INVESTIGATION OF ENERGY CONSUMPTION AND SURFACE ROUGHNESS IN ORTHOGONAL TURNING OF AISI-304 ALLOY STEEL USING FORMULATED VEGETABLE OIL-BASED CUTTING FLUID

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ABSTRACT

This research focuses on investigation of energy consumption in orthogonal turning of AISI 304 alloy steel, with a view of coming up with optimized parameters to accomplish minimum energy consumption and surface roughness in dry and wet cutting environments using mineral oil and vegetable oil based cutting fluids. The procedure involved sourcing of mineral and Jathropha vegetable oil. The vegetable oil was subjected to GC-MS test to ascertain the fatty acid composition profile followed by formulation of emulsion cutting fluids from both mineral oil and the vegetable oil. The formulated mineral oil and Jathropha vegetable oil cutting fluids were then characterised and mineral oil-based cutting fluid was found to have a viscosity of 1.00mm^2/s and pH value of 8.65. Both cutting fluids are corrosion resistant, milky in colour and of acceptable stability. Orthogonal turning experiments were then carried out based on design of experiment (DOE) using Response Surface Methodology (RSM) via minitab 17 statistical software. The input parameters for the experiments were cutting speed, feed rate and depth of cut while the measured responses were specific energy consumption and surface roughness. The results obtained from the orthogonal turning experiments were subjected to both Analysis of variance (ANOVA) and signal to noise (S/N) ratio analysis using minitab 17 statistical software. In dry turning, the ANOVA analysis revealed that depth of cut is most significant to both energy consumption (83.11%) and surface roughness (37.69%). In wet turning with mineral oil based cutting fluid, the ANOVA analysis showed that cutting speed is most significant to energy consumption (38.87%) while depth of cut is most significant to surface roughness (40.80%). In wet turning with vegetable oil based cutting fluid, the ANOVA analysis showed that feed rate is most significant to both energy consumption (52.44%) and surface roughness (92.77%). Multi response optimization via grey relational analysis (GRA) was also carried out and the result obtained was also subjected to ANOVA analysis. The ANOVA analysis of energy consumption and surface roughness in dry turning showed that depth of cut has the highest significant effect (43.89%) on both responses combined. In wet turning with mineral oil based cutting fluid, the most significant factor for the combined responses is depth of cut. (55.12%). In wet turning with vegetable oil based cutting fluid, the most significant factor was depth of cut (66.31%).

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ACRONYMS

AISI	American Iron and Steel Institution
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
CNC	Computer Numerical Control
TPED	Total Primary Energy Demand
WEO	World Economic Outlook
MTEC	Machine Tool Energy Consumption
GRA	Grey Relational Analysis
EFM	Environmentally Friendly Manufacturing
EEM	Energy Efficient Machining
IEA	International Energy Agency
PKO	Palm Kernel Oil
CSO	Cotton Seed Oil
MRR	Material Removal Rate
MQL	Minimum Quantity Lubrication
CAPP	Computer Aided Process Planning
MMC	Metal Matrix Composite
PCD	Polycrystalline Diamond
CBN	Cubic Boron Nitride
FEM	Finite Element Method
RSM	Response Surface Methodology
RA	Regression Analysis
ANN	Artificial Neutral Network
DOE	Design of Experiment
EDM	Electrodischarge Machining
GRC	Grey Relational Coefficient
GRG	Grey Relational Grade
OES	Optical Emission Spectrometer
WHO	World Health Organisation
FFA	Free Fatty Acid
FAC	Free Fatty Acid
GC-MS	Gas Chromatograph and Mass Spectrometer
PUFA	Polyunsaturated Fatty Acid.

I	Current
V	Voltage
P_A	Apparent Power
P_T	True Power
E_s	Specific Energy Consumption
V_c	Cutting speed
F_r	Feed rate
d	Depth of Cut
N	Spindle speed
NIST	Nigerian Institution of Science and Technology
DOF	Degree of Freedom
SS	Sum of Square of responses
MS	Mean Square (variance) of responses
F	Variance ratio
P	Contribution factor
y_i	The measured quality characteristics for ith repetition in an experiment.
Ra	Surface roughness.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Energy consumption of manufacturing processes need to be reduced. This becomes very paramount in view of the rising concern arising from reduction of fossil fuels and the accompanying global warming with some sources for generation of electricity (Composco-Negrete and Calderon-Najera, 2018). Manufacturing sector is the one involved in the transformation of raw input to desired outputs to satisfy the needs of the society using enormous energy. Machining being one of the existing manufacturing methods is a technique involving removal of workpiece's surface layers in form of chips. Machining process is usually necessary where light tolerances on dimension and fine surface finish is required.

Turning is a machining operation which primarily involves rotation of the workpiece against a moving single-point cutting tool to facilitate cutting. Lathes are the primary machine tools used in turning. Orthogonal is a two-dimensional cutting process where the tool's cutting-edge inclination is zero. The tool's movement is at right angle to the it's cutting edge and it involves only two components of force.

Recently, rising cost for energy heavily burdens large number of industries especially manufacturing sector the world over. Hence, visualising from both economic and environmental points of view, there is urgent need for improvement and imbibing energy efficient – manufacturing. Machine tools which includes lathes, milling and shaping machines are extensively used in production and industrial sectors are very prominent for consumption of energy. Reduction of energy in industry is very paramount towards achieving environmentally friendly manufacturing. The intensity of energy consumption in industrial and production sector has resulted in increased focus consequent upon its inauspicious effect on the environmental and depletion of natural resources. Globally, 36% emission of carbon dioxide and 30% of the total energy consumed worldwide are due to the activities of manufacturing industries (Yansong *et al*., 2012). In view of the rising cost of electricity and increasing environmental awareness, it becomes imperative for the energy requirement profile of advanced parts production machines such as computer numerical control (CNC) machines to be better understood (Balogun and Mativenga, 2013).

1.1.1 Trends of human energy consumption

The energy consumed globally are obtained from various primary sources which include renewable such as mineral fuels and fossil fuels. Non-renewable energy sources like biomass and hydroelectric have also been very useful. Presented in Figure 1.1 is cumulative preliminary energy request (CPER) between 1820 and 2010.

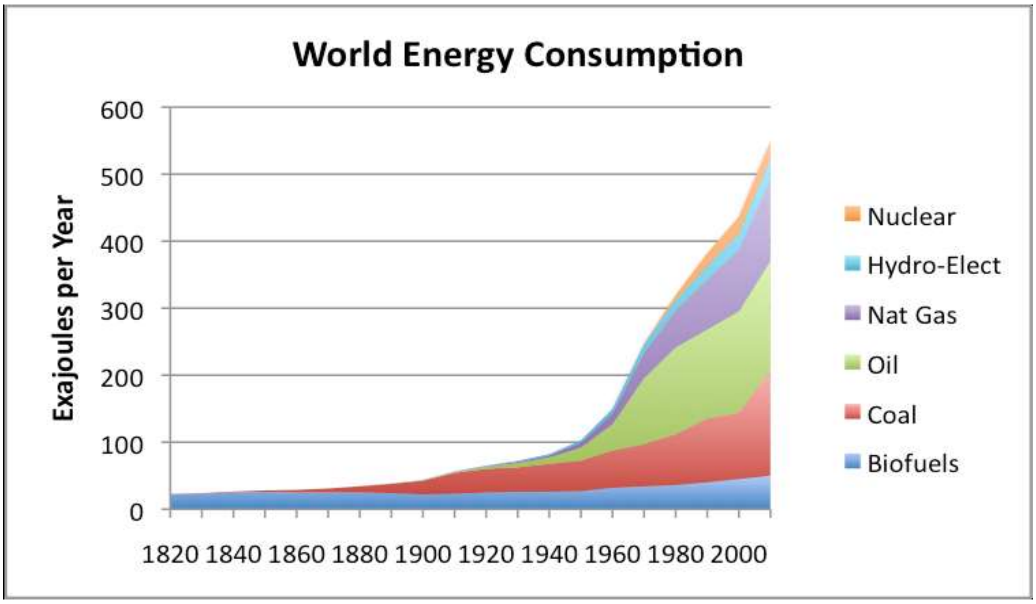


Figure 1.1: Components of global energy demand (CPER) between 1820 and 2010 (Source: Reza, 2013)

Figure 1.2 shows the percentage energy composition of each primary energy sources in total primary energy demand for 2010 AD

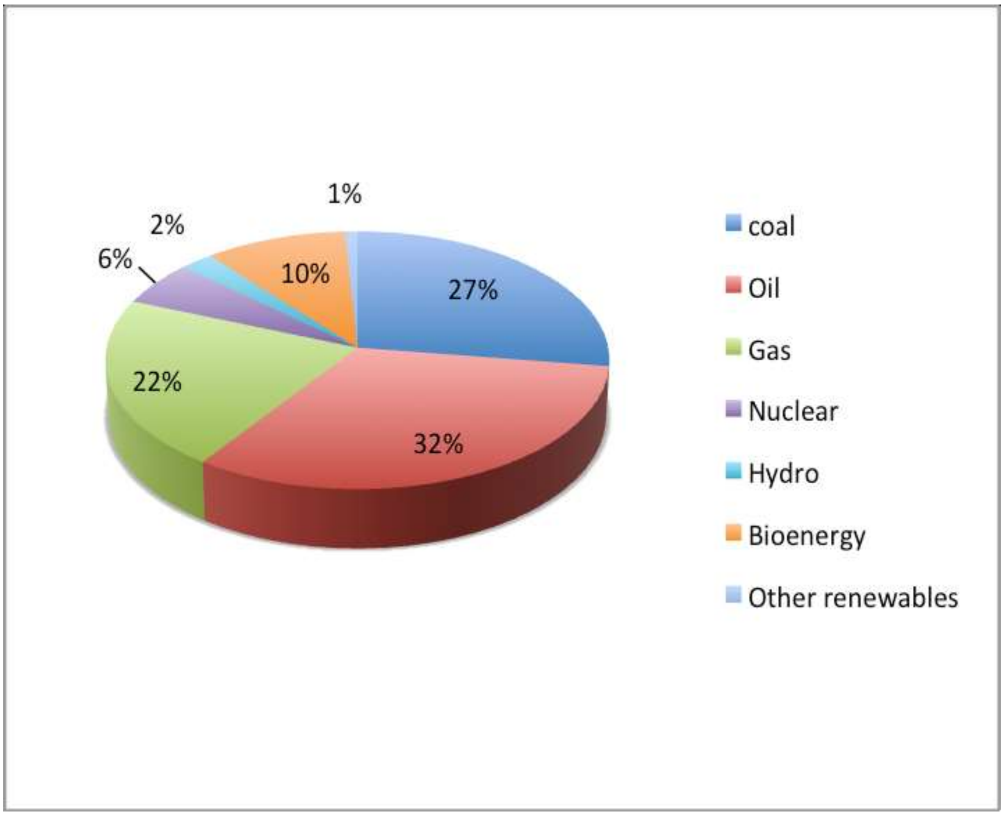


Figure 1.2: Percentage composition of each energy source in total primary energy demand, TPED for the year 2010 (Source: Asrai 2013)

1.1.2 Consequences of human energy consumption

One of the effects of energy consumption on the atmosphere is the increase of carbondioxide. In recent years, the increase in green house gases such carbon dioxide in the atmosphere has caused global temperature rise. Before the industrial revolution, the concentration of CO_2 in the atmosphere was 280ppm, and has been gradually but steadily increasing since then (Chiba *et al.*, 2019).

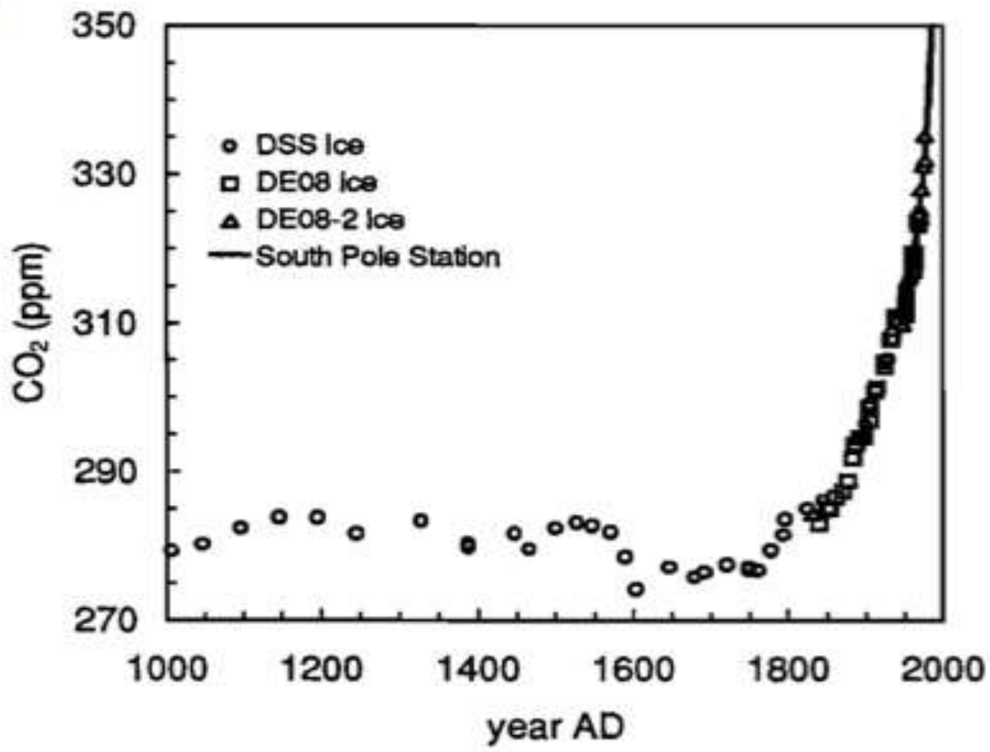


Figure 1.3: Concentration level of CO_2 in atmosphere between 1000AD to 2000AD (Source: Etheridge *et al*., 1996)

The principal factor in the determining the mean temperature of the atmosphere is the greenhouse consequence of CO_2. Average temperature of the earth's surface varies directly to the atmospheric concentration of CO_2 and the pronouncement of the greenhouse effect. The relationship between the temperature of the Antarctic and the atmospheric concentration of CO_2 in the last 350,000 years is presented in Figure 1.4.

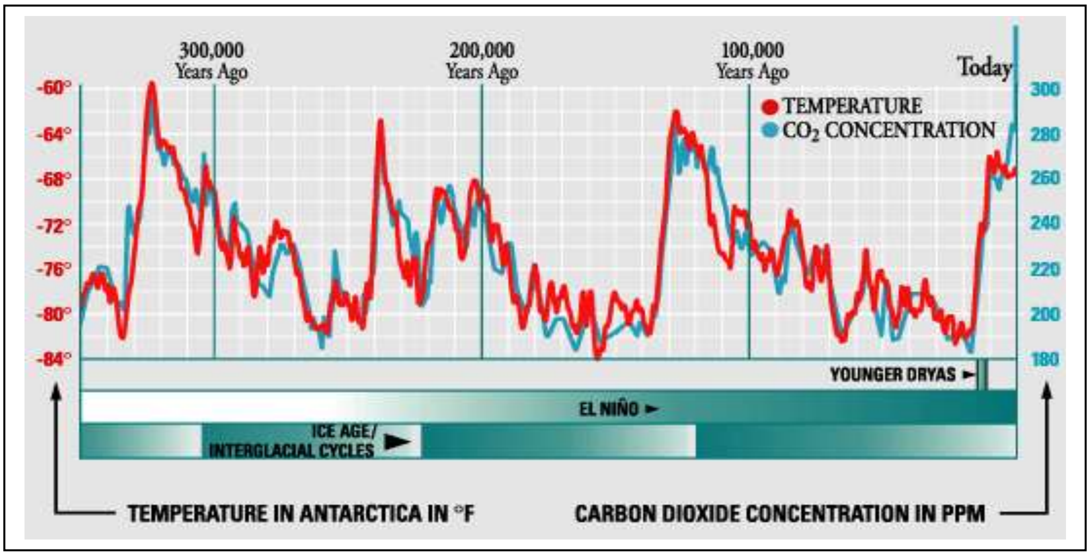


Figure 1.4: Link among the Antarctic temperature and CO_2 concentration in the atmosphere (Source: Reza, 2013)

Directly or indirectly, energy consumption by human beings is the agent cause of problems arising from pollution. Health problems relating to pollution of air in large cities are due to burning of fuels in heat engines of motor vehicles and electric power generating plants. Electricity consumed somewhere lives the power generating plant area with some pollution. Nuclear power plant waste and some other problems arising from pollution are caused by the need to generate electricity for domestic and industrial consumption. Permanent damage could result from this, and could persist for generations.

1.1.3 Reduction of energy consumption

Energy consumption of human beings in the future is a matter of serious concern, visualizing from both environmental and economic perspectives. If the future of human energy consumption is effectively managed, environmental disasters and economic catastrophes can be avoided. Energy is consumed by human beings through devices or power- operated systems to execute energy-consuming jobs such as combustion of fuel in a vehicle engine to move from one place to another, electricity is consumed in a fridge to preserve and keep foods and drinks cool, consuming electricity in a lathe to turn a cylindrical workpiece from the initial dimension to the designed finished dimension of the needed component and other similar instruments. The sum of energy consumed by these and similar instruments accounts for energy consumed globally. In order to cut-down the energy consumed world over, the energy consumption in performing the tasks mentioned and other similar ones, either domestically or industrially must be reduced.

1.1.4 Machine tool energy consumption

In CNC machining techniques, the energy consumed by the machine (ECM) comprises of energy used in driving the spindle in order to machine the component from the initial to the final dimensions, energy consumed in axis feed, energy consumed by coolant pump, energy consumed by tool change system and other components that consumed a fixed amount of energy.

$$E_T = E_S + E_f + E_t + E_C + E_{fx} \qquad 1.1$$

Where E_T = total energy consumed (J); E_S = energy consumed running the spindle (J); E_f = energy consumed in axis feed (J); E_t= energy consumed in changing tool (J); Ec= energy consumed by coolant pump (J); Efx = energy consumed by other components (J). To cut-down the sum of the energy consumed E_T, energy consumed by various components shown in equation 1.1 must be reduced. This reduction can be accomplished by optimal choice of the machining environment and machining variables. A carefully researched energy consumption model can be very useful in this situation.

1.2 Statement of the Research Problem

Despite the fact that several investigations have been carried out on orthogonal cutting, energy consumption profile of orthogonal cutting of the selected material-AISI 304 has not been researched into, based on the available literature. This research work investigates the energy consumption profile in orthogonal cutting of AISI 304 alloy steel to fill the research gap indicated. Reduction of energy consumption in turning will reduce production cost and also enhance green production. Optimal selection of cutting environment, cutting variables – cutting depth, speed of cutting, and rate of feed, which will ultimately cut-down the energy consumed to the least possible, and also accomplish precise surface texture of the turned workpiece is paramount. This will ultimately enhance the turning efficiency, manufacturing economy and environmentally friendly manufacturing (EFM).

1.3 Significance of the Study

The objective of any business organization is to minimise cost and maximise profit. In Orthogonal turning, the use of lathe for turning of cylindrical components involves huge energy consumption which increases manufacturing cost and decreases profitability. When the maximum output of available factory capacity is required, metal removal rate is important, and cost factors are more common conditions, and production costs must be kept as low as possible. In most manufacturing situations, this is a balancing act between maximizing output and minimizing production costs (Abu, 2010). The metalworking process is primarily an economic activity. During the roughening operation, the goal is to remove a sufficient amount of metal in the shortest time or at the lowest cost; in the finishing operation, the standard is to produce an acceptable surface finish. The economics of metal removal or machining and the creation of a good surface can be based on time or cost (Gokaya *et al.,* 2006; Abdullah *et al.,* 2008)

The demand for huge energy is accomplished with emission of carbon dioxide, CO_2 into the atmosphere and enhances the unwanted global climate change. Shailesh *et al.*, (2015), revealed that the need to estimate and understand the energy consumption profile in machining processes are very vital as it is the cause for a large amount of environmental onus in manufacturing industries. According to Taha *et al.*, (2010), every cutting variable has effect on power consumed in machining process. To accomplish minimum power consumption, combinations of cutting variables need to be optimized. Guo *et al.*, (2012), reported that a method which comprises two responses is proposed for optimisation of machining variables in finish turning. Consequent upon newly generated models for energy consumption and surface roughness, minimum energy consumption and precise surface finish are accomplishable. This research shall seek to accomplish minimum energy consumption in orthogonal turning of AISI 304 alloy steel by proposing a regression equation which takes cognizance of all input independent cutting variables which include, rate of feed, cutting depth and speed of cutting as well as output dependent parameters which include energy consumption and surface roughness at different machining environment.

Some of the major properties which popularise the use of AISI 304 is its high resistance to corrosive environments, sulphates and other salts. It resists corrosion even in acidic environment such as nitric acid. It's excellent corrosion resistance property also extends to alkaline, organic and inorganic salts environments. Generally, this material is highly resistance to corrosion in atmosphere and even in high salt spray like marine environment. The material is used in the production of component parts of pumps, valves, marine fittings, fasteners, papers and pulp machineries' component parts as well as petrochemical equipment. Production of these components involves substantial orthogonal turning. The model proposed in this research work shall seek to minimize energy consumption, reduce manufacturing cost, and increase profit.

1.4 Aim and Objectives of the Study

This study is aimed at investigating energy consumption during orthogonal turning of AISI 304 alloy steel.

The objectives of the study are to:

(i) Ascertain the physiochemical properties of Jathropha vegetable oil;

(ii) Formulate and characterise the mineral oil and vegetable oil emulsion cutting fluids

(iii) Ascertain the optimal process variables for minimum energy consumption and surface roughness; and

(iv) Ascertain the optimal combined process parameters using the GRA.

(v) Generate optimum cutting parameters to accomplish optimal combined responses,

1.5 Scope and Limitation of the Study

This research encompasses formulation of vegetable oil-based cutting fluid with jathropha oil as base stock. Mineral oil-based cutting fluid will also be developed using the commercially available mineral oil as base stock. Orthogonal turning experiment shall then be executed on AISI 304 alloy steel in wet and dry environments. Wet cutting will be executed with the formulated mineral oil - based and vegetable oil-based - cutting fluids. In this study, response surface methodology (RSM) will be used and this is because it contains and imbedded factorial design with middle point augmented with axial points. The impacts of process variables on energy consumption and surface roughness will be studied. The input variables to be investigated are cutting depth, speed of cutting and rate of feed under different machining environment.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Energy Efficient Manufacturing

Energy consumption in industries is attracting increased attention. This is consequent upon the exhaustion of natural resources and the effects on the environment. 36% of CO_2 emission worldwide and 30% of energy consumed globally are attributed to energy consumed by industrial and production sector. According to Reza (2013), energy efficient machining, (EEM) is described as an interaction between three significant areas which include the followings:

(a) Sustainable manufacturing

(b) Energy efficient machining, and

(c) Metal removal mechanics

The three research areas and their intersection which represent the major area of this research is illustrated in Figure. 2.1

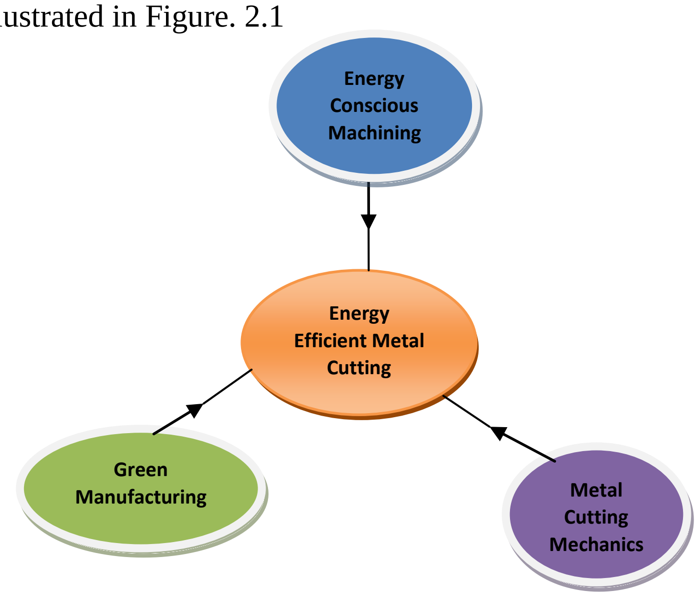


Figure 2.1: Three functional areas of EEM.
(Source: Asrai, 2013)

2.1.1 Green manufacturing

Green manufacturing can be visualized from different perspectives which include manufacturing of components or products with minimum energy consumption and clean environment. It also includes utilisation of renewable energy systems and deployment of various kinds of clean technology equipment. It includes waste recycling and reduction of emissions. Business organisations and corporate and professional bodies are being actively involved in waste recycling and redesigning of manufacturing systems to reduce emission and minimise environmental pollution. Until 19th century, the negative effects of human activities on the environment was not given serious attention in spite of the fact that researchers have been bothered about it since 19th century (Gari, 2002 and Urbinato, 1994). The severeness of negative effects of these activities was not known to the public until recently. Manufacturing as the nucleus of industrial activities, is a focus in environmental impacts assessment. One of the principal players in the assessment of these negative effects is machining. Series of studies have been conducted to assess the environmental effects of machining and to uncover feasible means of reducing these effects (Dahmus and Gutowski, 2004; Popke *et al*., 1999 and Zolghani *et al*., 2008). The environmental impacts of machining have been recognised to occur in the process of using energy, chemical emissions and generation of waste materials (Dahmus and Gutowski, 2004).

Sustainable production includes material, energy and technology which constitutes the three components of manufacturing. Yuan *et al.*, (2012), proposed a three-dimensional approach towards sustainable manufacturing.

