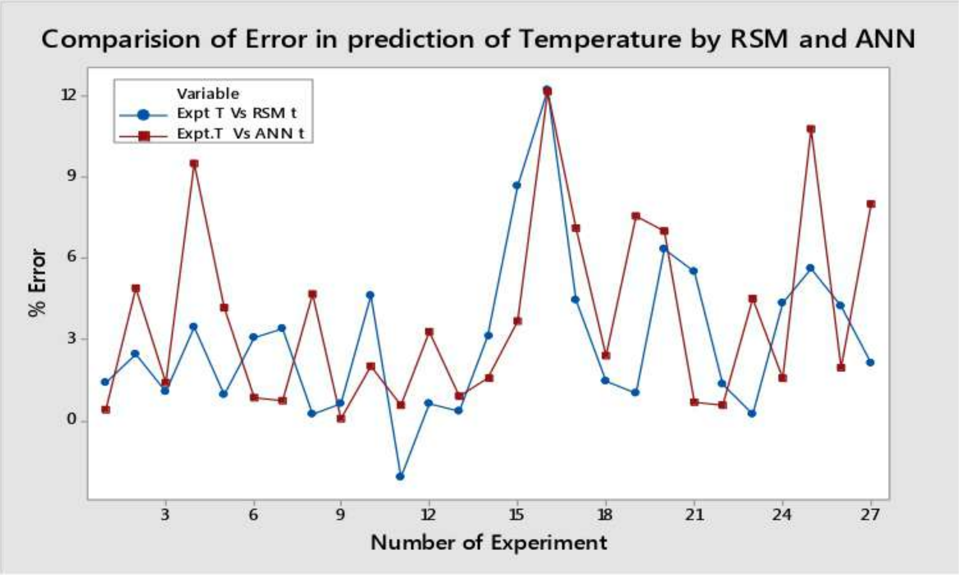

Figure 6.20 Validation of Temperature by RSM and ANN

Both ANN and RSM gave satisfactory and analogues predictions of temperature as shown in figure 6.20. The red and blue lines are in close proximity. This denotes that difference in error is negligible for temperature.

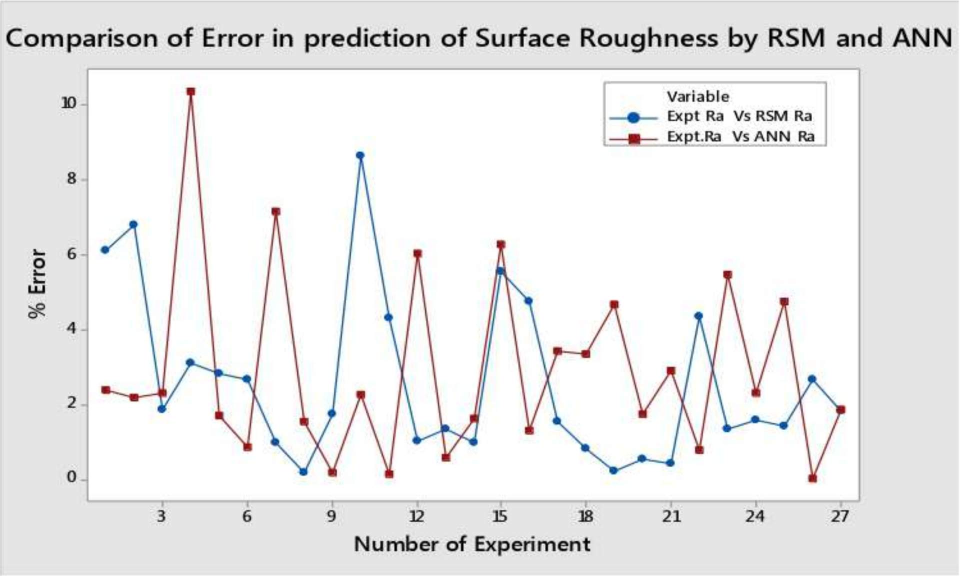

Figure 6.21 Validation of Surface Roughness by RSM and ANN

The error comparison between RSM and ANN for surface roughness is shown in figure 6.21. The average errors in predicting cutting forces by RSM and ANN are 2.58 % and 2.89 % respectively. This proposes that prediction of surface roughness is comparable by both the methods.