Legislation is the major driving force and motivation behind research into reduction of waste in waste and chemical emissions (Popke *et al.*, 1999). In machining, application of metal working fluids has been observed to be a vital source of waste and chemical pollution, consequent upon which investigation has been carried out on the use of minimum amount of cutting fluid (Popke *et al.,* 1999). According to Lawal *et al.,* (2013), investigation was carried out on the consequence of mineral oil, then vegetable oil-based metal working fluids in cutting AISI 4340 alloy steel using carbide tools with coating. In their experimental study, it was shown that cutting seed oil (CSO) and palm karnel oil (PKO) based metal working fluids are suitable to be applied in machining processes because they enhance reduction of occupational health risks and the cost incurred in waste treatment. This is consequent upon their better performance rate and higher biodegradability. To enhance effectiveness in dry machining, sound knowledge of workpiece and cutting tool materials is very important. Grey cast iron cutting, produces discontinuous chips and accompanied with low cutting forces and temperatures with the embedded graphite providing lubrication. Aluminium, by virtue of its heat conductivity and high thermal expansivity, it is crucial in dry machining. Cutting of Aluminium is most suitable with surface coated tools in dry turning. Tool with surface coating having ability to retain its hardness property at high temperature in dry machining condition, is most suitable for machining of hardened steels.

When hardened steel is being machined dry, the accompanying high temperature tend to soften the workpiece resulting in good surface finish, better chip production and stable cutting of workpiece and stable machining (Sivarajan, 2003). Dry machining is necessary for safe, cost effective, and clean process with good surface finish. In order to accomplish the best result from green machining, the cutting tool material and cutting variables must be carefully selected. (Gupta and Diwedi, 2014). To implement green manufacturing in Industries, cutting variables must be carefully selected with appropriate cutting condition and ultra-hard tool material with surface coatings (Sivarajan and Padmanaban, 2014).

2.1.2 Nigeria's green industry programme

Nigerias vision (NV) 20: 2020 revealed the description of the long-term developmental strategy of Nigeria which was developed by the National Planning Commission via (National Planning Commission,2009) The systematic plan is aimed at moving the country from its position as the 49th biggest economy over the world in 2009 to become the 20th biggest economy come year 2020. Two wide objectives are involved. These includes ensuring that natural resources are adequate to accomplish quick economic development in one hand and converting the economic development into fair and proportionate social development for the citizenry in the other hand. Following the event of Koko toxic waste of 1987, Nigerian government enacted a number of laws, standards and regulations for the purpose of environmental protection and enhanced sustainable development. This event also ushers the setting up and launching of Federal Environmental Protection Agency (FEPA) via Act 58 of 1988 and passing of harmful waste act 42 of 1988. This also led to the establishment of environmental protection agency of various states such as, Lagos State Environmental Protection Agency (LASEPA)

2.1.3 Mandate of energy efficiency

Existence of appreciable scope for energy conservation and efficiency in production sector was acknowledged by National Energy Policy. It calls for Institutional arrangements to enhance efficient utilisation of energy in industries and conservation of energy.

The need to establish institutional arrangements aimed at promoting efficient use and conservation of energy is ingeminated by the National Energy master plan. Its objectives include;

(a) To design a national programme on industrial energy efficiency and conservation in collaboration with the Manufacturers Association of Nigeria and specialists in research centres and higher institutions of learning.

(b) To introduce an industrial energy equipment labelling programme which indicates the efficiency of energy utilisation; and

(c) To encourage industries to set-up energy management units.

The master plan also includes some other relevant provisions which encourage provision of attractive motivating policies to encourage industries in switching to more suitable type of energy. It also restricts the establishment of industries operation of which will be based on foreign-sourced energy and also ensure strict compliance environmental pollution and energy-related standards.

In view of the need for smooth and uninterrupted power supply, most establishments engaging in manufacturing activities are not relying on national grid due to inadequacies experienced from this energy source but rather depend on their diesel-engine generator back up for the energy required for their operations. Consequently, the use of diesel is accompanied with high cost of production which poses threat on their competitiveness. On the average, the cost of diesel-generated electricity per Kilowatt hour is approximately twice the cost of electricity obtained from the national grid. Out of 183 countries, Nigeria ranks 177 on the basis of uneasiness in accessing electrical energy in terms of costs, times and number of techniques. Currently, the Nigerian power sector is characterised by chronic power shortages and poor power supply quality. With the increase population and diversification of economic activities, energy demand is increasing but the supply of infrastructure is stagnant (Obuka *et al.,* 2014). Therefore, more research into energy – saving manufacturing is paramount.

Presently, the energy demand of Nigeria is in excess of 15,000 MW while the available capacity is about 6,000 MW but the existing operation is in the range of 3,600 MW and 4,000MW. This wide gap is being augmented by commercial and industrial sectors with the use of diesel engine generating sets. Few households also augment the epileptic and insufficient electricity supply from national grid with petrol generating sets. Theses institutional arrangements, polices, energy and environmental issues directly or indirectly confine the green industry aspiration in Nigeria. The need to reduce environmental pollution and improve energy efficiency is needed significantly.

The policy of green industry should focus on improvements and efficient use of energy. However, it cannot address the need for improved, smooth and consistent energy supply required by the industrial sector but could be helpful in mitigating the main challenge on industrial and production activities. To some extent, more effective utilisation of the existing energy would be helpful although the constraint will not be eliminated. Additionally, Industrial energy efficiency improvement sometimes come about with reduction of input materials. All these will enhance

2.2 Energy Conscious Machining

According to Dufour *et al.,* (2012), Economic and environmental benefits coupled with social well-being of the society can be achieved through monitoring of energy consumption in machining operations. Zhang *et al.,* (2011), investigated end milling operation with a view to looked into its energy efficiency. He adopted an energy prediction model and proposed efficient tooth profiling strategy. At the design stage of the machine tool, research was conducted on synchronisation of increasing and decreasing the spindle speed with rapid feed with the aim of reducing the required energy (Mori *et al.,* 2011). A method where energy recovered from spindle speed reduction by application of kinetic energy recovery system (KERS) was proposed. Research into operation of machine tools to enhance reduction of energy through selection of optimal process parameters was carried out (Diaz *et al*., 2010, Kara and Li 2011, Mativenga *et al*., 2011, and Diaz *et al.*,2011). Since Taylor's tool life equations were published in 1907, for more than 100 years after, researches have been conducted to enhance machining efficiency through selection of optimal machining variables (Taylor, 1907).

Between 1950- 1970 and few years beyond, optimal suggestion on the basis of cutting parameters was proposed by researchers. The procedure involved in this optimization process includes sequence collection of data by conducting physical experiments, analysing of mathematical equation, mathematical modelling, and proposing optimal solutions. It was revealed that energy consumption per unit volume of materials machined reduces monotonously with increase in cutting parameters. This implies that energy consumption in machining process varies inversely as machining parameters. He also discovered that the rise in machining variables bring about reduction in energy consumed in operating the machine, but the energy consumption for starting up the machine tool remains constant. However, 83% reduction in energy consumption is achievable in milling operation with selection of high and optimal machining process parameters (Owodunni *et al.,* (2013). The result of the experiment is shown in Table 2.1.

Table 2.1: Optimal results comparison

Variables	Hand book value	Optimal value	Improvement
Rate of feed (mm/ tooth)	0.067	0.06	,
Cutting speed (rpm)	1500	4000	
Width of cut (mm)	5	10	
Depth of cut	1	5	
Cost (E/cm$^{3)}$	0.123	0.016	86.99
Energy (KJ)	18.612	3.079	83.46%
Time (sec/cm^3)	43.968	5.833	86.73

Source: Owodunni *et al*., 2013

Machine tool energy consumption, is a measure of the quantity of energy consumed in cutting a unit quantity of the material under specific process condition. Guo *et al*., (2012), with the aim of optimising energy consumption and surface roughness, energy-based optimisation of process variables was carried out for rough turning and finish turning separately. During rough turning, surface quality is of less importance which implies that other aspects such as tool life and machining time can be considered and process variables can be optimised by the trade- off between tool life and energy consumption. In finish turning, cutting variables are selected to satisfy the required surface roughness. Hence, to accomplish the required surface roughness, a two-step procedure to obtain optimal cutting variables was proposed.

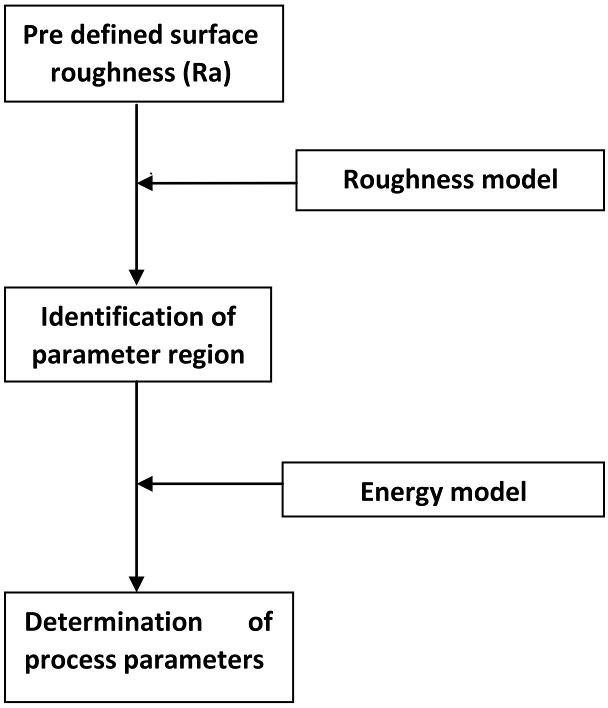


Figure 2.2: Flow chart for selecting finish-turning variables
(source: Guo *et al*., 2012)

The process commences with a predefined surface roughness value. Firstly, group of process variables – rate of feed (Fr), speed of cutting (Vc), and cutting depth (d) which will accomplish the pre-defined surface roughness as identified. Then, the optimum cutting variables which accomplishes minimum energy consumption, are chosen through the response initially selected. In fulfilling this process, Guo *et al.* (2012), described quantitative energy and roughness models. This approach resulted in minimum energy consumption and attainment of desired surface roughness value. In metal cutting processes, work is done and energy is consumed on the workpiece material to facilitate cutting and shaping to the desired dimension and produce a component part. According to Dahmus and Gutowski (2004), energy consumption give rise to unwanted effects on the surroundings due to the tasks involved in the metal cutting operations. Electrical energy required for industrial, production as well as machining operations are usually provided from the national grid. Then, it becomes very imperative to know the impact of this on electricity generation, transmission and distribution within various industries. Substantial portion of energy consumed in industrial and production processes are attributed to machining processes. After metal production processes, it is the second largest consumer of energy (Dahmus and Gutowski, 2004). In machining, researches are recently conducted to uncover the profile of energy consumption of various machine tools as well as areas of energy losses in metal cutting processes. The investigations revealed that conventionally, the cutting process is only responsible for 15 – 25% of the power supplied to a machine tool while non-material removal processes such as tool change, coolant pump and similar others consumed 75 – 85% (Dietma and Veri, 2009). It has also been suggested by various researchers that positive relationship exists between the specific energy consumed during a metal cutting process that is actually utilized for metal shearing and the relative size of machine tool used and that of the workpiece. Mishima (2007) revealed that the ratio of the size of workpice relative to the size of the machine tool varies directly to the machining efficiency and inversely to energy consumption. This implies that more energy is consumed when the size of the machine tool is too big relative to the size of workpiece. Gutowski (2010) revealed that in the case of nano manufacturing the efficiency can be as little as 10^{-6}, where the workpiece is comparatively of very little size compared to the size of the machine tool. The implication of this is that, less energy consumption can be recorded for the same component when smaller machine tools are used. This finding brought about, the idea of manufacturing of very small machine tools of comparable workpiece size as a strategy of reducing energy in machining processes (Mishima, 2007 and Neugebauer *et al*., 2009).

2.2.1 Electrical energy demand of machine tools

In manufacturing systems, inputs components are changed into palpable outputs via an orderly series of techniques which are executed by machinery. Machine tools are distinguished group of metal working machineries, defined as power driven device incorporating two motions, of which one is used for driving the workpiece and the other for actuating the cutting tool. In manufacturing, the role of machine tool is significant. According to the regulation of eco-design directive (EPTA, 2007), machine tool has been cited by the European commission as one of highest three priorities to be included into the product categories. Consequently, it is urgently needed for production sectors, especially machining outfits, to reduce energy consumed per component machined, to assist in meeting CO_2 emission target and eco-designer directives. This implies that designers of machine tools have to broaden their knowledge-base of energy consumption profile of various of machine tools' design features. The need for the industries and production sector to also have appreciable knowledge of the importance of machine tools' motions and path on energy consumption of machining processes is very paramount.

Balogun and Mativenga (2013) revealed that on the basis of operational characteristics, the state of operation of machine tools are of three classes which include basic state, ready and cutting states. Electrical energy is consumed at the basic state to activate the needed machine parts and ensures the machine tool is ready for the operation. During the ready state, energy is consumed in positioning the spindle and slides and also to move the cutting tool and workpiece to the appropriate location for cutting and select the required machining parameters. Illustrations include G00 (rapid transverse), T (tool change). and S (spindle speed). Energy consumption estimation model of machine tool proposed by Balogun and Mativenga (2013) is shown in Figure 2.4.

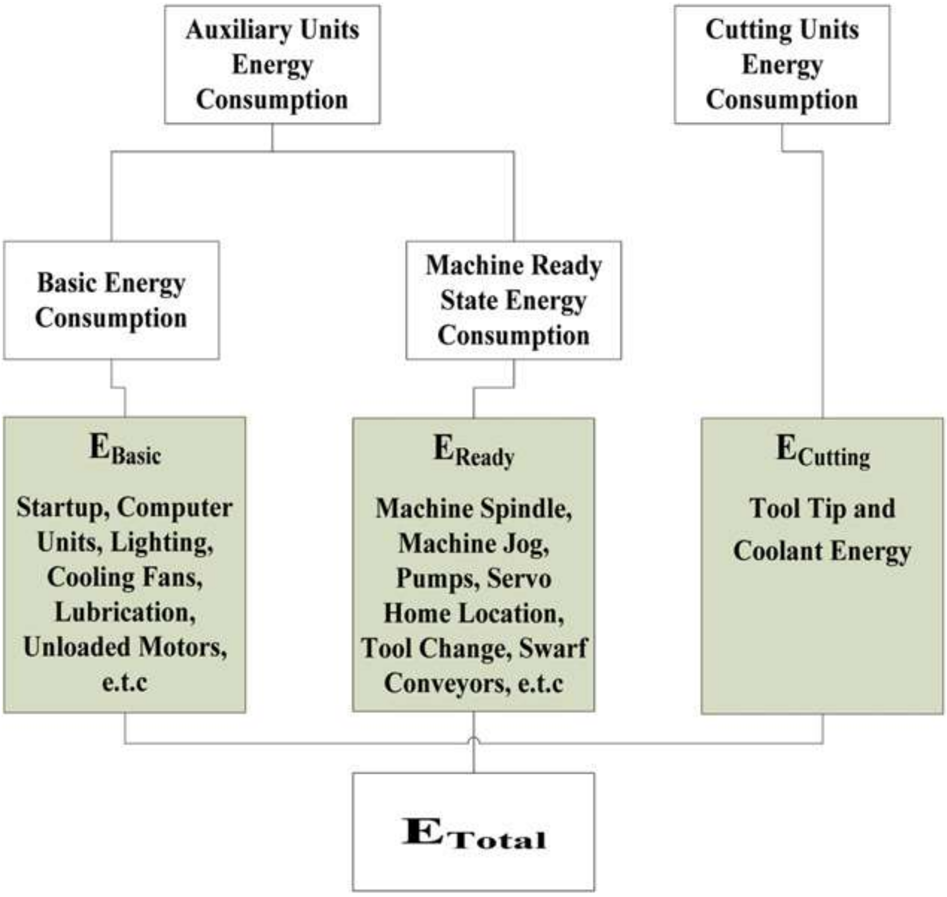


Figure 2.3: Electrical energy consumption model of machine tool
(Source: Balogun and Mativenga, 2013)

To create a focus for electrical energy improvement, the knowledge and understanding of electrical energy consumption and power distribution during machining is very vital. Mathematical model proposed by Gutowski *et al.* (2006) and presented in equation 2.1 is a good criterion for analysing energy consumption in machining processes.

$$E = (P_o + kv)\, t \qquad 2.1$$

Where E = direct energy in joules required in machining process; Po = power consumption in Watts, before commencement of cutting; K = required specific energy in Watts/mm^3 for cutting a workpiece of a specific material; V = rate of material removal, (MRR) in mm^3/secs, while t = time of cutting in seconds, Equation 2.1 shows that P_o accounts for the largest quantity of the energy required in metal cutting process. The implication of this is that machine tool selection significantly affects the energy requirement in machining. This mathematical model can be very valuable as it supports process planning and it enhances selection of machine tools with a view of minimizing energy consumption in machining a selected material

Flood cooling produces the best surface finish at low feeds but not for high feeds. It was also shown that with all the five cutting environments, the surface roughness value obtained at low feed values are close to each other but the trend was not the same at higher values of feed. MQL with vegetable oil render the best lubrication and also results in least energy consumption while cutting at high rate of feeding and high speed of cutting. Energy consumption was discovered to be inversely proportional to feed. Ranking different cooling and lubrication methods in machining operations poses some difficulties due to varieties of workpieces, materials and geometry of cutting tools as well as the type of machining operation involved (Lawal *et al.*, 2013).

Improved Performance was obtained with the vegetable oil environment using lubrication method of MQL. In their submission, Newman *et al.*, (2012), revealed that several investigations were conducted with respect to process control to cut-down the consumed energy in machining operations by improving the mechanics of tool-chip contact. Zolghani *et al*. (2008), researched into machine tools' energy efficiency improvement employing diamond-like carbon (DLC) coated tools. It was revealed that this method is capable of reducing by 36%, the power consumed by machine tools. Only 15- 25% of the sum of the machine tool's energy consumption is used in metal removal process (Vijayaraghavan and Dornfeld, 2010).

2.2.2 Energy conscious computer aided process planning

The need for measurement of the use of energy and the need to consider energy conscious machine tool process started appearing in published research papers since 1979 (Ippolito and De Fillippi,1979). Thereafter, no serious research in this field was noticed until 1995 during which Sheng *et al.* (1995), revealed their research finding on multi-objective process planning method which integrated environmental factor. A feed-forward model was identified in this approach and environmental factors which include process time, evaporated fluid, chip volumes and tool particles, process energy, fluid coated on chips and tool scrap fluid mist. This information was used in a model of environmental impact as well as process planning modules with process energy consumption, surface quality requirement and process time to generate machining process variables,

Srinvasan and Sheng (1999a), explored the micro (cutting tool variables) and macro (sequencing and set up feature) environmental planning levels (Srinkvasan and Sheng, 1999b). One of the works on Computer Aided Process Planning (CAPP) looked into relationship with systems of machine tools towards supporting green production with a system of CAPP which considers planning process as including optimisation of energy consumption (He *et al*., 2007).

2.2.3 Energy consumption and workpiece material

When component parts of machines (such as shaft) are being designed, the service condition of such component influences the mechanical properties of choice material. Mechanical properties of materials (which includes elasticity, strength, hardness and toughness and others) constitute significant factors affecting machinability of the material and the specific energy needed for their machining. The workpiece properties are a functional component of the machining energy consumption. For example, selection of a tough material such as titanium alloy gives advantages like corrosion resistance and high specific strength to the component (Leyens and Peters, 2005). Unfortunately, such difficult – to-cut materials require higher specific energy and require plenty quantity of cutting fluid for the machining processes. The use of coolant consequently results in greater environmental onus accompanying machining component from alloys of titanium. Machining process is extensively applied in industries for production of components of machines. Davim (2003) investigated the effect of machining environment on metal matrix composite (MMC), which has a metallic alloy base (such as alloy of chromium) reinforced with ceramics (such as Aluminium oxide). The conclusion revealed that the parameter which has the highest effect on energy consumed in turning is speed of cutting followed by the rate of feed. The implication of the outcome of Davim (2003) research is that cutting parameters influence significantly the energy consumption in machining.

2.2.4 Cutting tool's effect on energy consumption

The material of cutting tool used also influence the quantity of energy consumed in machining processes (Gizesik, 2003). The existing cutting tool materials which include but not limited to carbide tools, high speed steel (HSS), Cubic Boron Nitride (CBN), ceramics and polycrystalline diamond (PCD) are used in turning and other machining operations. PCD find useful utilisation mostly in aerospace and automotive industrial sectors. It is suitable for high speed cutting and ideal for cutting of ceramics and alloys of aluminium. CBN, being the second hardest substance known and in view of its physical properties, it exhibits some merits when being used alternatively to tungsten carbide for grinding operations. For high speed finishing and machining of special materials like hard-chill cast iron, high strength steels and super-alloys, cutting tools made of ceramic materials are good (De Garmo *et al*., 1997). When compared with carbide tools, the fracture toughness of ceramic cutting tools are lower, consequent upon which it's use becomes limited especially when the cutting process is accompanied with vibration. In view of these enumerated facts, machining of steels, is commonly done using tungsten carbide tools. It is consequently being considered for use in this research.

2.2.5 Effect of machining process on energy consumption

Energy consumption in producing a component part can be reduced through selection of optimum cutting parameters. The size of the component being machined also play significant role in the quantity of energy consumption. Sometimes, machining of a small component using a conventional machining centre is not suitable. Energy consumption as well as the space occupied by the machines reduced with the use of smaller machines (Okazaki *et al.,* 2004). In the study conducted by Liow (2009), it was shown that in conventional milling operation, energy consumption is 800 times more when compared with a micro milling machine. Hence, conclusion can be drawn that the right choice of machine tool and machining process is capable of enhancing reduction of energy consumption significantly.

2.2.6 Effect of cutting variables

In order to produce component part of machines, the usual process inputs are rate of feed, speed of cutting, and cutting depth. While selecting these machining variables, consciousness of the need to prevent tooth breakage and use of the machine tool outside its designed technological capability is very paramount. In view of this requirements, the machining process and cutting parameters' selection can accommodate improvement of tool life, reduction of machining cost, improved surface finish and rate of production as well as enhancement of profitability. The industry is well acquainted with these factors and they are available in relevant literatures. Nevertheless, research into reduction of energy consumption in machining processes remain inadequate. With selection of suitable cutting parameters, energy consumption can be reduced. Hinduja and Sandiford (2004) and Chen *et al.* (1989), worked significantly on the choice of condition of cutting to fulfil the least cost criterion.

According to Chapman (1974), detailed study of a specific machining method can be very useful in appraising and reducing energy consumed in machine tool processes. To accomplish detail study of a machining process, the factors affecting energy consumption of the process must be understood. In machine tool processes, the most important factors are the machining variables. To minimise energy consumption, the cutting variables must be optimised. Chen *et al.* (1989), gave a detailed information of the heuristic process of finding out most favourable cutting conditions with least cost. In their research, they enumerated the critical obstacles in finding the best cutting variables and also presented the cost model. The machine power and set up, highest allowable depth of cut and feed rate.

2.2.7 Energy consumption for indirect measurement

Energy consumed in machine tools processes needs to be adequately researched in view of its effects on the environment. It is also a pilot for other phenomena (like surface roughness, tool wear, metal removal rate MRR and others) in the processes of machining. The cutting tool’s condition such as tool wear can be indirectly monitored through measurement of electrical power consumption of the machine tool. This indirect method of measurement has been found to be of high reliability, low cost, quick and flexible method to monitor the condition of the tool (Al Sulaimon *et al.*, 2005). Astakhov and Xiao (2005), also established that the energy expended in a system of cutting can be utilized indirectly to calculate the cutting force. Peplenik and Dolinsek (1995), revealed that analysis and monitoring of energy consumed in machining process can be helpful in explaining the behaviour of the cutting processes. The machine tool's energy spectra were analysed and a parameter described as energy quanta was defined. A link between this parameter and the entropy change during the process of cutting to the process' physical condition was also developed.

2.3 Mechanics of Metal Cutting

In metal cutting processes, the cutting tool which is made of a sharp, and hard piece of metal is used in removing layers of material from the surface of the workpiece (another piece of metal). Since the invention of machine tools, the need to calculate cutting forces has been identified as it will enable machine tool designers carry out detail analysis and design machine tools suitable for cutting purposes. Determination of cutting forces will enhance the following:

(i) Estimation of power consumed in cutting, which also enhances selection of the power sources or prime movers during the machine tool's design phase.

(ii) Machine's structure, fixtures and tool system design.

(iii) Assessment of effects of geometry and material, cutting environment and different cutting variables on cutting forces.

(iv) Investigation of machinability characteristics and behaviour the workpiece materials.

(v) Monitoring of machine tool and cutting tool under various conditions.

Turning is a significant metal cutting method where a single point cutting tool cut unwanted material away from the internal or external surface of rotating cylindrical shaped (or any other shape) workpiece by generating process. The tool is fed against the rotating workpiece linearly in a direction parallel to its axis of rotation to generate a cylindrical surface or change the existing dimension as may be desired. Lathe is used in carrying out turning operation as it provides the power to turn the workpiece at a selected spindle speed, rate of feed of the cutting tool and cutting depth. Hence, three cutting variables which include feed rate, cutting speed, and cutting depth, have to be optimised in a turning process. One of the most significant operations used for production of machines' components in industries such as manufacturing, automotive and aerospace is turning (Nur, 2016). The three types of cutting forces produced in turning are as shown in Figure 2.3. The forces are F_f, which constitutes the main cutting force. It is acting in the direction of the cutting speed, feed force F_t, which is acting in the direction of tool feed and radial force F_r, which is acting in the direction perpendicular to the cutting speed. Out of the three components of force, the cutting force F_f constitutes 70% to 80% of the total force 'F'. Consequently, F_c is used in calculating the power (P) needed to carry out the cutting operation (Trent and Wright, 2000) and (Kalpakjian and Schmid, 2013).

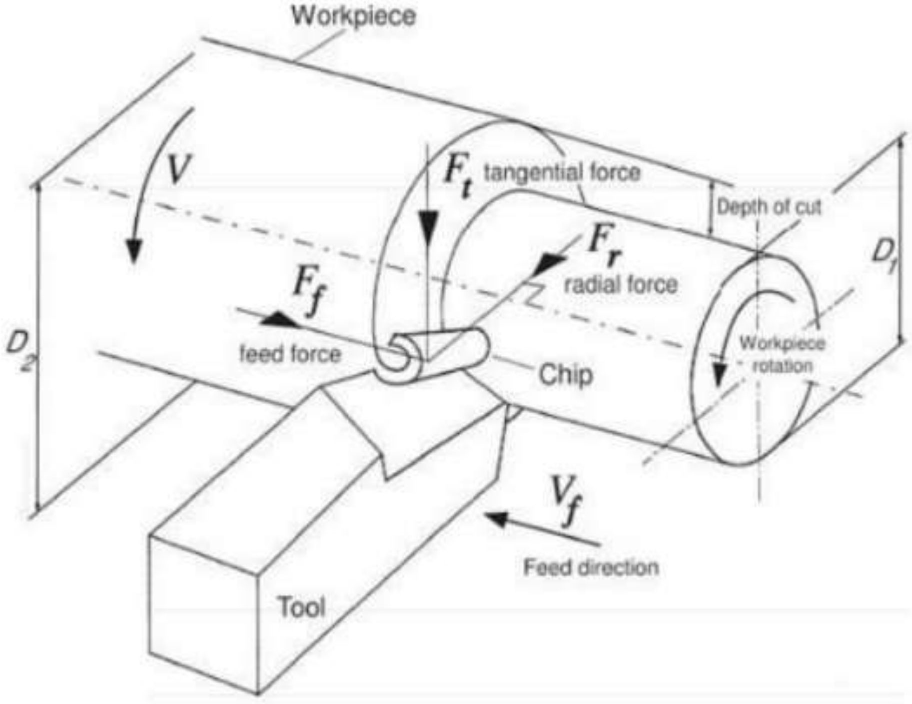


Figure 2.3: Three types of Forces produced in Turning process
(Source: Kalpakjian and Schmid, 2013**)**

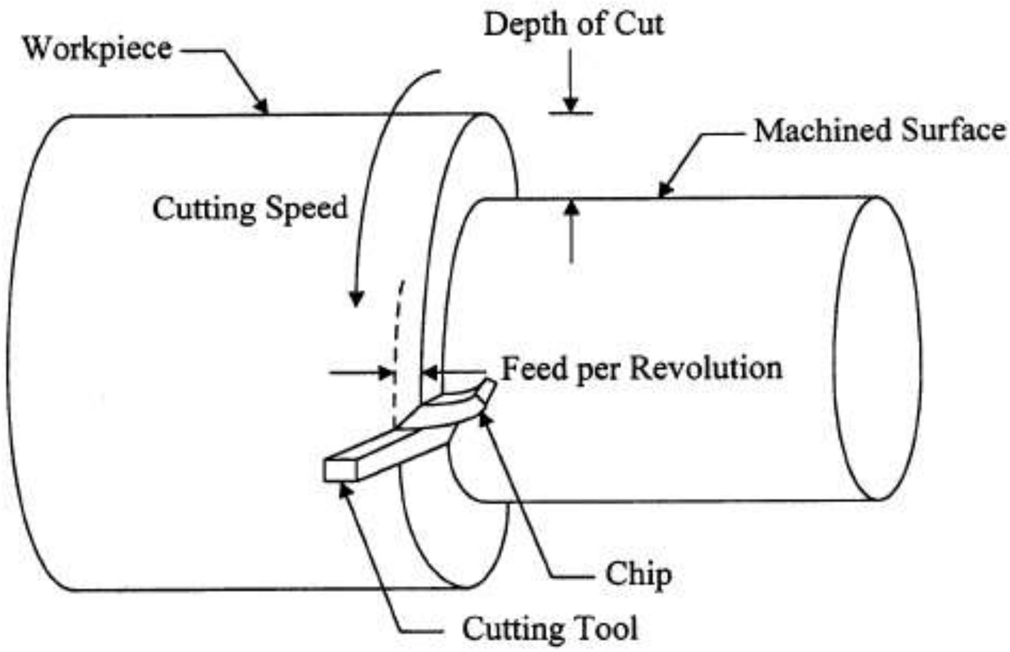


Figure 2.4: Orthogonal Turning process
(Source: Childs *et al*., 2001)

In metal cutting process, the cutting forces developed have direct influence on heat generated, surface roughness of machined part, tool life (tool failure or wear) and workpiece's accuracy. Cutting power is the product of cutting force and cutting velocity. The cutting power is a good standard for selection and design of machine tools and tool condition may be monitored with the aid of power demand in machining process. Equation 2.2 is power equation.

$$P_c = F_{c.\ Vc} \qquad 2.2$$

where P_c = cutting power (Watts); F_c = main cutting force (N) and V_c = cutting speed (m/min)

2.3.1 Ernst merchant circle

According to Childs and Rowe (1973), a major breakthrough in metal cutting mechanics was recorded in 1945 when the work of Ernst and Merchant was published. Their theoretical assumptions are as follows:

i. Metal cutting mechanism is made up of the failure of metal on a straight shear plane in the lead of the tool tip.

ii Shear plane angle Ø which is constant to the direction of tool path is shown in Figure 2.5. It is the angle of the shear plane where failure happens.

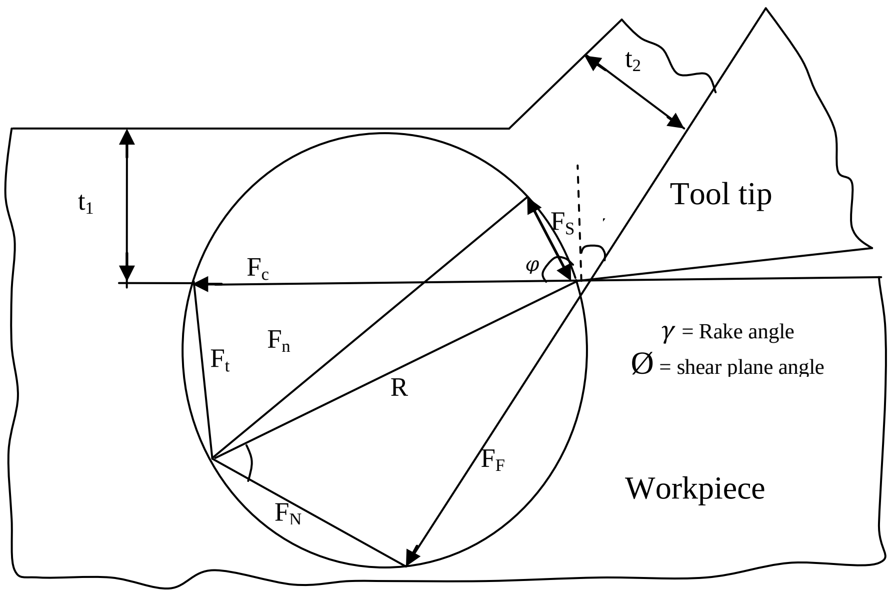


Figure 2.5: Ernst Merchant Circle (Source: Asrai, 2013)

From Merchants model, the minimum force needed to maintain the cutting process is given by

$$\boldsymbol{F_c} = \frac{\boldsymbol{F_s}\,(\boldsymbol{\mu} - \boldsymbol{r})}{\cos(\boldsymbol{\varphi} + \boldsymbol{\mu} - \boldsymbol{r})} \tag{2.3}$$

Where μ = frictional coefficient between workpiece materials and cutting tool;

F_s = shearing force fracturing the workpiece at constant surface and acting on the plane of shear

$$Fs = \frac{\tilde{\imath}\, wt}{\sin\varphi} \qquad 2.4$$

$\tilde{\imath}$ = shear strength /modulus of rigidity of the workpiece material; t = cutting depth, and w = width of cut.

With the discovery of Merchant's model, further investigations were conducted into the theory of metal cutting. In view of the variance observed between the results of the experiment conducted and theoretical predictions emanating from Merchant's shear plane model, some amendments were proposed. One of such modification is that of Atkin where a friction correction factor was suggested. Atkins (2003), proposed a friction correction factor defined as

$$Q = 1 \left[\frac{\sin\beta \sin\varphi}{\cos(\beta - r)\cos(\varphi - r)}\right] \qquad 2.5$$

where β = angle of friction

= angle for which tan β = μ

$$\Rightarrow \quad \beta = \tan^{-1}(\mu)$$

Hence, the cutting force is re-defined as

$$F_c = \frac{\tilde{\imath}\, w\psi t}{Q} - \frac{Rw}{Q} \qquad 2.6$$

where R = toughness of material of the workpiece

Ψ = shear strain in the direction of the shear plane

$$= \cot Ø + \tan Ø (Ø - r) \qquad 2.7$$

Fang and Jawahir (2002), modelled the cutting condition on the basis of universal slip-line model. This will enhance possibility of predicting chip back flow angle, cutting force and chip thickness in the specific case of restricted contact machine tools. This model's prediction matches the experimental results closely. Astakhov and Shvets (2004), investigated plastic deformation of workpiece in the cutting zone which is a more complex type of deformation than that of straight simple shear plane. Vertical flexibility in tool position was considered (Astakhov *et al.*, 1998). They created a dynamic model for the tool and the vibration which occurs in the system was then investigated. Despite the fact that standard shear plane model is being widely used as a basis for numerical and theoretical researches in machining processes. Astakhov and Xiao (2005), investigated the single shear plane model and argued that it is highly unrealistic and not able to provide a good approximation of the real cutting mechanics This is because all the boundary conditions cannot be satisfied by the simple shear plane model and infinite values are given to some physical quantities like shear strain. Oversimplification observed in the standard Merchant's model makes the tool a weak one for the analysis of certain aspects of mechanics of metal cutting. However, it is suitable for use in calculating the average cutting forces and can provide a very good approximation in most practical conditions with relatively few calculations. Consequently, it is being used for prediction of cutting force in most engineering systems. No pronounced error has ever been reported from its use (Reza, 2013).

2.3.2 Predictive modelling of machining operations

The most significant and the first step towards control and optimisation of machining process is predictive modelling. According to Kardekar (2005), predictive model is a precise link between the selected input parameters and the response or performance measures. Primarily, the aim of modelling machining operation is to facilitate accurate quantitative prediction of machining performances. Modelling can facilitate feasible planning of machining processes to accomplish productivity, cost and optimal quality. According to Van Luttervelt *et al.,* (1998), the major obstruction in the modelling of machining operations is ascribed to lack of background knowledge of basic mechanisms due to the mutual synergistic movement of cutting tools and the workpiece material as well as great variety and complexity of actual machining operations.

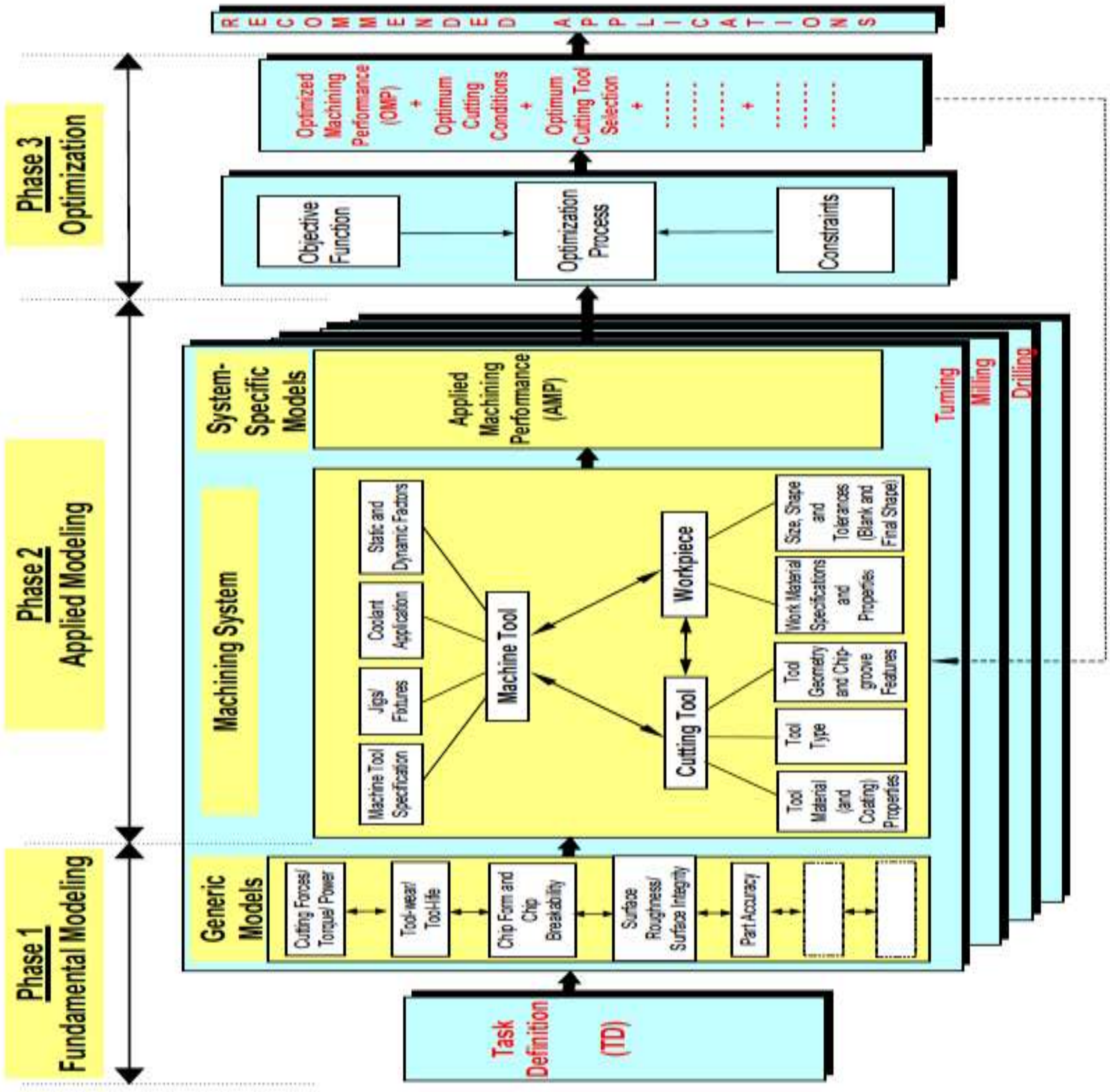


Figure 2.6: Predictive modelling and optimisation Phases in machining processes for practical application. (Source: Van Luttervelt *et al*., 1998)

For practical applications, predictive modelling of machining processes involves some stages as shown in Figure 2.6. These are stages 1 and 2. Stage 1 is the development of predictive models for machining parameters and stage 2 is development of models for machining performance. The typical input includes tool geometry, properties of tool material, properties of workpiece material, cutting conditions, dynamics of machine tool and some others. In stage 1, the fundamental phenomenon in the chip formation process such as the strains, strain rates, friction, temperatures, chip flow, tool-chip contact length, etc are anticipated. In stage 2, machining performance criteria like torque, energy consumption, cutting forces, power, life of tool (tool-wear), chip formation, surface finish, component's accuracy, etc required for practical applications are predicted. Transformation of outputs from phase1 to phase 2 is the major challenge. According to Arrazola *et al.* (2013), the phase 1 parameters must be mutually related to performance measures and quality of product of phase 2. According to Van Luttervelt *et al.* (1998), machining performance can be categorised as "technological' or "commercial".

Directly or indirectly, the technological machining performance measures affect the commercial machining performance measures. Numerous variables involved in machining process as shown in Figure 2.6 limits the technological machining performance. The major technological performance measures which include surface roughness, tool life, part accuracy, cutting force, energy consumption and chip formation are ascribed to the mutual action between the cutting tool and workpiece created by the relative motion provided by the machine tool in a machining process. Machine tool's operation capability is affected by the properties, shape and size of the workpiece material. It is further influenced by cutting tool material, geometry and presence of chip breaker. It is also affected by rigidity of the machine tool, cutting condition (use of coolant or dry cutting), cutting variables – rate of feed, speed of cutting and cutting depth coupled with operational features which may be continuous or intermittent cutting.

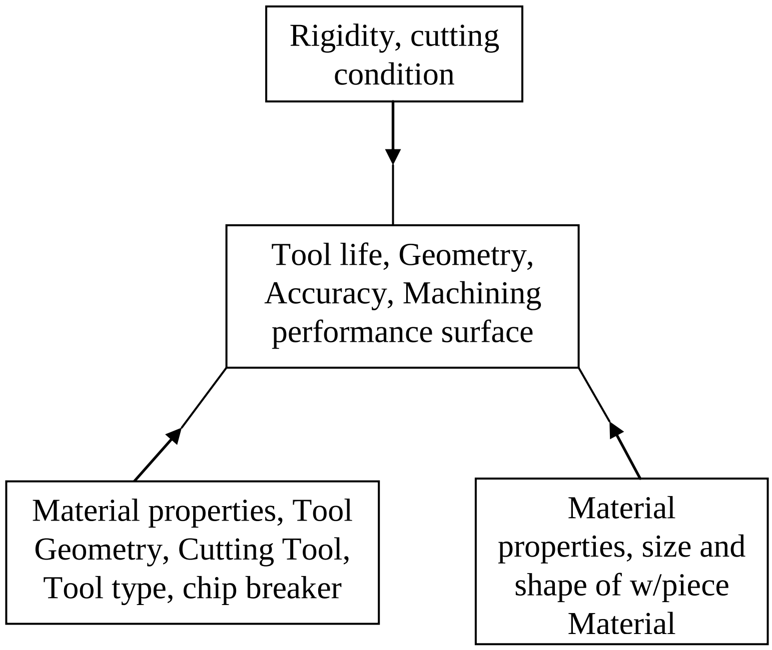


Figure. 2.7: Factors influencing technological machining performance (Source: Girish, 2016).

2.4 Modelling Techniques in Metal Cutting Processes

To come up with the connection existing between inputs and output variables in machining processes, many methodologies can be used. In view of the highly non-linear nature of metal cutting operations, no single methodology can perform the task reliably (Yigit, 2007). Over the years, modelling of machining processes has developed through three main stages which include analytical modelling, numerical modelling and empirical modelling. 43% of research groups used empirical modelling, 32% used analytical modelling and numerical modelling was used by 18%.

2.4.1 Analytical modelling

The fundamental theoretical physics of the machining process is the basis of analytical modelling. The input-output relationship is obtained by scientific analysis of the machining process. Analytical modelling has been in use as far back as 1940s. The basis of this approach is mechanistic, geometric or analytical modelling methods. The use of analytical modelling in metal cutting was largely initiated by Merchant in his modelling, which is based on physics and analysis of the staple system of force acting on the cutting tool, workpiece and chip formed in a process of machining. This method involves anticipations made from the fundamental physical and mechanical properties of the workpiece and cutting tool materials together with the dynamics and kinematics of the metal cutting procedure. After the suitable physical data has been decided upon, the effect of changes in cutting status (such as cutting variables and tool geometry) on the performance of machining (such as surface roughness, tool wear and geometrical accuracy) can be anticipated (Ernst and Merchant, 1941).

2.4.2 Numerical modelling

Numerical modelling is the modelling which is computer-based. It began to evolve in 1970 and was the trailblazing event in the advent of digital computer technology. According to Van Luttervelt *et al.* (1998), Finite – element methods (FEMs) is most frequently used among the numerical modelling techniques. The need to derive computational model for prediction of performance of machining measures such as temperature distribution, cutting force, tool wear, surface roughness, chip geometry and some others under various cutting conditions are very paramount. and it is the main aim of finite element studies. In finite element methods, small mesh representation of the workpiece and cutting tool materials which is based on the principles of continuity are used (Ozel and Altan, 2000; Guo and Liu, 2002; Ohbuchi and Obikama, 2003; Ceretti *et* *al.*, 2000). When thermal properties of the cutting tool and workpiece, tool-friction conditions, and material model are properly defined, Finite Element method can be used to model machining process such as elastic-plastic or rigid plastic, fixed mesh (Eulerian) or mesh flow with material (Langrangian), adaptive or non-adaptive meshing. Cutting edge of the tool causes some troubles in generation of meshes in Langrangian method. For correction of highly distorted element around the cutting edge, rezoning of mesh and dynamic remeshing technique are deployed.

2.4.3 Empirical modelling

Empirical modelling has been in existence as an organised process since late 1890s to early 1900s. In his research in estimation of reasonable economic machining conditions, Taylor adopted empirical methodology. The acknowledged father of metal cutting - Fredrick Taylor while working on his famous equation, $VT^n = C$, where V = cutting speed, T = tool life and C and n are constants. Empirical approach was used (Taylor, 1907). This equation was later expanded to accommodate other cutting parameters such as rate of feed and cutting depth. Tailor's equation and its expanded version are used nowadays for assessment of materials and machine tools economics. The simplicity of empirical model and ease of its application allow a broad scope of machining problems to be solved. Principle of design of experiment (DOE) are used in determining the link existing among the input parameters and the output responses. Responses such as residual stress, tool life, surface roughness and others can be modelled using empirical modelling technique. This is in view of the fact that empirical modelling is influenced by some hard-to-model factors (Ozel and Karpal, 2005; Chou *et al*. 2003; Wang and Feng, 2002).

In order to obtain dependable models, large numbers of investigations should be carried out. Regression equations and models generated on the basis of neural network are usually employed to create the link between inputs variables and outputs responses. Benardos and Vosniakos (2003), reviewed literature extensively and predicted neural network approach to be very effective in predicting surface roughness.

The classification of different empirical modelling techniques is shown in Figure 2.8.

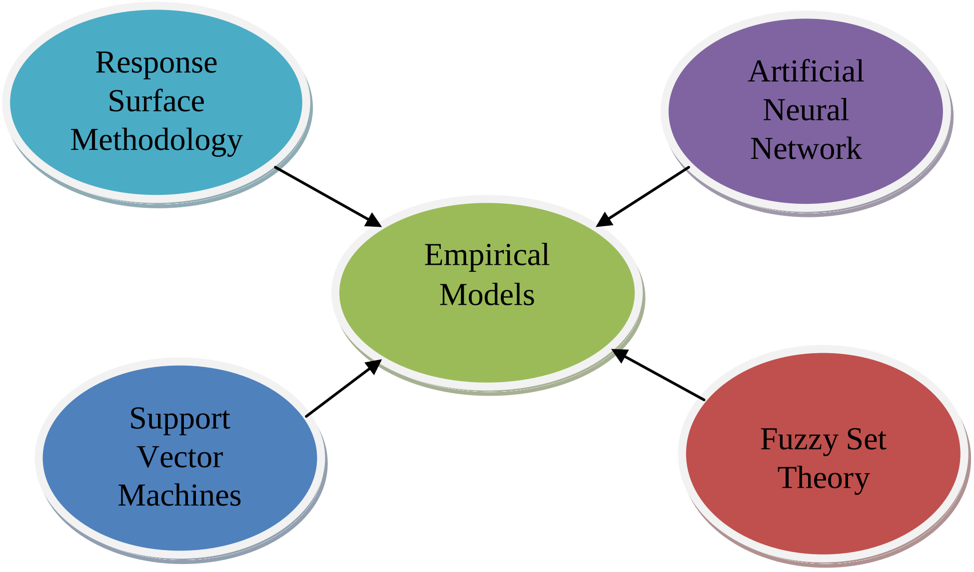


Figure 2.8: Empirical modelling techniques (Source: Mukherjee and Ray, 2006)

During turning of austenitic AISI 302, Al-Ahmari (2007), generated empirical models for surface roughness, cutting force and tool life. The input variables applied in the model were cutting depth, rate of feed, speed of cutting and nose radius. In this study, Regression Analysis (RA), Response surface methodology (RSM) and Artificial neural network (ANN) were investigated and compared with the aid of hypothesis testing and descriptive statistics. ANN models are found to be better than that of RSM and RA. Similarly, RSM models were found to be better than that of RA in anticipation of life of tool and cutting force. The effect of cutting variables (rate of feed, cutting depth and speed of cutting) on surface finish and cutting forces (feed force, thrust force and cutting force) in finish turning of MDN 250 alloy steel was carried out by Lalwani *et al.,* (2008) with the use of coated ceramic tool. They conducted machining experiments and also developed mathematical model based on RSM. It was discovered that the fluctuation of cutting forces with rate of feed and cutting depth is best fitted with linear model while non-linear polynomial model of second degree is most suitable in describing surface roughness variation, with rate of feed being the major contributing factor and the consequence of mutual action between cutting depth and rate of feed as secondary factor.