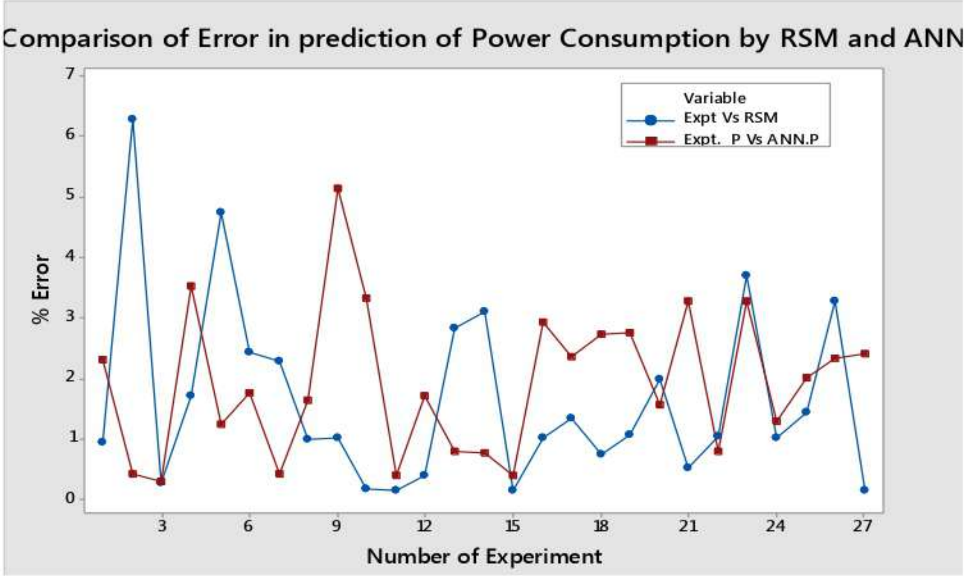

Figure 6.22 Validation of Power Consumption by RSM and ANN

The red and blue lines in figure 6.22 show that the variation between maximum and minimum value of error is not more than 5%. This signifies that ANN and RSM gave an acceptable prediction for power consumption.