2.5 Response Surface Methodology (RSM)

According to Montgomery (2009), A strong tool for modelling and analysis of link between operational parameters and specific responses which depends on the process parameters is design of experiment (DOE). Design of experiment can be defined as the process of planning experiments to facilitate statistical analysis of appropriate data to obtain valid objectives and conclusions (Masounave *et al.,* 1997). According to Bagei and Isik (2006), Response surface methodology (RSM) is an aggregation of mathematical and statistical methods used in analysing and modelling knotty situations where an output or response of interest is affected by many parameters with the aim of optimising the outcome of interest. The aim of RSM are to use a serially planned experiments to get an optimal response and to determine the existing relationship in the neighbourhood of the optimal response. In RSM, the input variables that are considered as most significant are used to build a model in which the experimental response is the dependent variable (Raveedran and Marimuthu, 2016). The relationship existing between some explanatory variables and some output responses are established using RSM. It is an empirical modelling technique for finding out the relationship existing among some process parameters and outcomes of interest (responses) so as to ascertain the significance of such variables to the responses. It is a technique which basically, combines regression analysis, statistical inferences and design of experiments. RSM can be used to reveal the degree of correlation between some selected parameters and one or more responses. This can be accomplished by using the line of best fit and statistical importance of the variables connected with a specific response and obtain the optimal condition lower and higher levels of the input variables for minimisation or maximisation of an interested response. (Karim *et al.,* 2018). RSM has being famous technique for optimisation of systems whereby input parameter, sometimes known as the independent variables are recognized. The values of these independent variables are derived from physical experiments. They could also be derived from experimental observations as well as simulation experiments. The formulated models have the requirement of being statistically analysed so as to determine their suitability. Thereafter, they could be employed for optimization of critical representation. Also, RSM uncovers the mutual action between the input variables as well as the response surface attained (Aloufi and Kasmierski, 2011).

The steps involved in RSM are presented in Figure 2.9.

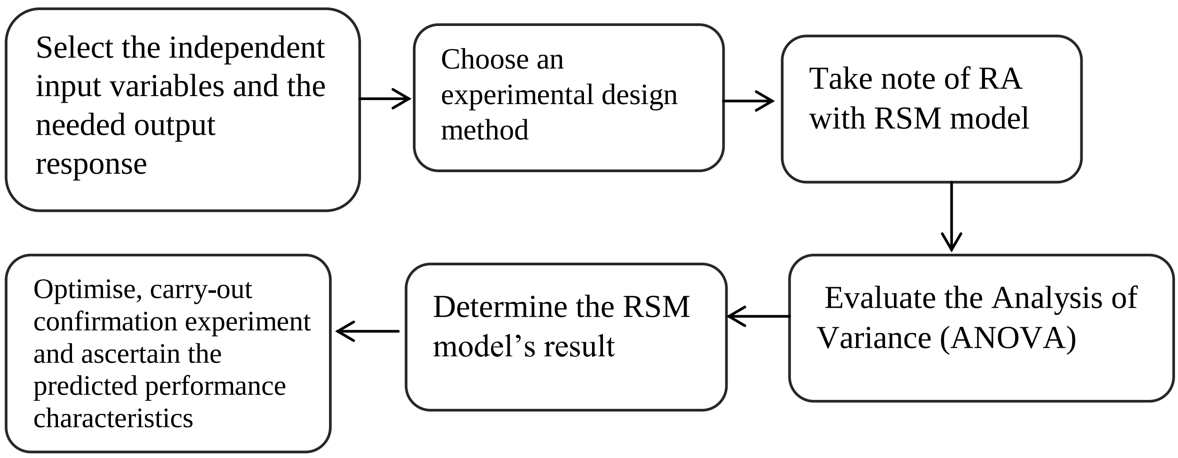


Figure 2.9: Process steps of Response surface methodology
(Source: Agrawal *et al.,* 2018)

2.6 Gray Relational Analysis (GRA)

According to Deng (1989) and Jeyapaul *et al*., (2005), complicated mutual relationships between multiple responses can be resolved applying GRA, the basis of which is theory of grey systems. To assess multiple responses, grey relational grade (GRD) is calculated. Consequently, optimisation of multiple responses can be changed-over to optimisation of single relational grade. Deng (1982), proposed grey systems theory. The wisdom underlying this theory is that data such as structures, mechanisms, characteristics and operational behaviours of a determined system are assumed to be partially known and deterministic. Traditionally, a system about which full information is available is known as a white box while a system without any data or known information is represented by a black box. Grey systems are the ones that feature inadequate data. The incomplete information are the grey elements and grey relation is the one with incomplete information (Liu and Lin, 2006). Tosun (2006), used GRA to determine optimum drilling variables, aiming at minimising the surface roughness and height of burr. GRA was proposed by Deng (1989) and it has been established to be very utile in tackling incomplete, ailing and undecipherable information. This grey theory-based analysis can be effectively applied in solving major, complicated mutual relationship between multiple performance responses. The use of this analysis will enable a researcher obtain a GRD which will be used in assessing the mutual relationship and performance responses. Consequently, optimisation of multi- response performance is changed into the optimisation of a single GRD (Kondapalli *et al.*, 2015).

GRA is advantageous in view of its straightforwardness, ease of calculations and being one of the best techniques of reaching a decision in business environment (Wei, 2011). Garcia and Duim (2017), applied grey relational approach in assessment postgraduate programs in Master of Business Administration in Brazili. The objective of GRA is to determine the relationship between a standard (or comparison) observations with reference observation. In their work, Prayogo and Lusi (2015), applied optimization technique of machining parameters while considering multiple performance feature of a non-conventional electro-discharge machining (EDM) process using GRA in combination with Taguchi technique. Combination of method of Taguchi with GRA was called Taguchi - GRA. The optimal levels of machining variables were recognised by means of GRA technique. According to Prayogo and Lusi (2015), the steps to be followed in GRA are as itemised as follows:

a. Normalisation of experimental results of required characteristics;

b. Determination of Grey relational generation and calculation of grey relational coefficients (GRC);

c. Calculation of the grey relational grade (GRG) by calculating the average of the grey relational coefficient;

d. Carry-out statistical analysis of variance (ANOVA) for the input machine variables using the grey relational grade and determine which variable significantly affects the process.;

e. Selection of the optimal level of process variables, and

f. Conducting confirmation experiments to corroborate the optimal process variables setting.

According to Slavek and Jovic (2012), the general formula in Grey relational analysis generations are:

For the nominal the better

(a) $X_i^* (k) = \dfrac{[Xi(k) - Xo(k)]}{\max Xi(k) - Xo(k)}$ 2.8

For the smaller the better

(b) $X_i^* (k) = \dfrac{\max Xi(k) - Xi(k)}{\max Xi(k) - \min Xi(k)}$ 2.9

For the larger the better.

(c) $X_i^* (k) = \dfrac{Xi(k) - \min Xi(k)}{\max Xi(k) - \min Xi(k)}$ 2.10

The Grey relational co-efficient is expressed as

$$\xi i(k) = \frac{\Delta \min + p\Delta \max}{\Delta xi(k) + p\Delta \max}$$ 2.11

Where; i = 1, 2…., m, K = 1, 2..., n, (m alternative, n criteria), X_i^* = generated Grey relational value, P = distinguishing co-efficient p is between 0 and1 but is commonly set at 0.5, ξ is Grey relational co-efficient.

Grey relational analysis was used by Sivarajan and Panmanaban (2014) in carrying out multi-objective optimization for 800 HT welded Incology, using the welding process of tungsten inert gas with filler rod of 1.2mm diameter (N82). Taguchi L9orthogonal array was used in conducting the experiment. GRA was used for optimisation of input parameters while the multiple output responses were also assessed simultaneously. The study identified the conversion of signal to noise ratio values from the original response value as the initial step in the GRA. ANOVA technique was used in determining the significance of variables in general quality of welded joint.

The summary of some of the literatures reviewed is presented in Table 2.2.

Table 2.2: Summary of Review and Literature

S/N	Author	Investigation	Work Piece Material	Cutting Tool Material	Machining Operation	Remarks
1.	Backraty *et al*., (2015)	The influence of cooling fluids to energy consumption during transversal turning	Steel 12050.1	Carbide Tool	Turning operation in wet conditions	16% saving in energy consumption was achieved with cutting fluid. Surface roughness was also enhanced.
2.	Compos Co-Negrete (2013)	Optimisation of machining variables by means of robust design for minimising energy consumed in lathe machining of AISI 1018 alloy steel while keeping MRR constant.	AISI 1018 steel	Carbide insert (DCMT II T3 04 PM)	Turning Operation	Minimum energy consumption was achieved using rate of feed of 0.2mm/ rev, cutting depth of 1.14mm and speed of cutting of 350m/min.
3.	Compos Co-Negrete and Calderon- Najera (2018)	Reduction of the environmental effects in relation to the energy consumption of machining process through sustainable machining using AISI 1045 steel.	AISI 1045 steel	Carbide Insert DCMT 11T30 8-PM 4235	Turning in dry condition	Rate of feed and cutting depth are the most significant factors for minimum energy consumption.

Table 2.2: Summary of Review and Literature continues

S/N	Author	Investigation	Work Piece Material	Cutting Tool Material	Machining Operation	Remarks
4	Ganta and Chakradhar (2014)	Application of GRA in multi response optimisation after subjecting 15-5PH stainless steel to hot machining.	15-5PH martensitic stainless steel	carbide tool	Hot turning operation	Cutting parameters-CS, FR and DOC are considered as primary factors while W/piece temperature is considered as secondary factor. Significant improvement is achieved by combination of both factors.
5.	Guo *et al.*, (2012)	Optimisation of energy consumption and surface roughness and in finish turning.	1. Steel 2. Aluminium	1. SPUN 120304 2. DCGT IIT 304	Turning operations in dry conditions	It was found that speed of cutting for maximum rate of production is smaller than the one for minimum energy consumption.
6.	Guptan and Diwedi (2014)	Optimisation of MRR and Surface roughness on CNC turning centre using different nose radius.	Aluminium Alloy 6061	Carbide inserts WNMG 331 RP, WNMG 332 RP and WNMG 333 RP	Orthrogonal turning in dry environment	The most important variable to surface roughness was feed rate.
7.	Hansda (2011)	Study of machinability of AISI 316 alloy steel with the use of cemented carbide tool insert of P30 grade.	AISI 316 alloy steel	Cemented carbide inserts without coating.	Dry turning operation	Tool wear is mostly affected with cutting speed

Table 2.2: Summary of Review and Literature continues

S/N	Author	Investigation	Work Piece Material	Cutting Tool Material	Machining Operation	Remarks
8.	Ithirpri *et al.*, (2015)	Specific energy consumption in turning operations was modelled using Taguchi L32 Orthogonal array design	AISI 1040 carbon steel rod	Diamond shaped carbide inserts with TiN coating (CNMG120408)	Turning was carried out under wet condition	The most important variable to energy consumption was rate of feed with percentage contribution of 84.38%
9.	Jurkovic *et al.*, (2016)	Application of GRA in optimisation of machining variables in turning for multiple response.	Carbon steel DIN CK 45	Coated insert DNMG 150608-PM4025	Dry turning operations	The mutual response behaviour (surface roughness with MMR) are influenced mostly by rate of feed, cutting depth and speed of cutting at 8.41%, 32.62%, 12.63% respectively.
10.	Kikarni *et al.*, (2014)	Optimisation of power consumed using Taguchi approach in turning of AISI 1040 on CNC lathe.	AISI 1040 medium carbon steel	Coated carbide inserts CNMG 120404 CNMG 120408 CNMG 120412	Turning operations in wet condition	Increase in concentration level of cutting fluid from 3% to 9% reflects a significant reduction in power consumed.

Table 2.2: Summary of Review and Literature continues

S/N	Author	Investigation	Work Piece Material	Cutting Tool Material	Machining Operation	Remarks
11.	Lavshmanan *et al*., (2013)	Application of RSM in optimisation of surface roughness in EDM with EN 31 tool steel	EN31 tool steel (oil hardened non-shrinking steel	EDM Electrode: Electrolytic Corper	Electro discharge machining EDM	For surface roughness, current is most significant followed by pulse and voltage being the least significant factor
12.	Li *et al*., (2014)	Optimisation of cutting variables for energy reduction	Aluminium alloy	Carbide tool milling cutter	Milling operation	Unreasonable selection of cutting parameters result in significant energy loss. Reduction of energy consumption and product quality can be achieved with optimized cutting parameters

Table 2.2: Summary of Review and Literature continues

S/N	Author	Investigation	Work Piece Material	Cutting Tool Material	Machining Operation	Remarks
13.	Mourtzis *et al.*, (2016)	Estimation of energy consumption in machining processes by means of real time shop floor monitoring through network of wireless sensor.	Aluminium Steel	HSS milling cutter	Milling operation in wet and dry environments	Energy requirement of cutting w/piece materials were determined with a view of reusing the process parameters of cases investigated
14.	Nur (2016)	Estimation of power requirement in lathe machining of AISI 316L alloy steel using cutting force.	AISI 316L stainless steel	1.Uncoated (UTi20T) CNMG120503 nano- textured Al_2O_3 (MC7025	Dry turning operating	Speed of cutting and rate of feed are the most significant variables to power consumption. Feed rate increase enhances surface roughness.
15.	Raveedran and Marimuthu (2016)	Machining variables optimisation for minimisation of surface roughness while turning GFRP rod using RSM.	Glass fibre reinforced plastic GFRP rods	Carbide tool coated with TiN	Dry turning operation	Surface roughness is mostly influenced by cutting depth, rate of feed and speed of cutting in that order.

Table 2.2: Summary of Review and Literature continues

S/N	Author	Investigation	Work Piece Material	Cutting Tool Material	Machining Operation	Remarks
16.	Screenivasulu and Rao (2012)	GRA application in drilling operation involving AL 6061 alloy for roundness error and surface roughness.	Aluminium AL 6061 Alloy	Twist drills of HSS material.	Drilling operation	To minimise surface roughness, speed of cutting of 25.13m/min, rate of feed of 0.3 mm/rev, point angle of 110^0 and cutting fluid mixture ratio of 12% were advocated.
17.	Shaikh and Sidhu (2014)	Experimental investigation and optimisation of process variables in lathe machining of AISI D2 alloy steel using various cutting fluids	AISI D2 steel	CNMG 120408 carbide inserts with coating	Turning operation in wet environment using three different cutting fluids	For various cutting fluids used, different cutting parameters were obtained
18.	Sivarajan and Padmanabhan (2014)	Use of surface coated tools in forming and green machining of	AISI 4340 steel	PCBN tool insert produced by WIDIA	Turning operation in dry environment	160m/min Cutting speed was most preferred with 0.1mm/rev feed rate for minimum temperature to prevent tool material from losing 'its' hot-hardness property.
19.	Zhao *et al* (2016)	Energy consumption characteristics evaluation method in turning	High quality carbon structural steel (45# steel)	Hard alloy YT15 A32 external turning cutter	Turning under emotion cooling condition	Large rate of feed and cutting depth within allowable limit will cut-down energy consumption.
20.	Agu *et al*., (2019)	Multi response optimisation of machining parameters in turning AISI 304 L using different oil-based fluids	AISI 304 L	TNMG 1604 tungsten carbide insert	Turning operation in wet condition using different cutting flids	Feed rate has the most significant effect on surface roughness

2.7 Research Gap

In the last 100 years, several investigations have been done on modelling and optimisation of machining variables for effects such as, surface roughness, cutting forces, temperature, tool wear, and some others. Taylor's expression which relates cutting speed to tool life Taylor (1907), was used extensively in some of these researches. Noticeably, research on optimisation of energy consumption of machining operations has been on the down play based on the available literatures. Moreover, economic and technological considerations have been the driving force behind machinery optimization processes in the past without cognizance of environmental dimension and energy consumption.

The available literatures for optimisation of power consumption and surface roughness for various materials reveal varying results - some authors revealed that the most important factor is speed of cutting with cutting depth following, towards reducing the consumed power (Aggrawal *et al*., 2018; Bhattacharya *et al.*, 2009; Bushan, 2013).

In the studies conducted by Hanafi *et al*. (2012), Fratala and Ceiza, (2011), they observed that the significant parameter is cutting depth with speed of cutting following towards reducing the power consumed. Camposeco-Negrete, (2013), revealed that the important variable is rate of feed with cutting depth following, towards reducing the power consumed. Consequently, the need to conduct more research in determining the effect of cutting variables on energy consumption as a performance characteristic is paramount. The need for a generalised link between the cutting variables and the process performance is also very paramount. A regression model to satisfy a condition of predetermined surface roughness with minimum energy consumption is hard to accomplish due to the complexity and varying nature of components and mechanisms involved in the process of machining. In this work, effort is geared towards filling this research gap. After more than 100years of research, machining remains an open field of research. This is due to the fact of changes in machining technology, changes in workpiece material, their composition and properties, advancement of computational technology as well as advancement in modelling and optimisation techniques.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Workpiece material

The workpiece material applied in the experiments of this study is an austenitic chromium-nickel stainless steel categorised as AISI 304 by American Iron and Steel Institute (AISI). The general chemical composition, physical and mechanical properties of this workpiece material are as shown respectively in Tables 3.1, through 3.3.

Table 3.1: **AISI 304 Alloy Steel general chemical composition**

Component	**Weight** %
Iron Fe	66.35 – 74.00
Chromium Cr	18 - 20
Nickel Ni	8.00 – 10.50
Silicon Si	1.00 max
Carbon C	0.008 max
Phosphorus P	0.045 max
Sulphur S	0.03 max
Manganese Mn	2.00 max

Source: NAS, 2016

The actual composition of the AISI 304 workpiece material used in this study is presented in Table 4.4 as revealed by material composition test via optical Emission Spectrometer (OES).

Table 3.2: AISI 304 Alloy Steel general Physical Properties

S/N	Property	Value
1.	Density	8g/cc
2.	Heat conductivity	16.2 W/M – k
3.	Relative permeability	1.008
4.	Mean co-efficient of thermal expansion	17.93 μm/m – ^{o}C
5.	Melting range	1400 – 1455^{o}c
6.	Specific heat capacity	0.5 J/g –^{o}C

Source: NAS, 2016

Table 3.3: AISI 304 Alloy Steel's general mechanical Properties

S/N	Property	Value
1.	Brinell Hardness	123
2.	Ultimate tensile strength,	305 MPa
3.	Tensile yield strength,	215 MPa
4.	Poisson ratio	0.29
5.	Modulus of Elasticity	193 – 200GPa
6.	Elongation at break	70%
7.	Charpy impact	325J
8.	Shear modulus	86GPa

Source: NAS, 2016

3.1.2 Oils

Mineral soluble oil (MO) Mobil Met 424 was sourced from Osogbo in Osun State. Jathropha curcas vegetable oil designated as JO in this study was sourced from Zaria, Kaduna state.

3.1.3 Additives for the cutting fluid

In formulation of cutting fluids, additives are very important components. These are substances which confer special desired qualities to cutting fluids. According to Alves and Oliveira (2008), the composition of additives in any cutting fluid may vary between 25 to 30%. The common additives used while formulating the cutting fluids include emulsifier, anti-oxidant, biocide and anti-corrosion. In this study, these additives were used in the formulation of vegetable oil-based cutting fluid. Description of the additives applied in the formulation is shown in Table 3.4.

3.1.4 Basic water quality required in formulating cutting fluid

The basic need in the formulation of oil-based emulsion cutting fluids is water quality as it affects performance and stability. Water hardness is ascertained by the quantity of magnesium and calcium salts it contains as they have effects on the quantity of emulsifier in the process of formulating the oil-based cutting fluid. Soft water enhances unneeded bubbling but formation of water insoluble soap is promoted by hard water which consequently reduces quantity of emulsifier used. Consequently, the quality required of drinking water has been recognised and certified as meeting the demand in formulating oil-based cutting fluids. This is because the level of micro-organisms such as yeast, fungi, bacteria and others for the emulsion can be stabilised. World Health organization, (WHO) standard for good drinking water specifies pH value of 6.8 – 8.5 and maximum hardness level of 400mg/L (WHO; 2008). The water for this research work is distilled water sourced from the Water resources, Aquaculture and Fisheries Technology (WAFT) department's laboratory in the School of Agriculture at Federal University of Technology, Minna, Niger State and pipe borne water sourced from Osogbo, Osun state. The water for formulation of the cutting fluids used in orthogonal turning experiments was the one sourced from pipe borne water in Osogbo, Osun state.

The two sources of water satisfy the World Health Organisation (WHO) standard for good drinking water.

Table 3.4: Description of additives for formulation of vegetable oil cutting fluid

Additives	**Composition**	**Source**
Emulsifier	0.5M sodium lauryl sulphate + sodium tripoly phosphate + sulphuric acid + calcium carbonate in 5 litres of water.	Prepared in Chemical Engineering Laboratory of Federal University of Technology, Minna-Nigeria.
Anti-Oxidant agent	It contains equal concentration of 0.5M zinc chloride + peroxide + calcium carbonate solution	Prepared in Chemical Engineering Laboratory, Federal University of Technology, Minna, Nigeria.
Biocide	Mixture of equal concentration of 0.5M hypo chloride + phenolic solution + tris (hydroxymethyl) nitro methane calcium carbonate solution	Prepared in Chemical Engineering Laboratory of Federal University of Technology, Minna, Nigeria.
Anti-corrosion agent	Banana plant juice	Sourced locally from Minna, Niger State, Nigeria.

3.1.5 Machine tools and equipment

Lathe

The lathe machine to be used for this research is a CNC lathe located at Prototype Engineering Development Institute (PEDI), Ilesha, Osun State – Nigeria. The machine's characteristic is as follows: The lathe is shown in Plate I

Table 3.5: Characteristics Experimental CNC lathe

Manufacturer	**PRODIS corporation, Taichung, Taiwan**
Rated Power	5Hp
Voltage	380 – 440V
Speed (motor)	2500
Current	7.5Amps
Spindle speed	26 – 2400rpm
Bed size	1.2m
Controls	Electric buttons
Bed width	350mm
Spindle hollow	80mm
Model	2060 ENC
Machine Number	080730287

Plate I: PRODIS CNC Lathe

Cutting tools and holder

The cutting tool used is CNMG 1204082H tungsten coated carbide tool insert (indexable) by Widia India Tools. The cutting tool insert and tool holder are shown in plates II and III respectively. The cutting tool insert (indexable) and holder are made by Widia Tools, India.

Table 3.6: Characteristics of cutting tool holder

Model	**DCLNR 2020 K/Z**
Brand	WIDIA
Cross section	20 x 20mm^2
Shank Length	120m

Plate II: Cutting tool insert

Plate III: Tool holder

3.1.6 Test equipment

(i) Plate IV shows Digital surface Roughness Tester used. It is specified as Model SRT – 6200 with Accuracy of ±10% with fluctuation display value of not more than 6%. The surface roughness tester is produced by Merit-mi Instruments Company, Limited.

Plate IV: Digital surface roughness tester

(ii) The Digital clamp meter used is shown in Plate V. The specification is Model DT – 266. It is a hand-held instrument with a frequency range of 50 – 60Hz.

Plate V: Digital Clamp meter

(iii) pH meter model PHS – 25 produced by Shangai Jingk of peoples Republic of China was used in this research, the pH meter is shown in Plate VI

Plate VI: pH meter

3.2 Experimental methods

3.2.1 Determination of physicochemical properties

The physicochemical properties of the vegetable oil (Jathropha) was analysed at the Water Resources, Aquaculture and Fisheries Technology (WAFT) department's Laboratory in the School of Agriculture, Federal University of Technology, Minna, Niger State while the determination of Fatty acid composition was conducted at Federal

Institute of Industrial research Oshodi, (FIIRO), Lagos state. The following parameters were determined:

(i) Specific gravity

(ii) Viscosity

(iii) Free fatty acid, FFA.

(iv) Acid value

(v) Sap value

(vi) Flash point

(vii) Pour point

(viii) Moisture content

(ix) pH value

(x) Iodine value

The method used in the test for each of the physicochemical properties of the vegetable oil is given in Table 3.7. The description of the experimental procedure used for the various parameters tested is attached as appendix B.

Table 3.7: Determination of Physicochemical Properties of vegetable oil

Property	Method	Description
Specific gravity	$\frac{weight\ of\ oil}{weight\ of\ equal\ volume\ of\ water}$	Determination of the ratio of weight of oil to the weight of an equal volume of water
Acid value	Acid value (mg/KOH/g)	$= \frac{Titre\ value\ x\ 0.1M\ KoH\ x\ 56.1}{weigh\ of\ sample\ (g)}$
Free fatty Acid	Free fatty Acid FFA	$= \frac{Acid\ value}{2}$
Saponification value	ASTM D558	
Flash value	ASTM D93	The sample's flash point was determined with the aid of flash point tester.
Iodine value	ASTM D5768	The Iodine value was evaluated using the AOAC (2006) with equation $iodine\ value = \frac{(\mathrm{B} - S)xMx0.1269\mathrm{x}100}{\mathrm{W}}$
Pour point.	ASTM D5949	
Moisture content	ASTM D5348	The oil was heated in the muffle furnace until the weight remains constant
pH value	ASTM D7946	pH meter was used in determining the pH value

3.2.2 Gas Chromatography and Mass Spectrometer (GC-MS)

The vegetable oil (Jathropha) was subjected to Fatty acid composition (FAC) analysis using a gas chromatograph linked to a mass spectrometer (GC - MS) instrument. GC - MS – QP- 2010 Schimadzu system imported from Japan. The machine conditions used were as follows:

Column over temperature	70.0^0C
Injection temperature	250.0^0C
Column flow	1.8mL/min
Total flow	40.8mL/min
Linear velocity	49.2cm/sec
Pressure	116.9 KPa

The GC-MS test was conducted at Federal Institute of Industrial Research Oshodi (FIIRO), Lagos. The equipment used is shown in Plate VII. The result of Fatty Acid Composition (FAC) analysis is presented in Table 4.2

Plate VII: GC-MS machine

3.2.3 Process of formulating mineral Oil-based and vegetable oil-based cutting fluids

Percentage ratio of oil to (water + additives) of 1:9 is the basis for preparation of oil in water emulsion metal working fluids. The method used is the one followed by Muniz *et al.* (2008), and Onuoha (2015). The method involves controlled addition of the additives to the oil. A magnetic stirrer (Magnetic stirrer with hot plate 79-1) was used to stir the mixture at a speed of 1400 rpm for 15 minutes at ambient temperature. Various additives were added to the vegetable oil. The additives are emulsifier, anti-oxidant, biocide and anticorrosion agent, which were added in different percentages, and mixed thoroughly with mechanical stirrer. Water was then added to 90% by volume in order to make the emulsion ratio of 1:9 of base oil (mineral oil or vegetable oil) and water. The percentage ratio of additives used for the formulation, are emulsifier 11.81%, anti-oxidant 0.76%, biocide 0.64% and anti-corrosive agent 3.67% (Lawal *et-al.*, 2014). The idea behind adoption of this ratio was due to the observed properties of the vegetable oil (Jathropha) especially the fatty acid composition, which is revealed by GC-MS test on Jathropha oil as having higher percentage of unsaturated fatty acid as shown on Table 4.3.

The formulation involves the mixture of oil and additives and stirred to form a homogenous liquid before adding water to make up for the balance of the required volume. The algorithm for the formulation is shown in Figure. 3.1 and Figure. 3.2 for mineral oil-based and vegetable oil-based metal-working fluids respectively.

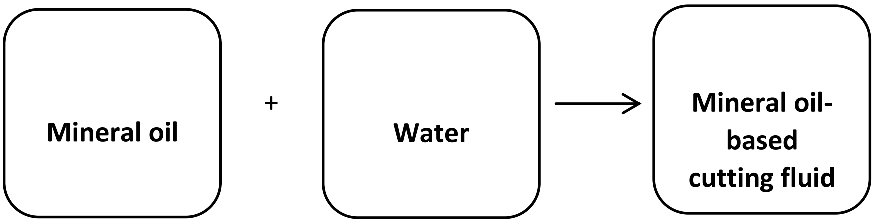


Figure 3.1: Formulation of mineral oil-based cutting fluid.

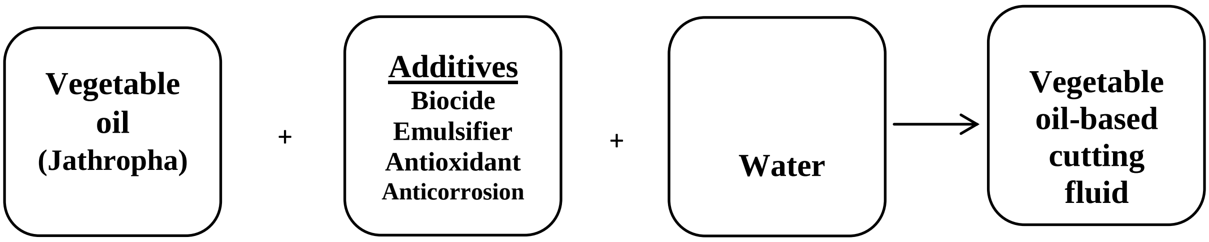


Figure 3.2: Formulation of vegetable oil-based cutting fluid

In preparation of one litre (1000ml) of mineral oil-based cutting fluid, the soluble oil concentrate was mixed with water in ratio 1: 9.

However, in preparation of one litre (1000 ml) of vegetable oil-based cutting fluid, the following calculation was applied to obtain the appropriate volume of each component.

1. 10% of oil in 1000 = 100mL
2. 11.81% emulsifier in 1000 = 118.1mL
3. 0.76% Anti-oxidant in 1000 = 7.6mL
4. 0.64% biocide in 1000 = 6.4mL
5. 3.67% Anti corrosive in 1000 = 36.7mL
6. Balance (73.12%) water = 731.2mL (Distilled water of 7.35 pH value)

3.2.4 Characterisation of formulated cutting fluids

(a) pH Value

An indication of the general condition of a fluid's acidity or alkalinity is its pH value. Reduction of a cutting fluid's pH value reflects a fall in its performance. When the pH value of a fluid becomes very high or very low, it becomes very dangerous to machine operators and problematic to dispose. Microbial contamination of cutting fluid occur in acidic medium rather than an alkaline medium. Consequently, and in accordance with Rao *et al.* (2007), a higher pH value enhances the fluid's resistance to microbial attack. According to Alves and Oliveira (2008), pH value range of 9 to11 has been suggested. It has been proved that an acidic (low pH value) will cut-down the corrosion protection of the workpiece and machine components; and consequently, cut-down their life stability. However, if the cutting fluid is strongly alkaline (high pH value), it will have the tendency to cause skin irritation to the operator and other users.

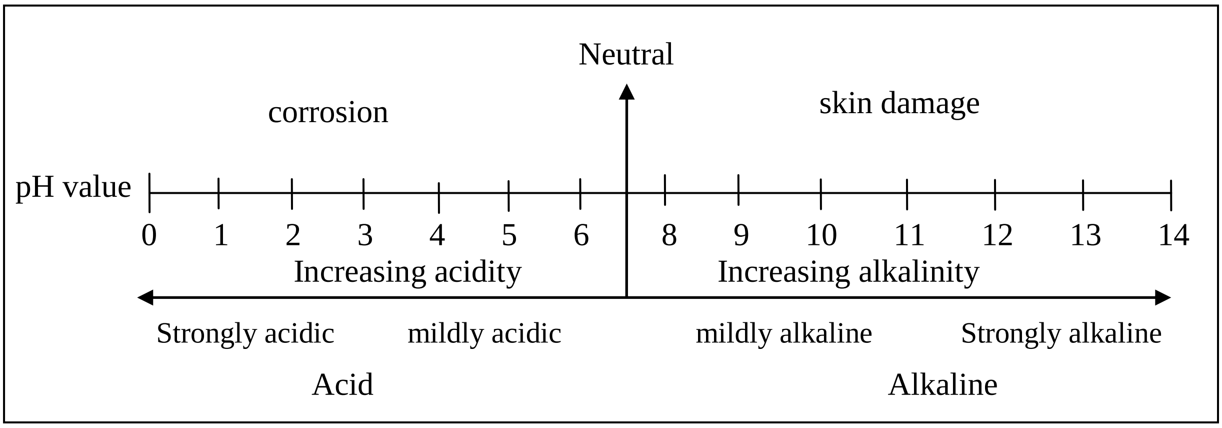


Figure 3.3: Effects of pH value on workers' health and materials.
Source: Alves and de Oliveira (2008)

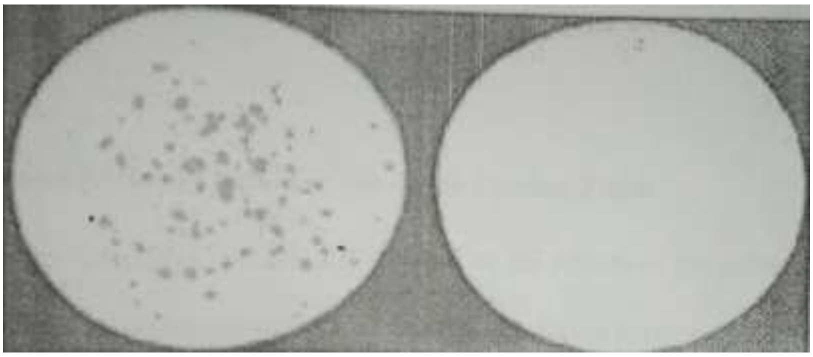
pH meter was used in determining the pH values of the cutting fluids in the Chemical Engineering Laboratory of Lagos State Polytechnic, Ikorodu, Lagos State, Nigeria. Before using the pH meter, it was first calibrated using buffer solution. After every reading, the electrode was cleaned with distilled water before another reading was taken. The results obtained is presented in Table 4.4.

(b) Viscosity

Viscosity is the measure of internal flow in liquids, semi-liquid or semi-solid substance. It is a measure of resistance of a liquid to flow. It is also the ratio of shear stress to the rate of shear during flow. For effective evaluation of the lubricating property of a cutting fluid, one of the deciding parameters in kinematic viscosity. According to Rao *et al,* (2007), the lubricating property of a cutting fluid increases with an increase in its kinematic viscosity. ASTM D445 method was used in determining the viscosity of formulated cutting fluids at the Chemical Engineering Laboratory, Federal University of Technology Minna, Niger State, Nigeria.

(c) Corrosion Level Test

Definition of corrosion is given as the deterioration of the surface layer of a metal due to chemical reactions between it and the environment surrounding it. The chemical reaction results in conversion of the useful materials such as metals and their oxides into useless oxides. The procedure used by Alves and Oliveira (2006) was used in determination of the corrosion level of the formulated cutting fluids. The test was carried out to examine the number of corrosion spots on a test filter paper resulting from the corrosive actions of the formulated vegetable oil-based cutting fluids. The procedure involves measuring 1g of cast Iron chips onto a filter paper placed on a petri dish. Then 2ml of the cutting fluid (mineral oil or vegetable oil) collected with a pipette was applied in wetting the iron chips placed on the filter paper in a petri dish. It was then covered for two hours. The iron chips were later thrown away and the filter paper properly rinsed away with pipe born water. Acetone was then used to treat the paper and then dried at ambient temperature. The corrosion level was then evaluated by visual inspection as shown in Plate VIII.



Before After

Plate VIII: Corrosion level test of cutting fluid

(d) Stability

Stability evaluation of the cutting fluids formulated was done on the basis of visual transparency within 24 hours period at ambient temperatures (26^{o}C) as to separation of water and oil in a graduated 100mL measuring cylinder. See Plate IX.

Plate IX: Stability test of emulsion cutting fluids

3.2.5 Characterisation of workpiece material

The need to ascertain the composition of the workpiece material is very paramount. Characterisation of the workpiece material was carried out at MIDWAL Engineering metallurgical and testing laboratory located at Ikota, Lekki peninsula, Lagos state. Optical Emission Spectrometry, (OES) method was used in determining the elemental composition of the AISI 304 Alloy steel workpiece material used in this research. The equipment used for this purpose is shown in Plate X. The procedure involves cutting a workpiece of Ø25mm by 25mm length. In view of the need for the workpiece sample to be a true representative, homogeneous and with smooth surface in order to eliminate factors which may have negative effects on the results, the two flat surfaces of the material were polished by means of small table-top disc grinder and polishing machine. The polished flat surface of the material was then positioned on the signal point of the OES machine and the machine switched on. The elemental composition of the material was then displayed on the screen. The procedure was then repeated for the second polished flat surface of the test workpiece. The result obtained is presented in Table 4.2

Plate X: Optical Emission Spectrometer (OES)

3.3 Design of Experiment

In science and engineering world, Design of experiment (DOE) is a vital tool for planning of experiment and analysis of experimental results. It is also used in activities involved in engineering design with the aim of developing new products or improve on the existing ones. According to Masounave *et al.*(1997), Statistical design of experiment addresses the arrangement and organisation of an experiment to facilitate collection of appropriate data, analyse the data using statistical method to obtain conclusions which are valid and objective. Experimental design methods which include Taguchi, Response surface methodology, Factorial design and some others are presently being used widely instead of the old method of one factor at a time (OFAT) method of experiment which is too exorbitant, costly, laborious and time-consuming (Das *et al.,* 2013). Any experiment is of two aspects which include the aspect of the design of the experiment and the aspect of statistical analysis of data. The pre-experimental planning activities for this study includes recognition and statement of the problem- which is Investigation of the energy consumption in orthogonal turning of AISI 304 alloy steel using formulated vegetable oil-based cutting fluid. Other pre-experimental activities include:

(i) Choice of the response parameters – Energy consumption and Surface roughness; and

(ii) selection of factors levels and their ranges.

In the design of this investigation, the machining variables which include depth of cut (d), cutting speed (Vc) and feed rate (Fr) are very significant and are consequently the major input factors. Similarly, the three cutting environments being investigated which include dry condition, wet condition (with mineral oil-based cutting fluid) and wet condition (with vegetable oil-based cutting fluid) may have effects on the energy consumption as well as surface roughness of the workpiece. Hence, they are considered as the input variables. Consequently, the potential design variables of the experiments are:

i. Cutting depth (d)
ii. Speed of cutting (Vc), and
iii. Rate of feed (Fr)

Two levels of experimentation were selected as low (-1) and high (+1). The chosen method of design of experiment was Response Surface Methodology (RSM). This choice of DOE was bore out of the following reasons;

i. It includes factors outside the chosen variables, that is below the minimum and above the maximum variables with twenty (20) experimental runs
ii. It gives accurate and powerful test with reduced error variance
iii. It gives a greater precision which can be obtained in estimating the overall main factor effects; and
iv. Interaction between different factors that is properly identified and explored without confounding the effects.

The criteria used in selecting cutting variables are shown in Tables 3.6 and 3.7. Three factors which include cutting depth, speed of cutting and rate of feed were used at two levels. A total of 20 experimental runs were carried out in each of the three cutting environments which include dry and the two wets – mineral oil-based cutting fluid and vegetable oil-based cutting fluid. The experimental runs are presented in Table 3.8.

Table 3.8: **Cutting parameters and levels**

Input variable	**Unit**	**Lower limit** **Low (-1)**	**Upper limit** **High (+1)**
Cutting depth (A)	mm	-1	+1
Speed of cutting (B)	rev/min	-1	+1
Rate of feed (C)	mm/min	-1	+1

Statistical analysis of the data collected from the experiments was carried out with the use of minitab 17 statistical software and design expert statistical software was used to generate the Regression equations.

Table 3.9: **Cutting parameters (factors) and their limits**

Input variable	**Unit**	**Lower limit** **Low (-1)**	**Upper limit** **High (+1)**
Cutting depth (A)	mm	0.25	0.50
Speed of cutting (B)	rev/min	600	1200
Rate of feed (C)	mm/rev	0.5	1.0

RSM experiment of central composite design (CCD) is shown in Table 3.7. A total of 20 experimental runs shall be carried out in each of the three cutting environments – dry, wet (with mineral - oil-based cutting fluid) and wet (with vegetable - oil-based cutting fluid). For every experiment, new cutting edge of the cutting tool insert was selected and used in order to ensure that the geometry of the cutting tool is kept constant. During wet cutting experiments, the cutting fluid was applied by conventional wet (flooding) technique at a flow rate of 3.1L/min. Values of these variables were selected in the experimentation based on the characteristics of the CNC lathe, values available from literature and observations from the preliminary experiments conducted

Table 3.10: Experimental layout of L $_{20}$ orthogonal arrays

Run order	Speed of cutting Vc (rev/min)	rate of feed Fr (mm/rev)	Cutting depth d(mm)
1.	600	0.5000	0.25000
2	600	0.5000	0.75000
3	600	1.00000	0.25000
4	600	1.00000	0.75000
5	1200	0.50000	0.25000
6	1200	0.50000	0.75000
7	1200	1.00000	0.25000
8	1200	1.00000	0.75000
9	395.46	0.75000	0.50000
10	1404.54	0.75000	0.50000
11	900	0.32955	0.50000
12	900	1.17045	0.50000
13	900	0.75000	0.079552
14	900	0.75000	0.92000
15	900	0.75000	0.50000
16	900	0.75000	0.50000
17	900	0.75000	0.50000
18	900	0.75000	0.50000
19	900	0.75000	0.50000
20	900	0.75000	0.50000

3.4 Experimental Method for Orthogonal Turning Process

All turning investigations were executed on a 3-jaw CNC lathe made by PRODIS having speed varying from 26 – 2400 rpm and 5 Hp rated power (see plate XI). Rhombic shaped Tungsten coated carbide tool inserts CNMG 120408RH by Widia Tools, mounted on a right-hand tool model DCLNR 2020 k 12 (produced by WIDIA Tools) was applied with a new cutting edge for each experimental run. The investigation of energy consumption and surface roughness were carried out on stainless steel (AISI 304) circular rods of 25mm diameter and length of 600mm fixed on the 3-jaw dependent chuck of the CNC lathe and then centre-drilled. The workpiece was then re-positioned on the chuck with an overhang length of 550 mm and also supported with a revolving centre positioned on the tail stock. Firm holding of the workpiece was achieved by proper tightening of the 3-jaw dependent chuck after ascertaining the concentricity of the mounted workpiece. The need to support the workpiece arise from the fact that, the ratio $\frac{l}{d} = \frac{550}{25} = 22$ .When the ratio $\frac{l}{d} > 4$, the workpiece must be supported, l being the overhang workpiece's length and d being diameter. (Lawal *et al*., 2011). The workpiece was then supported with the tail stock, since for this research, the ratio $\frac{l}{d} > 4$,. Orthogonal turning operations were then carried out at ambient temperature. Figure 3.3 shows the schematic diagram for the orthogonal turning process, adopting the step used by Suhail *et al.*, (2010). The experimental scene for orthogonal turning is shown in Plate XI.

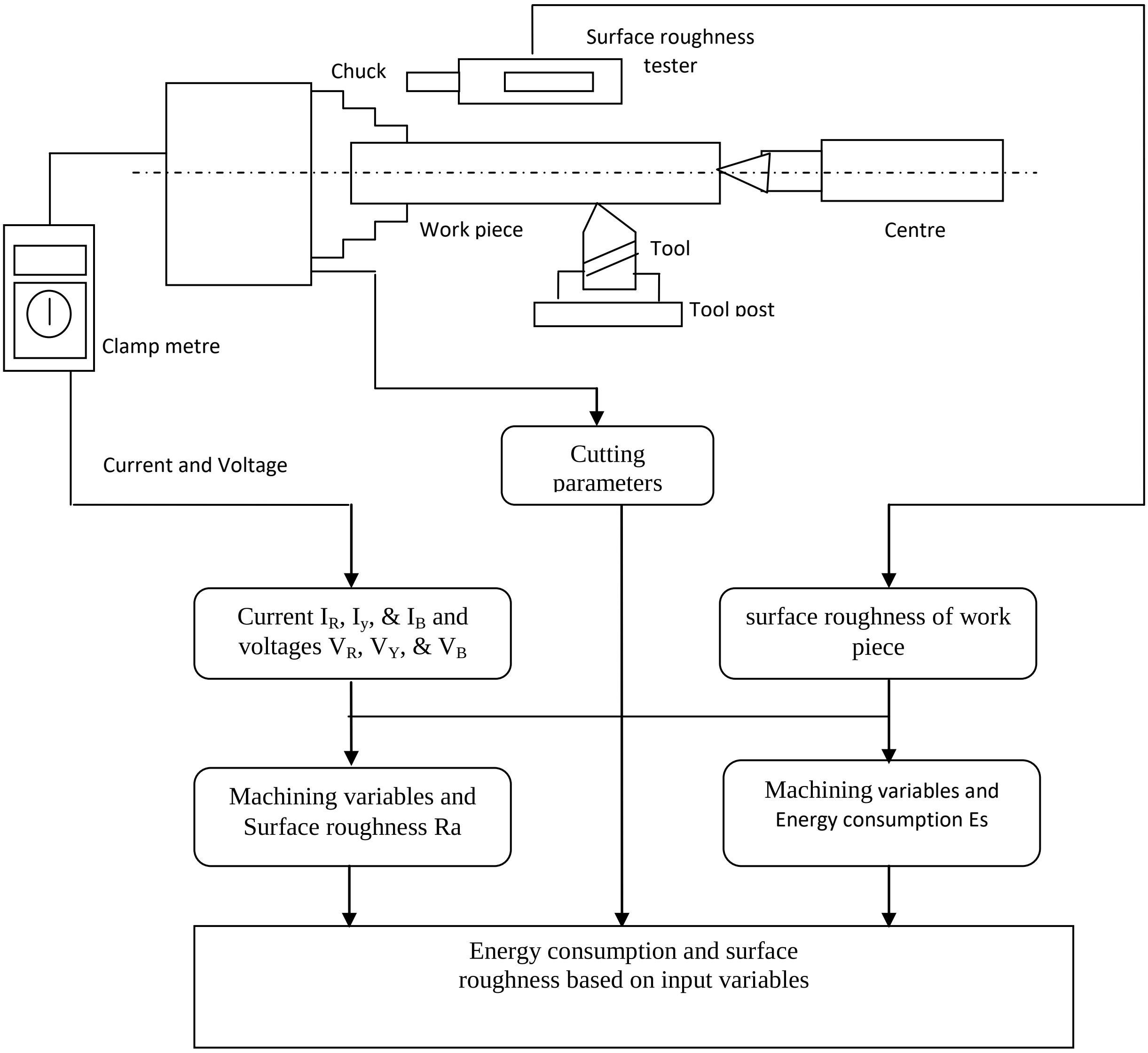


Figure 3.3: Schematic Diagrams of the machining operations
Source: Suhail *et al*., (2010)

Plate XI: Experimental scene for orthogonal turning

3.4.1 Evaluation of current and voltage

(a) Measurement of current

For each experimental run, the clamp meter shown in plate IV was used in measuring the current flowing through each of the 3-phase mains wire – red, yellow and blue phase wires. The measurements were accomplished by setting the knob of the instrument to current mode and then clamp the jaws of the clamp meter around the phase wire. The experimental set up for measurement of current is shown in plate XII. The current flowing through the wire is then displayed on the instrument and was noted and recorded. The current flowing through red, yellow and blue phases was recorded as I_R, I_Y and I_B respectively. The values obtained are presented in Tables 4.3, 4.4 and 4.5 for dry, wet using mineral oil-based cutting fluid and wet with vegetable oil-based cutting fluid environments respectively.

Plate XII: Experimental set up for measurement of current

(b) Measurement of voltage

Clamp meter was also used to measure the voltage on each phase. This was accomplished by setting the knob of the instrument to voltage mode and then connected to the mains supply wire as shown in plate XIII. The voltages for red, yellow and blue phases were recorded as V_R, V_Y and V_B respectively. The values obtained are presented in Tables 4.1, 4.2 and 4.3.

Plate XIII: Experimental set up for measurement of voltage

3.4.2 Surface roughness measurement

The mean value of the surface hills and valleys of every machined portion of the workpiece were checked using surface roughness tester, model SRT – 6200 as shown in Plate XIV. The equipment has an accuracy of + 10% and fluctuation display value of 6%. Measurements were checked and noted at three different locations around the circumference and along the length of the round bar workpiece and the average of the three readings evaluated and recorded for each experiment. The values obtained are presented in Tables 4.1, 4.2 and 4.3.

A good surface finish is required to improve the performance, fatigue strength corrosion resistance and aesthetics of the machined part. The manufacturing industry pays special attention to dimensional accuracy and surface finish. In order to obtain the best performance and accomplish the best possible surface finish, the manufacturing industry has turned to manual-based and operator's experience. This traditional practice leads to in-correct surface finish and lower productivity due to insufficient processing capacity (Ragnath and Vipint, 2014).

Plate XIV: Experimental scene for measurement of workpiece's surface roughness

3.4.3 Energy consumption evaluation

The steps used for calculation of energy consumption for each experimental run is as enumerated in this section.

(a) Evaluation of power consumption.

According to Theraja (2004),

Apparent power $P_A = V \times I$ (Volts Amperes) 3.1

True power $P_T = V \times I \times p.f$ (Watts) 3.2

Where p.f = power factor

The true power on each phase is thus calculated as follows:

For red phase, power $P_R = V_R \times I_R \times p.f$ 3.3

For yellow phase, power $P_Y = V_Y \times I_Y \times p.f$ 3.4

For blue phase, power $P_B = V_B \times I_B \times p.f$ 3.5

Hence, power consumption for each experimental run is given by:

$Pi = P_R + P_Y + P_B$ 3.6

Where i = run order number = 1, 2, 3 ……… 20.

(b) Energy consumption

According to Ithipri *et al.*, (2015),

Specific energy consumption, Es = $\frac{P_i}{V_c \, x \, f \, x \, d}$ (J/mm^3) 3.7

Where d = cutting depth (mm),

$V_{C =}$ speed of cutting (mm/min), and

f = rate of feed (mm/rev)

Since, Spindle speed N = $\frac{1000V_c}{\pi D}$ (rev/min) 3.8

Where D is workpiece diameter (mm)

Hence, $V_c = \frac{\pi DN}{1000}$ 3.9

Since workpiece's diameter D is 25mm,

Hence, $V_C = 0.07854N$ (mm/rev) 3.10

The specific energy consumption for each experimental run was then calculated and presented in Tables 4.7, 4.8 and 4.9 for dry, wet with mineral oil-based cutting fluid and wet with vegetable oil-based cutting fluid respectively.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physicochemical Characterisation of Jathropha Oil

Zaria sourced vegetable oil (Jathropha) is of yellow colour while the mineral oil purchased from Osogbo had a golden yellow colour. Both oils are stable at room temperature 25^{o}C.

The physiochemical property of the vegetable oil was assessed using standard methods. Table 4.1shows the result of the physicochemical properties of Jathropha vegetable oil.

Table 4.1: **Physiochemical Properties of Jathropha Vegetable Oil**

S/N	Parameter	Value
1.	Specific gravity	0.916
2.	Acid value (mg/100g)	7.85
3.	Free Fatty Acid (mg/100g)	3.93
4	Saponification value (mgKOH/g)	189.33
5	Flash point (^{0}C)	219
6.	Pour point (^{0}C)	-7
7.	Moisture content (%)	0.89
8.	pH value	5.09
9.	Iodine value g/100g of KOH	113.4
10.	Viscosity@ 25^{0}C (mm^{2}/s	32

From the result of physicochemical analysis, the specific gravity of vegetable oil is 0.916 which confirms that it is lighter than water and also within the standard range of 0.76 - 0.92 for lubricants as revealed by (Godfrey and Herguth, 1995). This value also agrees with that of Aminul Islam *et al. (*2012), where Jathropha curcas from different origins were found to be within 0.914 and 0.920 with mean value of 0.916, the same value as specific gravity obtained for the oil of this study.