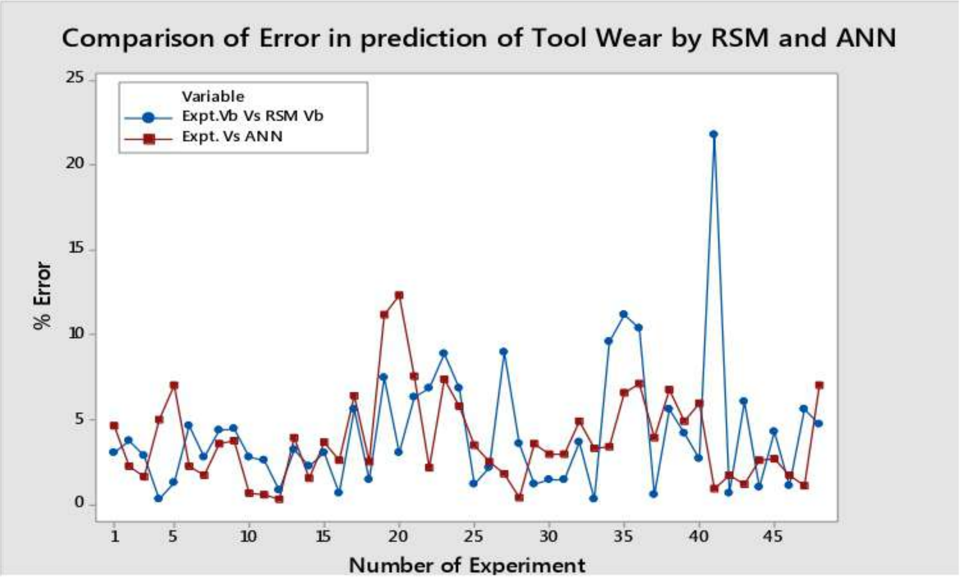

Figure 6.23 Validation of Tool Wear by RSM and ANN

The error comparison between RSM and ANN for temperature is shown in figure 6.23. 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 2.47%, 2.384%, 1.43%, 3.03%, 2.58%, 1.66% and 4.23% for feed force, radial force, cutting force, temperature, surface roughness, power consumption and tool wear respectively. The average percentage error between experimental results and predicted values by ANN model is 2.28%, 1.95%,1.56,%, 3.82%, 2.8 %, 1.9 % and 3.66 % for feed force, radial force, cutting force, temperature, surface roughness, power consumption and tool wear respectively.

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 are 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%).

CHAPTER 7

CONCLUSIONS

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. Response surface methodology and artificial neural network are 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 reduced tool wear, lower cutting temperature and surface roughness. The cutting forces and power consumption during MQL is considerably reduced. MQL also saves the large quantity of the cutting fluid.
- MQL using vegetable oil as cutting fluid shows notable enhancement in the overall performance during turning as compared to blasocut.
- Soyabean oil recorded the lowest cutting forces by 9 % compared to blasocut.
- The result shows that the feed forces for sunflower oil, groundnut oil, blasocut and coconut oil are 6%, 8%, 12%, and 15% more than that of soyabean oil respectively.
- It is also observed that soyabean oil produces 8%, 10%, 14% and 18% of less radial forces as compared to sunflower oil, blasocut, coconut oil and groundnut oils respectively.
- 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.

- Power consumed during machining is very less when soyabean oil is used as a cutting fluid. Soyabean oil consumes 7%, 9%, 13% and 19% of less power as compared to sunflower oil, blasocut, coconut oil and groundnut oil respectively.

- 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 respectively.

- Soyabean oil shows an average 7%, 17%, 21% and 33% of improvement in tool life as compared to sunflower, groundnut oil, coconut oil and blasocut oil respectively.

- A mathematical model was developed using response surface methodology to predict the cutting forces, temperature, tool wear and surface roughness during turning for the different cutting environment. ANOVA test 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.

- The RSM based desirability approach was used to optimize the multi-responses in machining. Obtained optimum value of the depth of cut is 0.5 mm, the feed rate is 0.35 mm /rev, speed value is in between 50-60 m/min, which gives minimum cutting forces, lower temperature, less power consumption, and minimum surface roughness. Desirability analysis indicates that the optimization process is feasible.

- The effect of various cutting parameters (cutting velocity, feed and depth of cut) on cutting performance are investigated during turning of hardened AISI 4130 steel. Overall observation shows that the depth of cut for all cutting environments influences the cutting forces. The depth of cut and feed mostly affects temperature. Cutting speed is also the most significant influencing factor in case of power consumption, in all machining environments.

- The cooling as well as lubricating properties of vegetable oil offers a competitive performance in comparison with conventional mineral-based oil. The most outstanding performance was observed in the case of soybean oil, among the other vegetable oils. Higher molecular weight of the soyabean oil results in very less evaporation loss of the sample. Soybean oil contains the highest number of unsaturated fatty acid esters compared to other vegetable oils so soyabean oil correlates for better lubrication properties, which results in improved performance.
- 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.
- In most of the industries, mineral-based cutting fluid exposure is more for various operations. These cutting fluids are very harmful to operator health. The developed MQL system is more economical, even small domestic units can afford it. The required quantity of cutting fluid is very less in MQL so saving in cutting fluid in each operation is possible. Ultimately, it reduces the cost. Using vegetable oil as cutting fluid, problems related to operator health are reduced. The combined MQL and vegetable oil system proves to be more economical, harmless and environment friendly without affecting the performance.

Future Scope

- The concepts developed in this study is limited to small-scale industry and domestic unit. The machine, cutting tools and material were selected considering the need of small industry. New material and advanced tool, computerized machining center can be used for further study.
- Non-edible vegetable oil is the great source of bio lubricant. The performance of non-edible oil can be verified in terms of various machining parameters.

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