The flash point of the Jathropha vegetable oil is 219^oC which makes it safe for use as lubricant. This result agrees with the outcome of Foidi *et al.* (1996), and Oudraogo *et al*. (1991). Generally, vegetable oils have high flash points which enhance their safety for lubrication in fire-risk operation (Oseni *et al*., 2013). Flash point of Jathropha is similar to that of other vegetable oils. Its pH value is 5.09 which show that it is acidic. This is close to the range of 5.30 to 6.07 reported by (Ibeto *et al*., 2010). The reference point for monitoring oil condition during use is provided by the acidity of the oil (Oseni *et al*., 2013). An increase in acidity during use indicates the accumulation of oxidation products in the oil. The most significant attribute for establishing the thickness, temperature and pressure of an oil for lubrication is viscosity. Viscosity of vegetable oil (Jathropha) used is 32mm^3/s and this agrees with the findings of Abdullahi *et al*. 2013), Saponification value (SAP) is a measure of the average molecular weight of the oil and its ability to form soap. Since the saponification value (SAP) of this oil is greater than 100, it indicates the existence of fatty acids which are unsaturated and characteristics of foaming ability (Duduyemi *et al*., 2013). The SAP of the Jathropha oil for this research is 189.23mgKOH/g of oil. This agrees with the outcome of Aminul Islam *et al*., (2012).

Iodine confers oiliness in lubricants, hence lowering the coefficient of friction of lubricants. It also improves load bearing capacity and anti-wear characteristics of lubricants (Furey and Heights, 1962). The Iodine value reflects degree of unsaturation of fats and oil. Higher Iodine value reflects higher saturation of fats and oils (Knothe, 2002). The Iodine value of 113.4mg/g of oil obtained in this research is the same for a Jathropha oil sample sourced from India as reported by Aminul Islam *et al*., (2012).

The unsaturation of oil reflects the susceptibility of oil to oxidation (Jaiyeoye *et al*., 2014). The values obtained for other parameters tested are within acceptable range. This confirms the suitability of Jatropha vegetable oil for cutting fluid formulation for machining purpose. However, it should be noted that according to Sayak and Patel (2010), physiochemical properties of oil changes with respect to the atmospheric condition and location.

4.2 Gas Chromatograph and Mass Spectrometer (GC-MS) Analysis

Figure 4.1 shows the graph of the gas chromatograph and mass spectrometer (GC-MS) of the Jathropha vegetable oil.

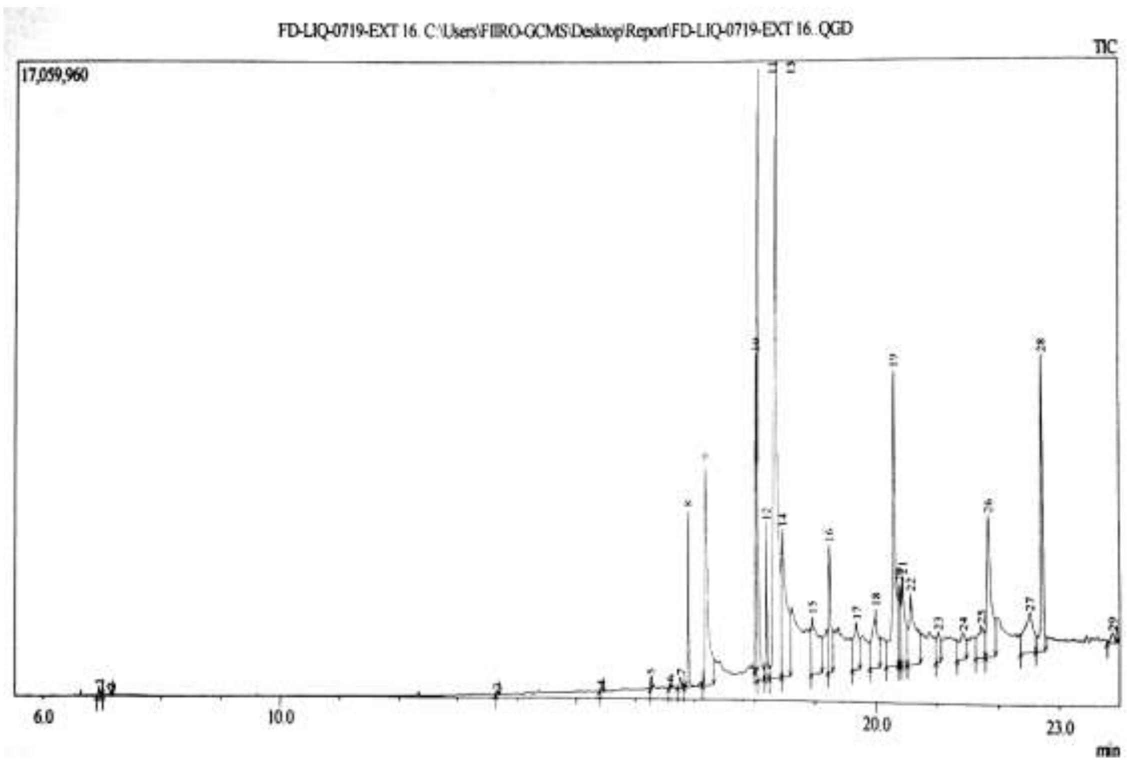


Figure 4.1: Graph of GC-MS of the Jathropha vegetable oil

Interpretation of GC-MS was done using the data base of Nigerian Institution of Science and Technology, (NIST), having very large patterns in the Library that is built into the GC-MS machine. Tables 4.2 show the Fatty Acid composition results of jathropha seed oil. From the results, unsaturated acid has the highest values of 77.02 %. This implies that the selected vegetable oil – Jathropha is liquid at room temperature and consequently fit for formulation of cutting fluid. Table 4.2 shows the fatty acid composition of the Jathropha vegetable oil used while the fatty acid profile is presented on Table 4.3.

Table 4.2: Jathropha Seed Oil's Fatty Acid Composition

S/N	IUPAC name	chemical formula	fatty acid	type of fatty acid	value (%)
1.	Hexadecanoic	$C_{17}H_{34}O_2$	Palmitic	Saturated	2.20
2.	n-Hexadecadienoic	$C_{16}H_{32}O_2$	Palmitic	Saturated	6.21
3.	Octadecadeinoic	$C_{19}H_{34}O_2$	Linoleic	Poly-unsaturated	3.64
4.	11-octadecenoic	$C_{19}H_{36}O_2$	Elaidic	Unsaturated	7.39
5.	Methyl stearate	$C_{19}H_{38}O_2$	Stearic	Saturated	1.72
6.	Cis-vacenic	$C_{18}H_{34}O_2$	Oleic	Mono-unsaturated	20.71
7.	Oleic	$C_{18}H_{34}O_2$	Oleic	Mono-unsaturated	6.48
8.	9-Octadecenal (z)	$C_{18}H_{34}O$	Linoleic	Poly-unsaturated	3.94
9.	15-Hydroxypentadecenoic	$C_{15}H_{30}O_3$	Palmitic	Saturated	2.85
10.	17-Octadecynoic	$C_{18}H_{32}O_2$	Stearic	Saturated	2.34
11.	9-Octadecenoic (z)	$C_{21}H_{40}O_4$	Oleic	Saturated	3.17
12.	Cis-9-Hexadecenal	$C_{16}H_{30}O$	Linoleic	Poly-unsaturated	8.48
13.	8-Hexadecenal	$C_{18}H_{34}O$	Linoleic	Poly-unsaturated	1.80
14.	Cis-9-Hexadecenal	$C_{16}H_{30}O$	Linoleic	Poly-unsaturated	2.85
15.	Hexadecanoic	$C_{19}H_{35}O_4$	Palmitic	Saturated	4.64
16.	13-Tetradecenal	$C_{14}H_{26}O$	Myristoleic	Mono-unsaturated	1.77
17.	17-Octadecynoic	$C_{18}H_{32}O_2$	Stearic	Saturated	1.70
18.	16-Dieporydexadecanol	$C_{16}H_{30}O_4$	Oleic	Poly-unsaturated	1.95
19.	9-octadecanoic	$C_{21}H_{40}O_4$	Oleic	Mono-unsaturated	5.90
20.	13-Octadecedien	$C_{18}H_{34}O$	Oleic	Mono-unsaturated	3.49
21.	Squalene	$C_{30}H_{50}$	Linoleic	Poly-unsaturated	6.07
22.	sum of fatty acids with insignificant values				0.68

Table 4.3: Jathropha vegetable oil's

S/n	Acid	Form	Value (%)
1.	Myrinstoleic	C 18:1	1.17
2.	Oleic	C18:1	39.75
3.	Palmitic	C16:0	15.90
4.	Stearic	C18.0	5.96
5.	Linoleic	C 18:2	28.73
6.	Elaidic	C 18: 1	7.37
7.	Others	-	1.12
	Total		100.00

From Table 4.3, it can be deduced that

∑ Saturated Fatty acid = 21.86%

∑ Unsaturated Fatty acid = 77.02%

∑ Others = 1.12%

Grand Total = 100%

This result agrees with the findings of Heller (1996) which reported that Jathropha oil is made of high quantity of about 78 – 84% unsaturated Fatty acid. The ratio of Unsaturated acid: Saturated acid: Others is approximately 7:2:1. This implies that the oil is unsaturated in nature; it will remain liquid at room temperature and is consequently suitable to formulate cutting fluids for machining.

4.3 Characteristics of Cutting Fluids

Table 4.4 shows the characteristics of the formulated mineral oil-based and vegetable oil-based cutting fluids used in the experiments of this research. The pH value, viscosity, corrosion level, colour and stability of the mineral oil-based and vegetable oil-based oil-in-water cutting fluids which has 10% Oil and 90% water by volume for these samples are presented in Table 4.4

Table 4.4: Characteristics of various cutting fluids

S/N	Parameter	Values	
		Mineral oil	**Vegetable oil**
1.	Colour	Milky	Milky
2.	Stability	Stable	Stable
3.	Viscosity (mm^2/s)	1.00	2.315
4.	pH value	8.9	8.65
5.	Corrosion level	Corrosion resistant	Corrosion resistant

Viscosity

Viscosity is a fluid's ability to resist flow. A good metal working fluid is expected to have moderate viscosity so that it can be easily pumped from the sump through pipes and hoses into the cutting zone to enter and lubricate between the cutting tool and chip to reduce heat and friction, and also cool to take away the heat generated.

pH value

The pH value of formulated cutting fluids is influenced by the choice and quantity of additives. It is a measure of the fluid's alkalinity or acidity. The pH value of a cutting fluid should be maintained within a limited of alkalinity range of 8.3 to 11 (Alves and Oliveira, 2008). The results obtained for the two cutting fluids formulated lies within this range.

Corrosion level

Spots of rust could not be seen on the filter paper after the test for the two cutting fluids formulated. This implies that both formulated cutting fluids exhibit good corrosion resistance characteristic.

Stability

The two formulated cutting fluids show adequate stability within 24 hours and after seven days. This result agrees with the uncovering of Aminul Islam *et al* (2012) and Zhao *et al* (2006). Hence, both oils are suitable for formulation of cutting fluids for metal cutting purpose.

4.4 Characterisation of Workpiece material

The result of the characterisation of the workpiece material conducted via Optical Emission Spectrometer is presented in Table 4.5. The material composition results and certificate of characterisation obtained from the test laboratory – Midwal Engineering are attached as appendix C1 and C2 respectively.

Table 4.5: AISI 304 Alloy Steel Workpiece Composition

Element	Fe	Cr	Ni	Mn	Si	Cu	Co	C	V	N
Composition (%)	70.7	18.04	8.33	1.36	0.408	0.329	0.199	0.096	0.0729	0.0409

The result agrees with the expected composition of AISI 304 as reported by NAS, 2016 and as presented in Table 3.1. This implies that the workpiece material used is truly AISI 304 intended to be used for this investigation. The laboratory certificate for the material composition test is attached as Appendix C.

4.5 Results of Turning Experiments

The DOE applied in this research was Response Surface Methodology (RSM), for the turning of AISI 304. 20 experiments each was conducted in each of the three environment – dry, wet, (with mineral oil in water) and wet (with vegetable oil in water) to make a total of 60 experimental runs. The results obtained were analysed by means of ANOVA and signal to noise ratio optimization procedure to appraise the machining performance with respect to energy consumption and surface roughness.

According to Onuoha (2015), performance characteristics using S/N ratio are commonly applied as stated below:

1. Nominal – the better, S/N = $10 \log \left[\frac{y^2}{S^2}\right]$ 4.1

2. Bigger – the – better, S/N = $-10 \log \left[\frac{1}{n} \sum_{i=1}^{n} 1/y_i^2\right]$ 4.2

3. Small – the better, S/N = $10 \log \left[\frac{1}{n} \sum_{i=1}^{n} y_i^2\right]$ 4.3

Where S/N is the signal to noise; y_i = individual responses; n = number of responses for the given factor combination; and S = Responses standard deviation for the given factor level combination.

4.5.1 Experimental results

The experimental results showing the measured current and voltage for each experimental run are presented in tables 4.6, 4.7 and 4.8 for dry, wet (with mineral oil-based cutting fluid) and wet (with vegetable oil-based cutting fluid) environments respectively

Table 4.6: Experimental results in dry turning

Run order	Current I (A)			Voltage V (volts)			Surface roughness Ra (µm)
	I_R	I_Y	I_B	V_R	V_Y	V_B	
1.	6.5	6.6	6.5	227	224	228	1.34
2.	6.5	6.3	6.4	231	232	228	3.81
3.	5.7	5.5	5.4	226	227	227	5.48
4.	5.7	6.0	5.9	227	227	226	7.92
5.	5.5	5.4	5.2	226	227	227	4.24
6.	6.4	6.0	5.8	232	227	228	4.15
7.	3.7	3.9	4.0	229	229	228	4.40
8.	4.3	4.1	4.1	226	228	228	4.17
9.	6.0	6.1	6.1	231	230	227	5.15
10.	6.9	6.5	6.2	229	230	231	5.26
11.	6.8	6.0	6.0	227	228	226	4.85
12.	3.4	3.5	3.4	226	229	227	4.25
13.	5.8	6.2	5.9	230	229	228	2.07
14.	3.8	3.8	3.8	228	229	229	3.70
15.	6.2	6.3	6.2	228	227	227	5.05
16.	6.8	6.4	6.4	229	220	221	4.87
17.	6.4	6.3	6.5	227	228	226	5.15
18.	6.5	6.3	6.1	230	230	229	4.88
19.	6.1	6.3	6.1	281	230	229	4.76
20.	5.7	6.0	5.9	227	227	226	5.48

Table 4.7: Experimental results in wet turning with mineral oil-based cutting fluid

Run order	Current I (A)			Voltage V (volts)			Surface roughness Ra
	I_R	I_Y	I_B	V_R	V_Y	V_B	(μm)
1.	3.3	3.3	3.0	228	228	226	2.73
2.	5.9	6.0	5.7	228	225	224	1.25
3.	6.1	6.2	5.8	229	228	229	3.93
4.	6.8	6.4	6.5	228	227	226	1.57
5.	6.0	6.1	5.7	228	224	224	2.85
6.	4.8	5.4	5.4	228	227	226	2.66
7.	3.6	3.5	3.3	228	228	226	4.36
8.	6.0	5.2	4.9	229	230	226	2.70
9.	6.1	5.9	6.0	228	231	227	5.55
10.	4.7	4.3	3.9	224	228	226	4.27
11.	4.0	3.9	3.7	227	228	226	3.43
12.	4.1	3.9	3.5	226	228	226	1.59
13.	6.1	7.5	6.0	230	232	234	2.86
14.	6.1	6.0	6.0	229	228	226	3.27
15.	6.0	6.1	5.8	228	227	228	3.39
16.	5.4	5.0	4.8	229	229	228	3.11
17.	6.1	6.2	6.0	229	227	227	3.35
18.	6.0	6.1	6.0	228	231	227	3.31
19.	6.0	5.8	5.7	226	228	226	3.41
20.	5.1	5.3	5.5	227	228	226	3.15

Table 4.8: Experimental results in wet turning with vegetable oil-based cutting fluid

Run order	Current I (A)			Voltage V (volts)			Surface roughness Ra
	I_R	I_Y	I_B	V_R	V_Y	V_B	(µm)
1	7.6	10.2	10.4	223	229	227	1.41
2	6.6	5.8	5.8	232	229	228	1.15
3	5.4	5.3	5.0	233	226	230	3.74
4	7.0	9.9	5.9	227	226	223	4.22
5	5.3	5.6	5.3	227	228	226	1.33
6	6.4	6.4	6.2	244	241	236	1.57
7	3.9	4.3	4.0	228	229	224	3.22
8	4.0	4.2	4.0	240	229	234	3.41
9	6.0	6.2	6.0	227	227	224	2.64
10	5.9	6.5	5.9	227	227	225	2.18
11	5.7	5.8	6.0	236	230	224	1.085
12	3.3	3.4	3.3	226	226	223	3.84
13	5.8	5.6	5.3	230	231	227	2.78
14	3.4	3.6	3.5	227	227	227	2.56
15	5.8	6.0	6.2	230	227	226	2.88
16	6.2	6.1	6.0	231	236	224	2.66
17	4.8	6.0	5.3	226	228	223	2.64
18	6.1	6.2	6.1	232	229	227	2.94
19	5.7	6.1	5.9	229	229	226	2.88
20	3.2	3.5	3.3	230	229	225	2.64

4.5.2 Experimental process parameters and results

The experimental process parameters and results using the experimental design layout shown in Table 3.7 is presented in Table 4.9, 4.10 and 4.11.

Table 4.9: **Experimental Process variables and results for dry turning.**

Run order	Speed of cutting Vc (rev/min)	Rate of feed Fr(mm/rev)	Cutting depth d (mm)	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (µm)
1.	600	0.5000	0.25000	318.031	1.34
2.	600	0.5000	0.75000	118.012	3.81
3.	600	1.00000	0.25000	270.897	5.48
4.	600	1.00000	0.75000	60.038	7.92
5.	1200	0.50000	0.25000	100.100	4.24
6.	1200	0.50000	0.75000	247.802	4.15
7.	1200	1.00000	0.25000	49.257	4.40
8.	1200	1.00000	0.75000	124.748	4.17
9.	395.46	0.75000	0.50000	195.166	5.15
10.	1404.4	0.75000	0.50000	88.941	5.26
11.	900	0.32955	0.50000	293.122	4.85
12.	900	1.17045	0.50000	85.785	4.25
13.	900	0.75000	0.079552	864.208	2.07
14.	900	0.75000	0.920000	68.385	3.70
15.	900	0.75000	0.500000	132.500	5.05
16.	900	0.75000	0.500000	136.032	4.87
17.	900	0.7500	0.500000	132.300	5.15
18.	900	0.75000	0.500000	132.178	4.88
19.	900	0.75000	0.500000	131.010	4.76
20.	900	0.75000	0.500000	134.500	5.48

Table 4.10: Experimental Process Parameters and Results for wet turning with mineral oil-based cutting fluid

Run order	Speed of cutting Vc (rev/min)	Rate of feed Fr(mm/rev)	Cutting depth d (mm)	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (µm)
1.	600	0.5000	0.25000	233.195	2.73
2.	600	0.5000	0.75000	354.035	1.25
3.	600	1.00000	0.25000	53.523	3.93
4.	600	1.00000	0.75000	245.08	1.57
5.	1200	0.50000	0.25000	39.908	2.85
6.	1200	0.50000	0.75000	272.384	2.66
7.	1200	1.00000	0.25000	140.521	4.36
8.	1200	1.00000	0.75000	47.153	2.70
9.	395.46	0.75000	0.50000	252.588	5.55
10.	1404.4	0.75000	0.50000	27.152	4.27
11.	900	0.32955	0.50000	180.877	3.43
12.	900	1.17045	0.50000	28.987	1.59
13.	900	0.75000	0.079552	75.242	2.86
14.	900	0.75000	0.920000	58.074	3.27
15.	900	0.75000	0.500000	124.973	3.39
16.	900	0.75000	0.500000	124.214	3.11
17.	900	0.75000	0.500000	121.964	3.35
18.	900	0.75000	0.500000	122.672	3.31
19.	900	0.75000	0.500000	124.907	3.41
20	900	0.75000	0.500000	124.921	3.15

Table 4.11: Experimental Process Parameters and Results for wet turning with vegetable oil-based cutting fluid.

Run order	Speed of cutting Vc (rev/min)	Rate of feed Fr(mm/rev)	Cutting depth d (mm)	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (µm)
1.	600	0.5000	0.25000	305.53	1.41
2.	600	0.5000	0.75000	107.903	1.15
3.	600	1.00000	0.25000	154.826	3.74
4.	600	1.00000	0.75000	62.698	4.22
5.	1200	0.50000	0.25000	94.644	1.33
6.	1200	0.50000	0.75000	249.738	1.57
7.	1200	1.00000	0.25000	122.994	3.22
8.	1200	1.00000	0.75000	41.136	3.41
9.	395.46	0.75000	0.50000	196.292	2.64
10.	1404.4	0.75000	0.50000	74.082	2.18
11.	900	0.32955	0.50000	276.336	1.085
12.	900	1.17045	0.50000	126.703	3.84
13.	900	0.75000	0.079552	76.547	2.78
14.	900	0.75000	0.920000	74.913	2.56
15.	900	0.75000	0.500000	124.144	2.88
16.	900	0.75000	0.500000	124.624	2.66
17.	900	0.75000	0.500000	123.338	2.64
18.	900	0.75000	0.500000	123.335	2.94
19.	900	0.75000	0.500000	124.352	2.88
20.	900	0.75000	0.500000	125.381	2.64

From Tables 4.9, 4.10 and 4.11, it can be ascertained that the values of the responses (energy consumption and surface roughness) change with variation in process parameters.

4.6 Analysis of Experimental results for dry turning

4.6.1 Analysis of variance (ANOVA) for energy consumption

In order to determine the significance of the input variables which include speed of cutting, rate of feed and cutting depth, analysis of variance (ANOVA) was carried out on all the three cutting conditions – dry and the two wets. Confidence level of 95% and significance level α of 0.05

The sum of squares (SOS), degree of freedom (DeOF), mean squares (MnS), f-ratio and percentage contribution (Contribution%) were calculated using equations 4.4 – 4.9.

$$SOS_{\tau} = \sum_{i=1}^{n}(y_i)^2 = -\frac{1}{n}\sum_{i=1}^{n} y_i^2 \quad 4.4$$

DeOF = number of levels – 1 4.5

$$\text{MnS} = \frac{SS\ (individual)}{DOF} \quad 4.6$$

$$\text{f – ratio} = \frac{SS\ (individual)}{MS\ _{(error)}} \quad 4.7$$

$$\text{Contrbtn} = \frac{SS\ (individual)}{SS\ _{\tau}} \quad 4.8$$

Error = Total - $\sum DOF$ 4.9

(Montgomery *et al.*, 1998; Montgomery, 2009)

Table 4.12: ANOVA for Energy consumption in dry turning

Input Variables	De OF	SOS	MnS	f-ratio	Contrbtn (%)
Cutting speed	4	28150	7037.5	1.42	4.69
Feed rate	4	38545	9636.25	1.94	6.42
Depth of cut	4	498967	124741.75	25.18	83.11
Error	7	34684.34	4954.91		5.78
Total	19	600346.34	31597.18		100

Percentage error of 5.78 % with depth of cut (83.11%) indicating the most important variable, with rate of feed (6.42%) following, and cutting speed (4.69%) being the least significant factor. The effects of the variables are important since their individual + - values are higher than 0.05%. The results are presented in Table 4.12.

Table 4.13: ANOVA Table for surface roughness in dry turning

Input Variables	De OF	SOS	MnS	f-ratio	Contrbtn (%)
Speed of Cutting	4	4.20	1.05	40.36	12.67
Rate of feed	4	12.14	3.03	47.19	36.62
Cutting depth	4	14.27	3.57	49.24	43.05
Error	7	2.54	0.36		7.66
Total	19	33.14	1.74		100

Surface roughness ANOVA in dry turning presented in Table 4.13 reveal a percentage error of 7.66 while depth of cut (43.05 %) specifies the most significant parameter, followed by feed rate (36.62 %) and cutting speed (12.67 %) being the least significant. The impacts of all the variables are important since their individual contributions are higher than 0.05%.

4.6.2 Signal-to-noise (S/N) ratio analysis in dry turning

The need to evaluate Signal-to-noise ratio for each response is very paramount. This is due to some unavoidable disturbances present in the experimental system which include backlashes on the machine slides, little vibration from the machine base, possible fluctuation of electric current and some others which cannot be easily controlled.

The following procedure was used in determining the optimum levels of responses:

i. Determination of the signal-to-noise (S/N) ratio;
ii. The main effects graphs were plotted using the S/N ratio
iii. Optimum values from the main effects' plots were substituted in the regression equation
iv. Calculation of the theoretical value and determination and confirmation of the test value.

S/N analysis shown in Tables 4.14, 4.17 and 4.20 was carried out to accomplish optimisation and to investigate how variations in input variables affect the experimental process. The smaller, the better-quality characteristic presented in equation 4.3 was applied to accomplish optimisation for energy consumption and surface roughness.

$$\text{S/N ratio} = -10 \log_{10} \left(\sum y_i^2\right)$$

where y_i = response

Table 4.14: S/N ratio value for experimental results in dry turning.

Run order	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (μm)	S/N Ratio for Energy Consumption Es (db)	S/N Ratio for Surface roughness Ra (db)
1.	318.031	1.34	-50.049	-2.542
2.	118.012	3.81	-41.439	-11.618
3.	270.897	5.48	-48.656	-14.776
4.	60.038	7.92	-35.369	-14.975
5.	100.100	4.24	-40.009	-12.547
6.	247.802	4.15	-47.882	-12.361
7.	49.257	4.40	-33.849	-12.869
8.	124.748	4.17	-41.921	-12.403
9.	195.166	5.15	-45.808	-14.436
10.	88.941	5.26	-38.982	-14.420
11.	293.122	4.85	-49.341	-13.715
12.	85.785	4.25	-38.668	-12.568
13.	864.208	2.07	-58.732	-6.319
14.	68.385	3.70	-36.699	-11.364
15.	132.500	5.05	-42.444	-14.066
16.	136.032	4.87	-38.982	-14.420
17.	132.300	5.15	-49.341	-13.715
18.	132.178	4.88	-38.668	-12.568
19.	131.010	4.76	-58.732	-6.319
20.	134.500	5.48	-36.699	-11.364

4.6.3 Main effects plots in dry turning

Figure 4.2 shows the main effects plots of the signal to noise (S/N) ratio used in determining the optimal value for each of the input variables in the turning processes for energy consumption.

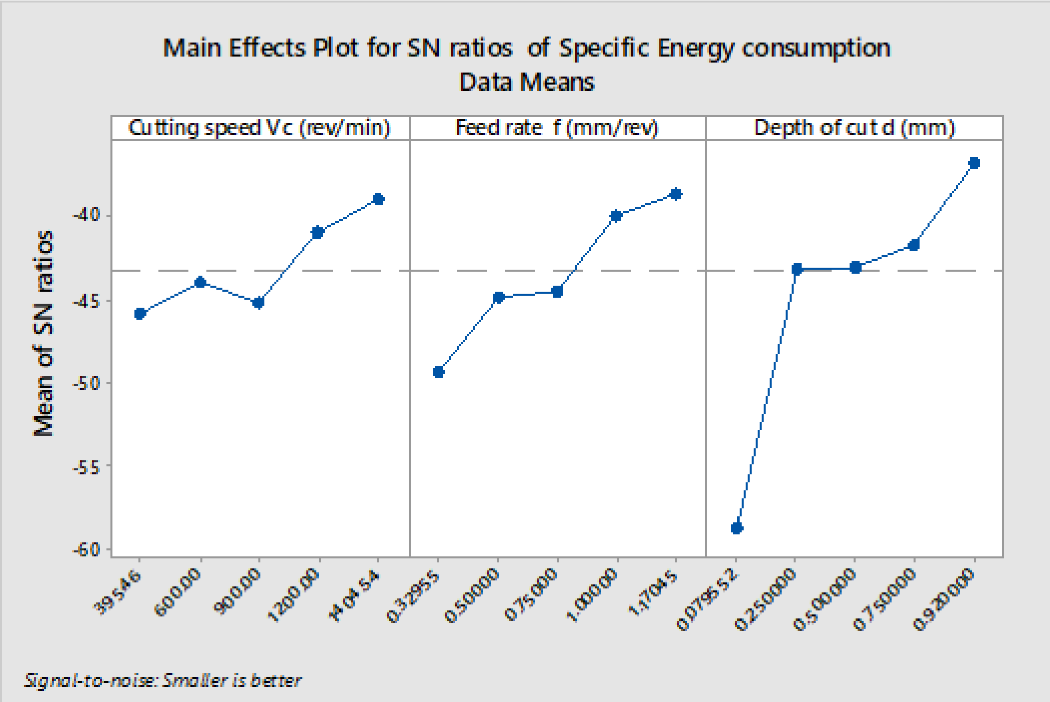


Figure 4.2: Main effects plots for S/N ratio of Energy consumption in dry turning

The optimum energy consumption in dry turning can be achieved as shown in Figure 4.2 using a speed of cutting of 1404.5 rev/min, rate of feed of 1.107045 mm/rev, and cutting depth of 0.9200 mm.

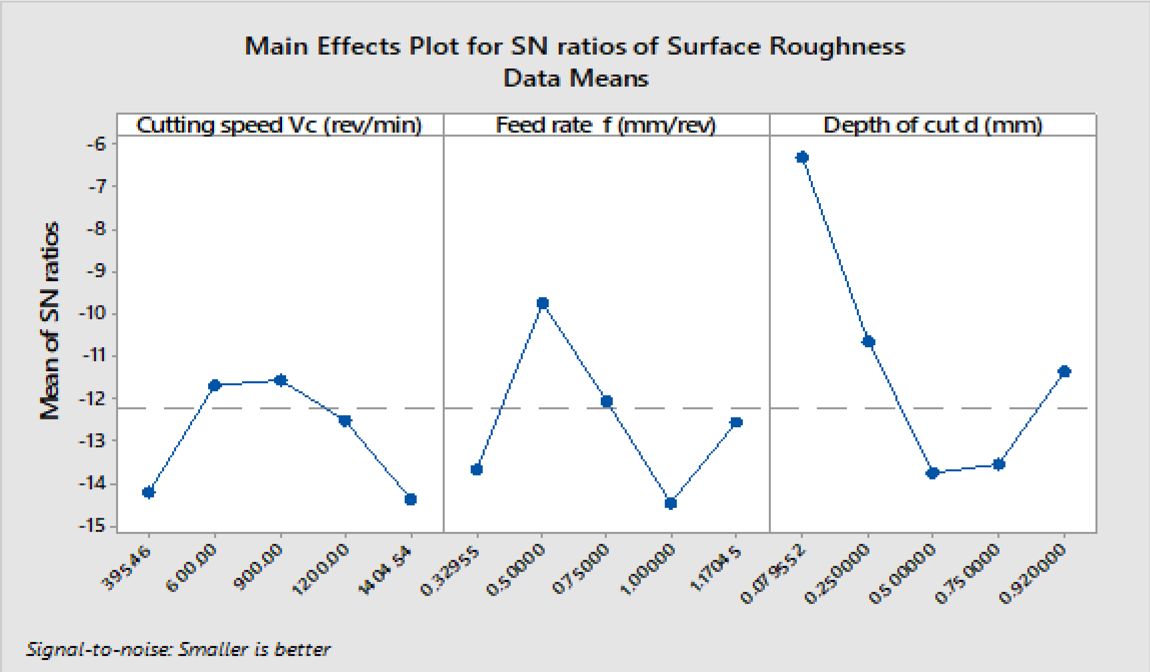


Figure 4.3: Main effects plots of S/N ratio of surface roughness in dry turning

The optimum surface roughness in dry turning can be achieved as shown in Figure 4.3 by using a speed of cutting of 900 rev/min, rate of feed of 0.5 mm/rev and cutting depth of 0.0795mm.

4.6.4 Contour plots in dry turning

Minitab 17statistical software was used to develop the contour plots. These plots were used to appraise how variation in two variables affect the response when the third factor is kept constant in a selected cutting environment as well as determine the significant effect on the responses.

The contour plot of interaction effect of rate of feed and cutting speed on specific energy consumption in dry turning is shown Figure 4.4. Contour plots for other interaction effects are presented in Appendix D.

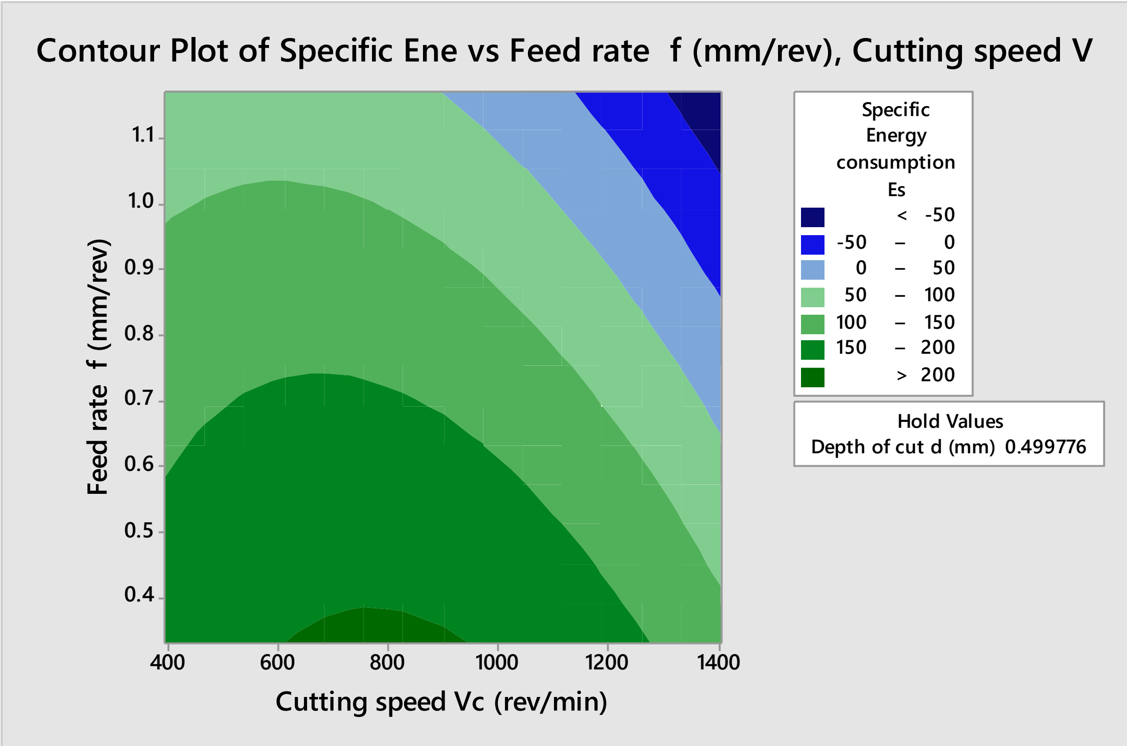


Figure 4.4: Contour plots for Specific Energy consumption against Rate of feed and Speed of cutting in dry turning

Figure 4.4 indicates how rate of feed and speed of cutting affect the specific energy consumption when the Cutting depth is kept constant at 0.4998mm. It is observed that as cutting speed increases, the feed rate also increases and vice versa .

The contour plot of interaction effect of rate of feed and speed of cutting on surface roughness in dry turning is shown in Figure 4.5. Contour plots for other interaction effects are presented in Appendix D

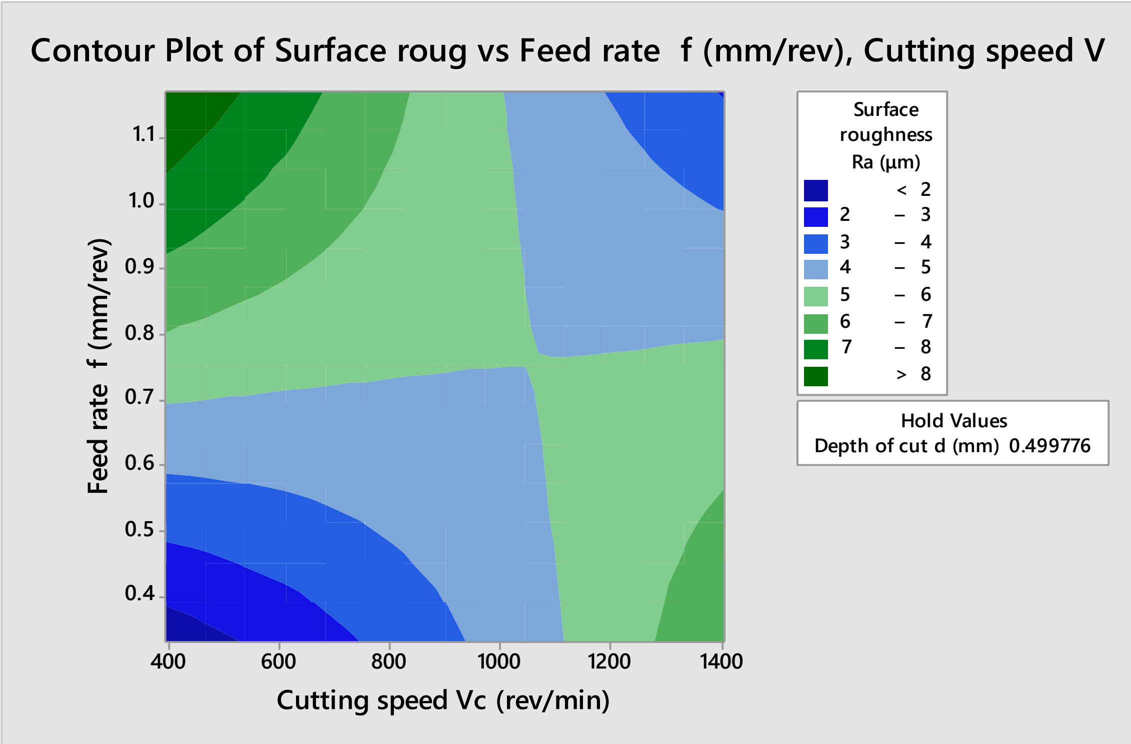


Figure 4.5: Contour plots for Surface roughness against rate of feed and speed of cutting in dry turning

Figure 4.5 indicate how rate of feed and speed of cutting affect the surface roughness when the cutting depth is kept constant at 0.499 mm. It is observed that as cutting speed increases, the feed rate also increases and vise versa. Other contour plots for surface roughness are presented in Appendix E.

4.6.5 3D surface plots

While the contour plot shows the synergistic interactions of input variables and response in two dimensions, the 3D surface plot shows the synergy in three dimensions. The 3D surface plot of interaction effect of rate of feed and speed of cutting on specific energy consumption is presented in Figure 4.6.

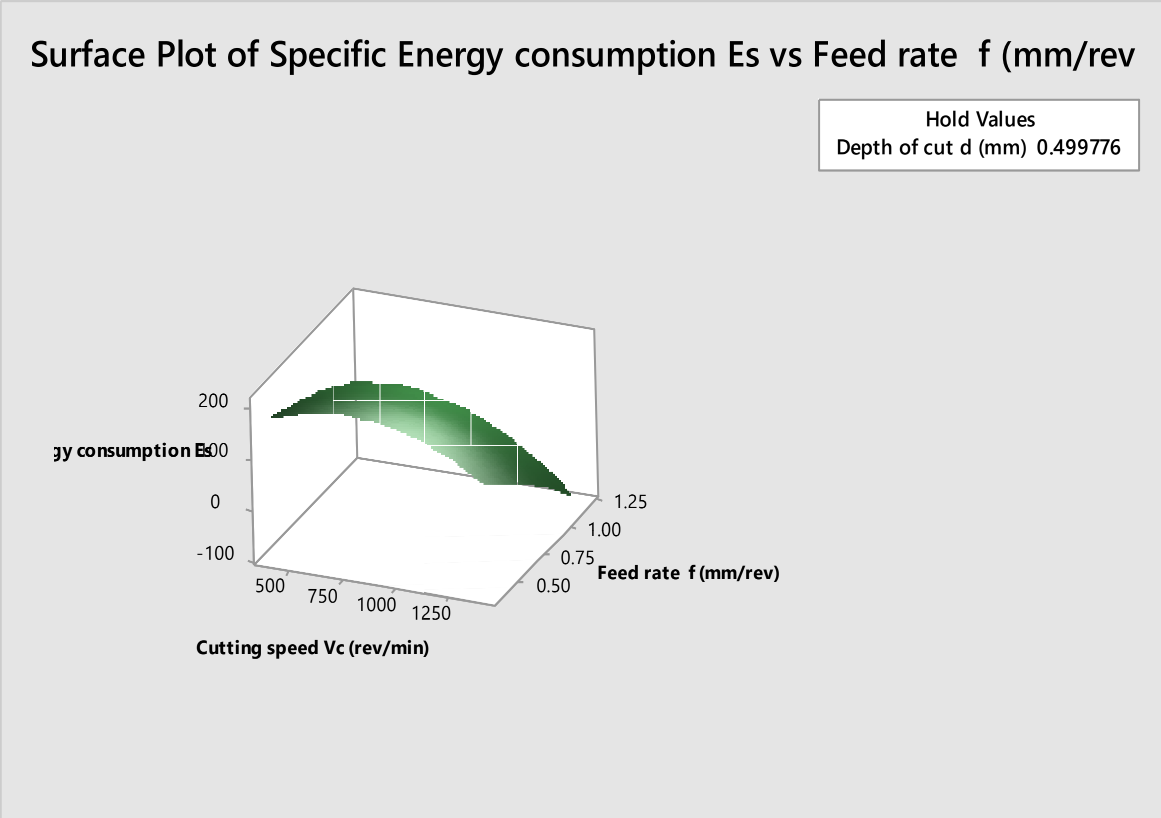


Figure 4.6: 3D Surface plots for specific energy consumption against rate of feed and speed of cutting in dry turning

The interpretation given for contour plot of Figure 4.4 also hold for the 3D surface plot of Figure 4.6. Other 3D surface plots are shown in Appendix F. The 3D surface plot of surface roughness versus cutting speed and feed rate is shown in Figure 4.7, while other surface plots for the surface roughness response are presented in Appendix G.

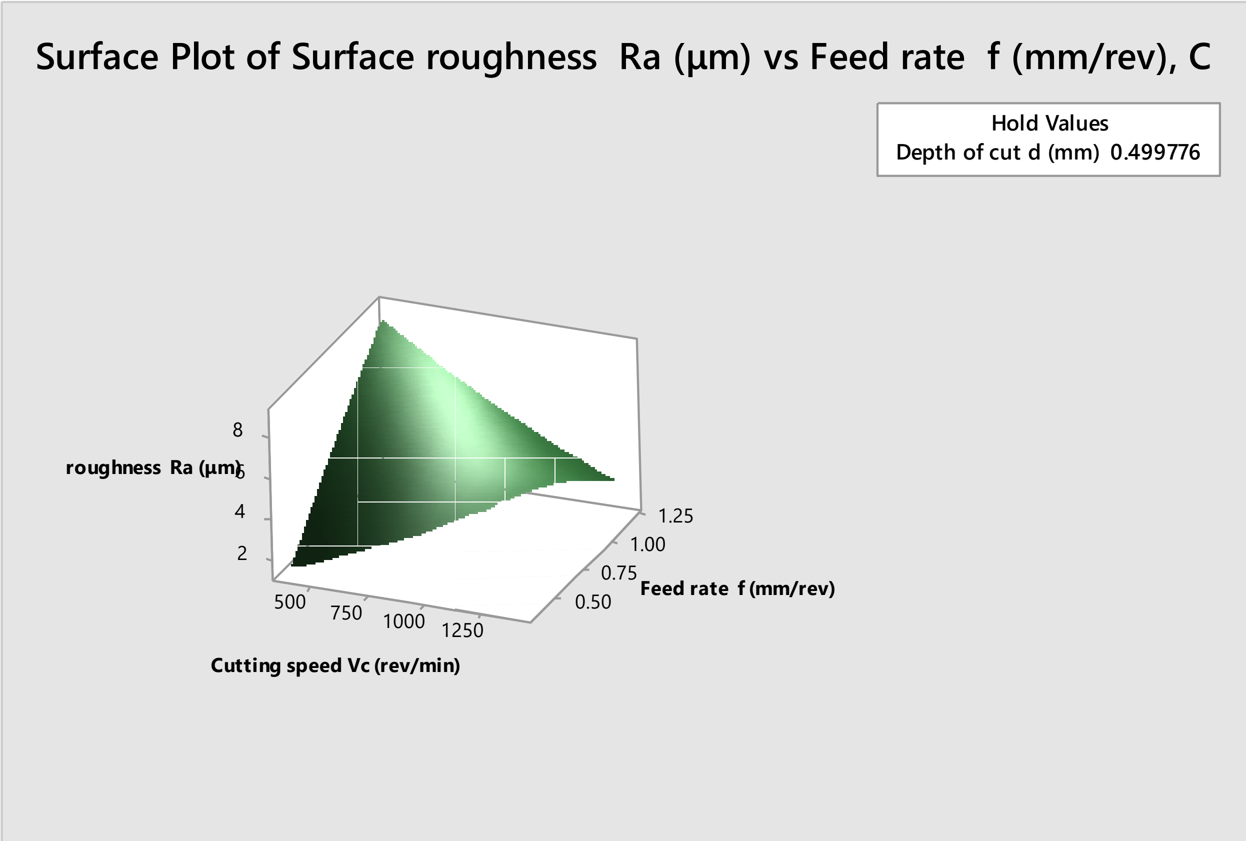


Figure 4.7: 3D Surface plots for Surface roughness against speed of cutting and rate of feed in dry turning

4.6.6 Normal probability plots for energy consumption and urface roughness in dry turning

The normal probability plots for Energy consumption and Surface roughness in dry turning are presented in Figure 4.8 and 4.9 respectively.

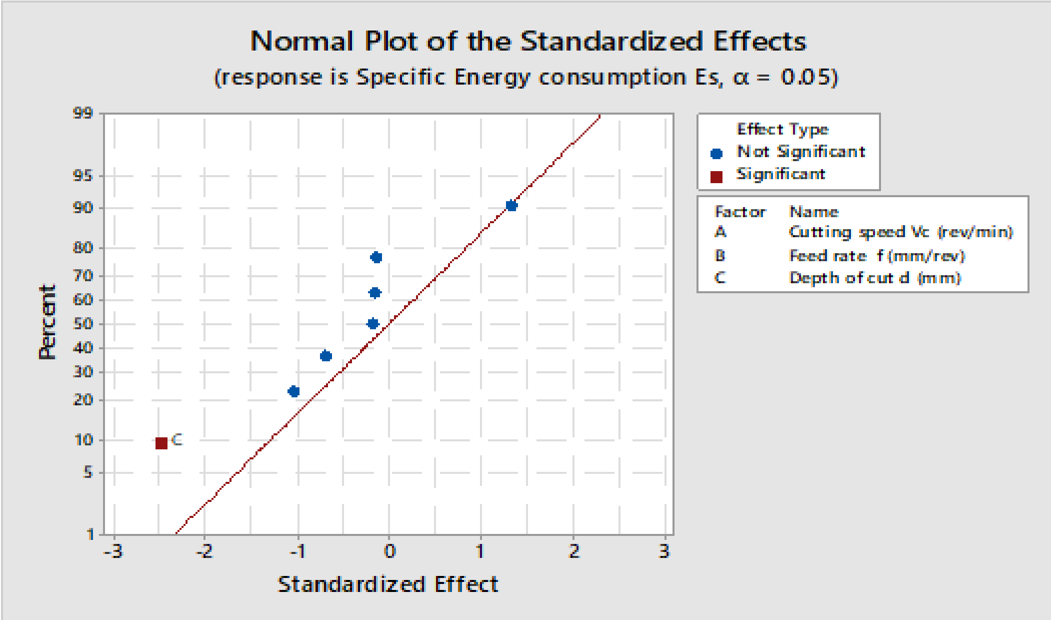


Figure 4.8: Normal Probability Plots for Energy consumption in dry turning

From Figure 4.8, it can be observed that cutting depth has significant effect on Energy consumption in dry turning. The normal probability plots for Surface roughness in dry turning is presented in Figure 4.9

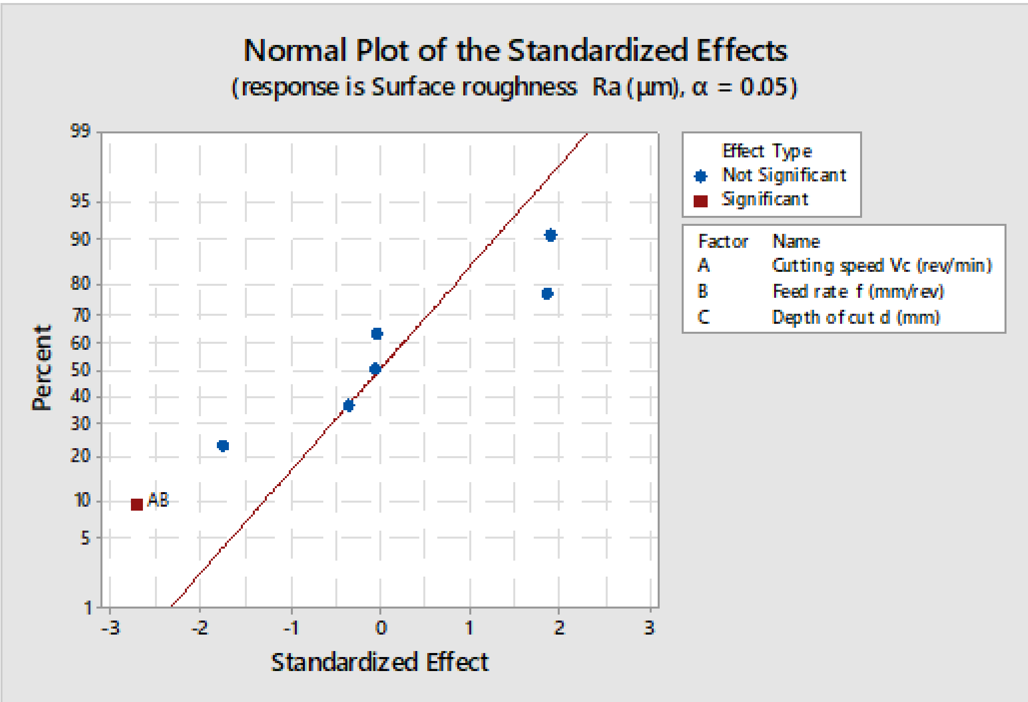


Figure 4.9: Normal Probability Plots for Surface roughness in dry turning

From Figure 4.9, it can be observed that combination of speed of cutting and rate of feed have significant effects on Surface roughness in dry turning.

4.6.7 Interaction plots

The intraction plots for energy consumption against speed of cutting, rate of feed and cutting depth is presented in Figure 4.10. There was an interaction at rate of feed of 0.75 mm/rev and speed of cutting of 900 rev/min. Interaction was also observed at cutting depth of of 0.5 mm for four cutting speeds while interaction also occur at a cutting depth of 0.55 mm and rates of feed of 1.0 mm/rev and 0.75 mm/rev.

In Figure 4.10, it is also observed that interactions occurred at rate of feed of 0.5 mm/rev and speed of cutting of 900 rev/min as well as cutting depth of 0.5 mm and speeds of cutting of 1200 rev/min and 900rev/min. Also, interactions occurred at cutting depth of 0.5mm and rate of feeds of 1.0 and 0.75mm/rev and also at a cutting depth of 0.6mm and rate of feeds of 0.5 and 0.75mm/rev

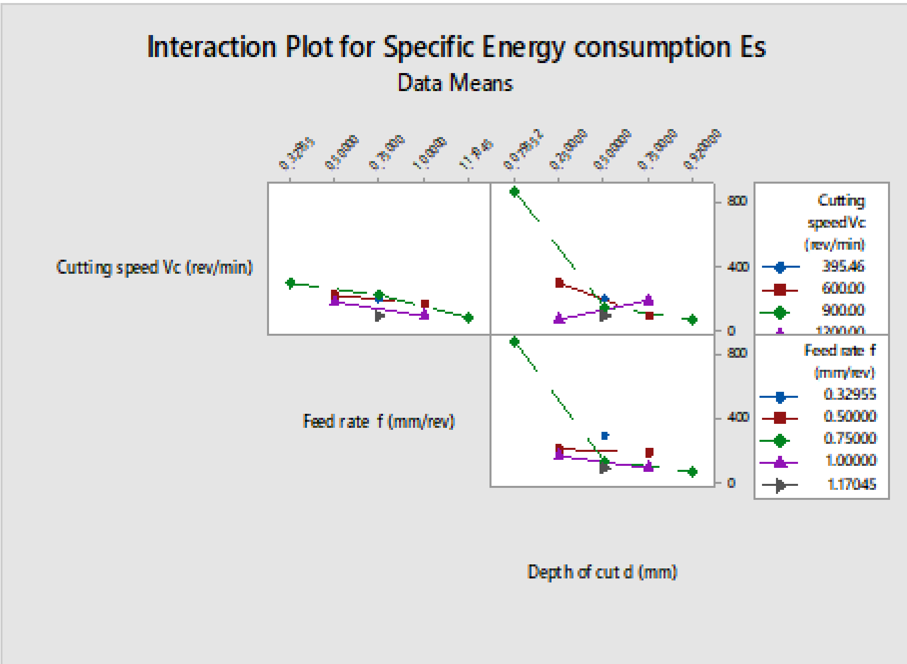


Figure 4.10: Interaction Plots of Specific energy consumption versus speed of cutting, rate of feed and cutting depth at different values in dry turning

Interaction occur at a rate of feed of 0.6mm/rev between speeds of cutting of 900 and 1200rev/min in Figure 4.10. The speeds of cutting of 1200rev/min and 900rev/min interacted also with a rate of feed of 0.8mm/rev. It is also observed that interactions occurred at rate of feed of 0.9mm/rev with speeds of cutting of 900 and 600rev/ min. Observation also reveal that interactions occurred at a cutting depth of 0.4mm between speeds of cutting of 1200 and 900rev/min. Also, at a cutting depth of 0.3mm, interaction occurred among rate of feeds of 1.17 and 0.75mm/rev. Similarly, interactions occurred at a cutting depth of 0.7mm between rate of feeds of 0.5 and 0.75mm/rev.

The the interaction plots for surface roughnesses in dry turning is presented in Figure 4.10. Figure 4.10 shows that speeds of cutting of 600 and 1200 rev/min interact at a rate of feed of 0.75mm/rev on one hand and also at a cutting depth of 0.5 mm on the other hand. Also at a cutting depth of 0.4mm, interaction occur between speeds of cutting of 1200 and 900 rev/min. Intraction also occur between at speeds of cutting of 1200 and 600 rev/min at 0.28 mm cutting depth .

Figure 4.10 also show that interaction occur between speeds of cutting of 1200 and 900 rev/min at rate of feed of 0.7 mm/rev and also between speeds of cutting of 600 and 900 rev/min at rate of feed of 0.96 rev/min. At a cuting depth of 0.6 mm, interaction occurs between speeds of cutting of 1200 and 900 rev/min . Interaction also occur at cutting depth of 0.55mm between speeds of cutting of 1200 and 600 rev/min. Also, between rate of feeds of 1.0 and 0.75 mm, interaction occurs at 0.70 mm cutting depth .

Figure 4.10 shows that interaction occurs among speeds of cutting of 600 and 1200 rev/min at a rate of feed of 0.75 mm/rev. Also at a rate of feed of 0.85 mm/rev interaction occur between speeds of cutting of 900 and 1200 rev/min. Interaction also occur at a cutting depth of 0.3 mm between speeds of cutting of 1200 and 600 rev/min.

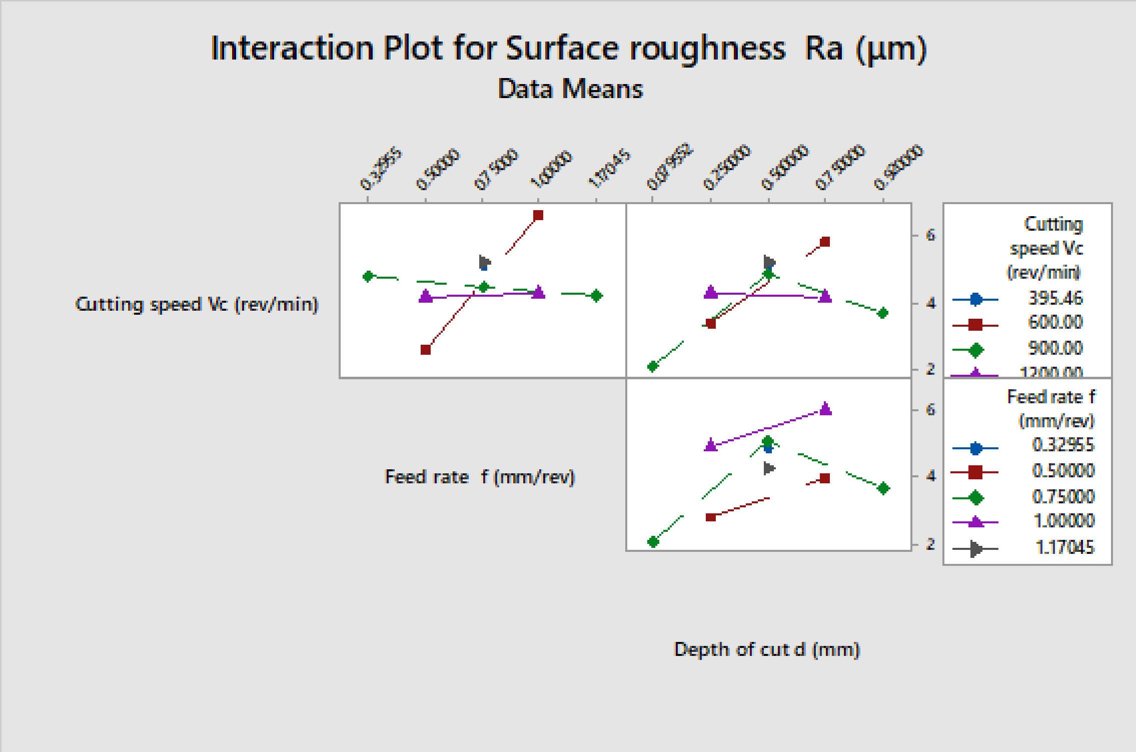


Figure 4.11 : Interaction plots of Surface roughness against speed of cutting, rate of feed and cutting depth at different values in dry turning

4.6.8 Regression equations

Empirical Regression model was developed using Design expert statistical software. This regression equation can be applied to predict the values of the experimental responses (energy consumption and surface roughness).

In dry cutting, the regression equation for energy consumption, surface roughness and the respective R-sq values are shown in equation 4.10 from Figure 4.1and equation 4.11 from Figure 4.2 respectively.

$$Es = 639 - 0.103\,Vc - 184\,F_r - 447d \qquad 4.10$$

where Vc is speed of cutting, Fr is the rate of feed and d is the cutting depth.

R-sq = 65.41%, R-sq (adj) = 53.29%

Surface roughness Ra (μm) = 2.15 - 0.00034 Vc + 2.17 Fr + 2.15d 4.11

R-sq = 74.29%, R-sq (adj) = 60.77%

To validate the empirical regression equation, the optimal process variables obtained from the main effects' plots were substituted in regression model to obtain the optimal energy consumption.

From the main effects plots (Figure 4.2), the optimal process variables are speed of cutting = 1404.54 rev/min, rate of feed = 1.17045 mm/rev, cutting depth = 0.92mm.

Es = 150.2859 J/mm^3

From the main effects plots (Figure 4.3), the optimal process variables are speed of cutting = 900 rev/min, rate of feed = 0.5 mm/rev, cutting depth = 0.079mm.

Hence, Ra = 0.93μm

4.7 Analysis of Experimental results for wet turning with mineral oil-based cutting fluid.

4.7.1 ANOVA for energy consumption in wet turning with vegetable oil-based cutting fluid

The ANOVA table for energy consumption in wet turning with mineral oil-based cutting fluid is presented in Table 4.12

Table 4.15: ANOVA for Energy Consumption in wet turning with mineral oil-based cutting fluid

Input Variables	DeOF	SOS	MnS	f-ratio	Contrbtn (%)
Cutting peed	4	62548	15637	209.50	38.87
Feed rate	4	49978	12494.5	167.40	31.05
Depth of cut	4	47886	11971.5	160.40	29.75
Error	7	522.483	74.64		0.32
Total	19	160934.5	8470.24		100

Table 4.15 reveal that, in wet turning with mineral oil-based cutting fluid, the percentage error obtained is 0.325%. The most significant variable is cutting speed (38.87%) and feed rate (31.05%) following while the least significant being depth of cut (29.975). All the factors have significant effect since their individual contribution are higher than 0.05%.

Table 4.16: ANOVA for surface roughness in wet turning using mineral oil-based cutting fluid

Input Variables	DeOF	SOS	MnS	f-ratio	Contrbtn (%)
Cutting speed	4	**3.03**	0.76	10.06	23.60
Feed rate	4	4.45	1.11	14.74	34.60
Depth of cut	4	4.84	1.21	16.06	37.69
Error	7	0.53	0.08		4.11
Total	19	12.85	0.68		100

The ANOVA for surface roughness in wet turning with mineral oil-based cutting fluid presented in Table 4.16 shows a percentage error of 4.11 while cutting depth (37.69 %) specifies the most significant parameter, followed by rate of feed (34.60 %) and speed of cutting (23.60 %) being the least significant. The effects of all the variables are significant since their individual contributions are higher than 0.05%.

Table 4.17: S/N Ratio Value for Experimental Results in wet turning with mineral oil-based cutting fluid

Run order	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (µm)	S/N Ratio for Energy Consumption Es (db)	S/N Ratio for surface roughness Ra (db)
1.	233.195	2.73	-35.280	-10.291
2.	354.035	1.25	-48.048	-11.005
3.	53.523	3.93	-48.704	-8.498
4.	245.08	1.57	-34.571	-11.888
5.	39.908	2.85	-29.244	-4.028
6.	272.384	2.66	-42.955	-12.790
7.	140.521	4.36	-32.021	-9.097
8.	47.153	2.70	-41.936	-10.604
9.	252.588	5.55	-41.883	-9.855
10.	27.152	4.27	-41.725	-10.501
11.	180.877	3.43	-45.148	-10.706
12.	28.987	1.59	-50.981	-1.938
13.	75.242	2.86	-28.676	-12.609
14.	58.074	3.27	-47.354	-8.723
15.	124.973	3.39	-41.775	-10.397
16.	124.214	3.11	-41.932	-10.655
17.	121.964	3.35	-33.470	-8.627
18.	122.672	3.31	-41.933	-9.966
19.	124.907	3.41	-37.529	-9.127
20.	124.921	3.15	-47.786	-3.918

4.7.2 Main effects plots for wet turning with mineral oil-based cutting fluid

The main effects plots of signal to noise (S/N) ratio for energy consumption in wet turning with mineral oil-based cutting fluid is shown in Figure 4.10.

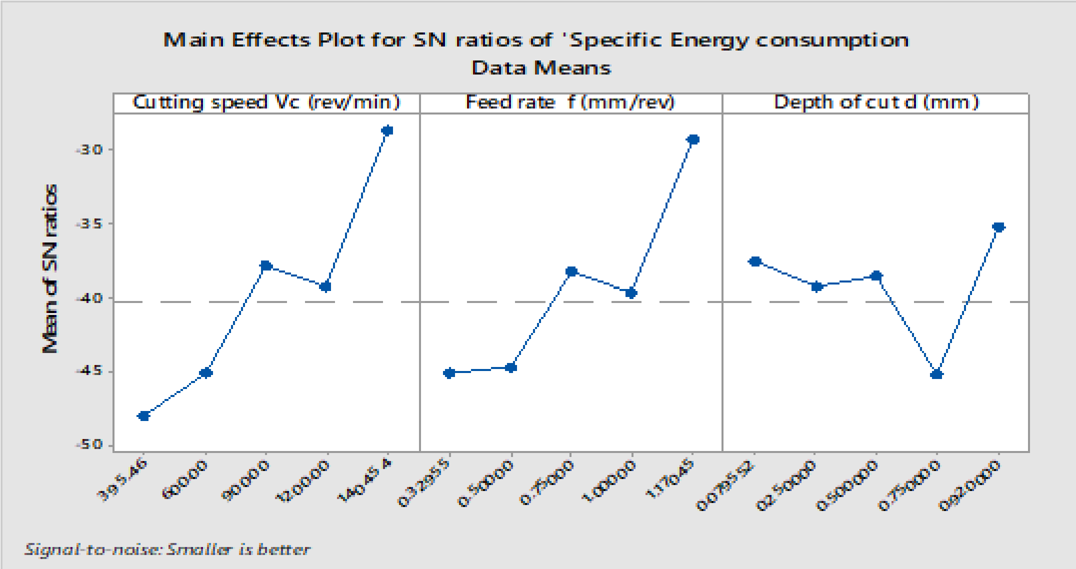


Figure 4.12: Main effects plots for S/N ratio of Energy consumption in wet turning with mineral oil-based cutting fluid

In wet turning with mineral oil-based cutting fluid, the optimum energy consumption can be achieved as shown in fig. 4.10 using a speed of cutting of 1404.5 rev/min, rate of feed of 1.17045 mm/rev and cutting depth of 0.9200 mm.

The main effects plots of signal to noise (S/N) ratio for surface roughness in wet turning with mineral oil-based cutting fluid is shown in Figure 4.13.

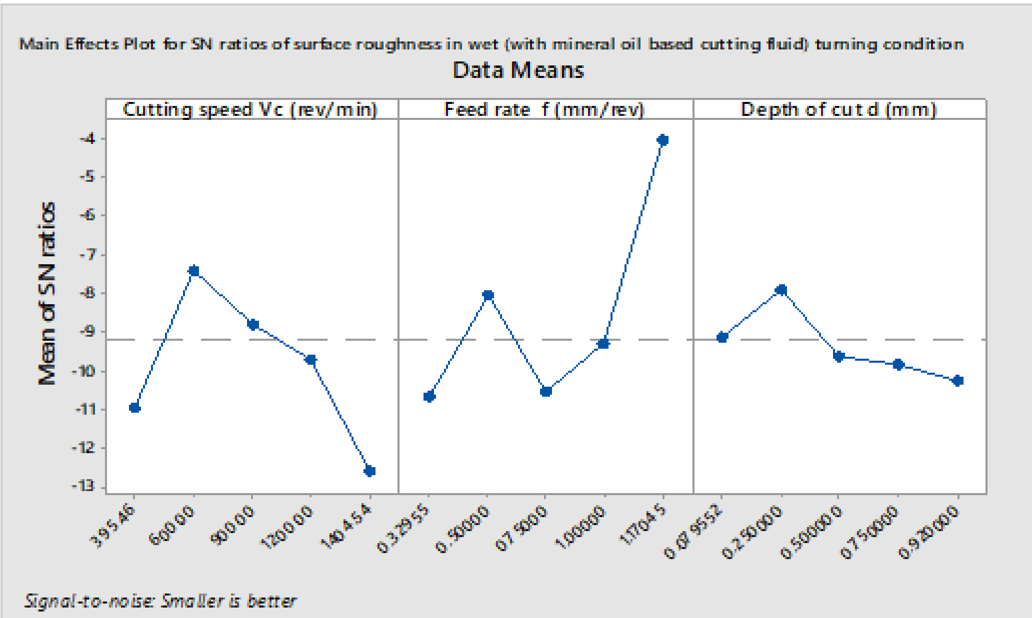


Figure 4.13: Main effects plots for S/N ratio of Surface roughness in wet turning with mineral oil-based cutting fluid

In wet turning with mineral oil-based cutting fluid, the optimum surface roughness can be accomplished as shown in Figure 4.10 using a speed of cutting of 600rev/min, rate of feed of 1.1704mm/rev, and cutting depth of 0.75mm.

4.7.3 Contour plots in wet turning with mineral oil-based cutting fluid

The contour plot of interaction effect of feed rate and cutting speed on energy consumption in wet turning with mineral oil-based cutting fluid is shown Figure 4.14. Contour plots for other interaction effects are presented in Appendix IV

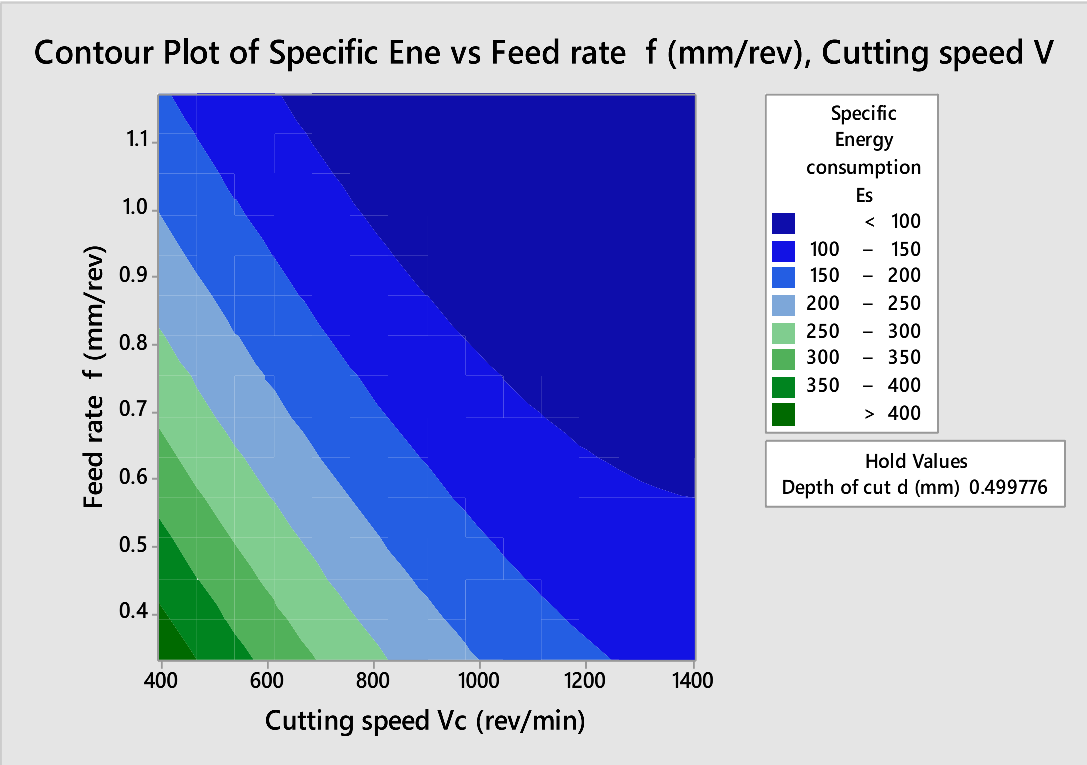


Figure 4.14: Contour plots of energy consumption with rate of feed and speed of cutting in wet turning with mineral oil-based cutting fluid

Figure 4.14 indicates how rate of feed and speed of cutting affect the specific energy consumption when the cutting depth is kept constant at 0.4998mm. It is founded that speed of cutting varies inversely as the feed rate. The contour plot of surface roughness with rate of feed and speed of cutting in wet turning with mineral oil-based cutting fluid is shown Figure 4.15. Contour plots for other interaction effects are shown in Appendix D

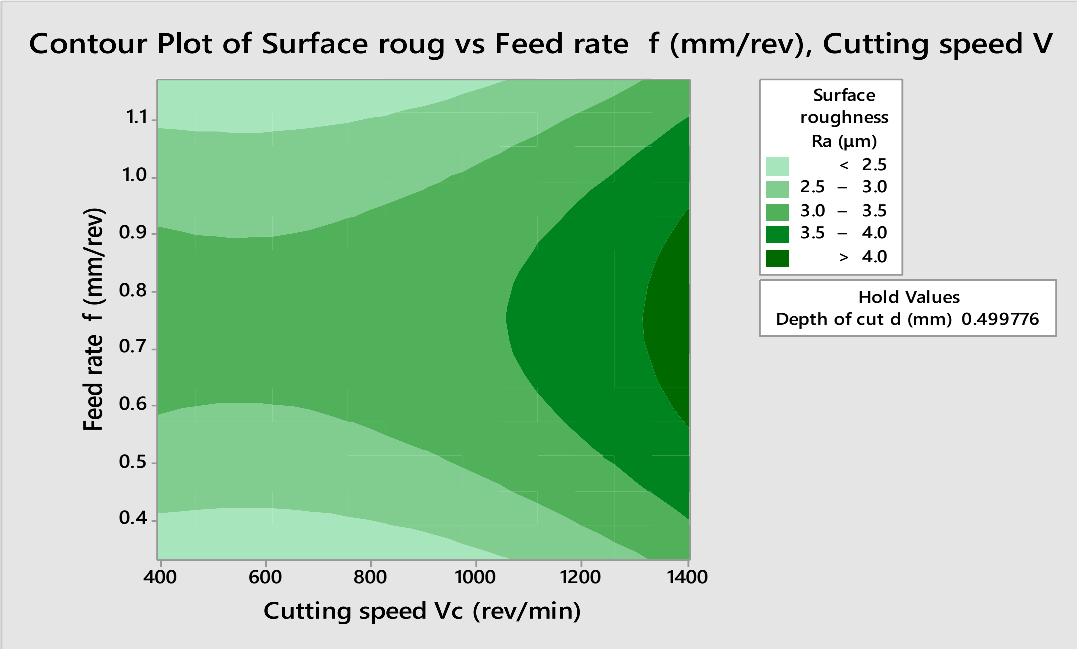


Figure 4.15: Contour plots for surface roughness versus feed rate and cutting speed in wet turning with mineral oil-based cutting fluid

From Figure 4.15, with cutting depth held at 0.499 mm, suitable values of rate of feed and speed of cutting to obtain a desired value of surface roughness can be obtained. For example, if a surface roughness of less than 2.5µm is desired, suitable rate of feed and speed of cutting are selected within the contour of the colour behind < 2.5 on the contour plot.

4.7.4 3D Surface plots in wet turning with mineral oil-based cutting fluid

The 3D surface plot is the one that shows the how change in the values of input parameters affect the response values in three dimension. The 3D plots for energy consumption and surface roughness are presented in Figures 4.16 and 4.17 respectively.

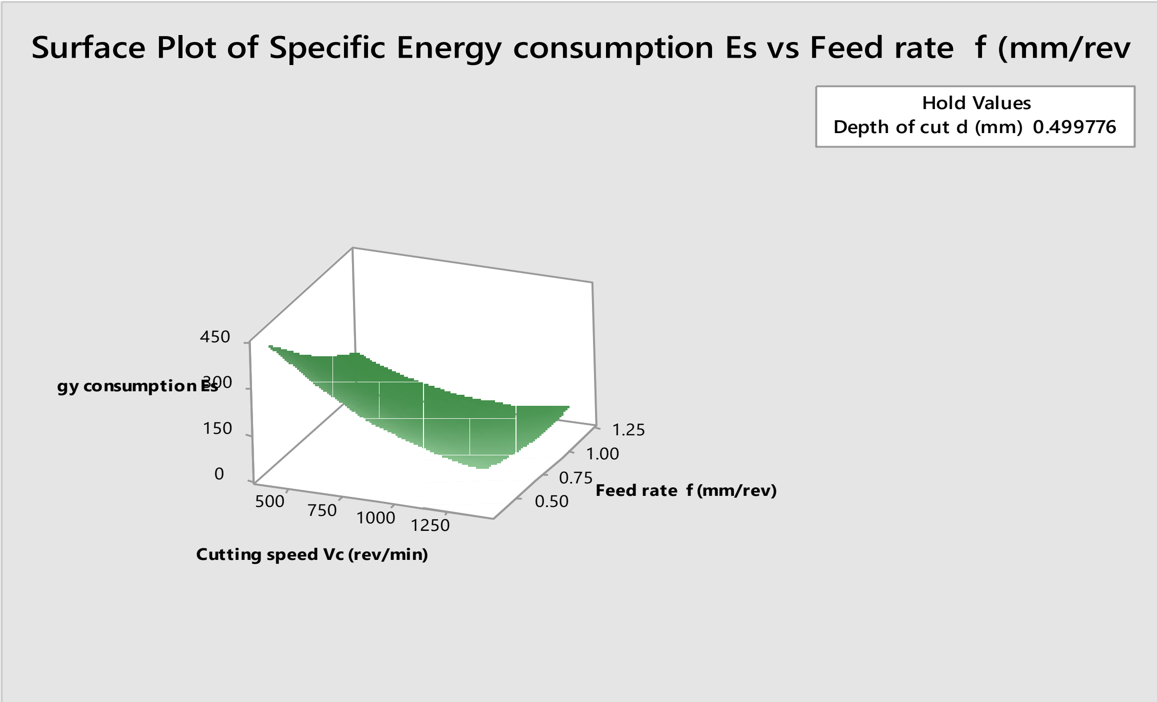


Figure 4.16: 3D surface plot of Energy consumption against speed of cutting and rate of feed in wet turning with mineral oil-based cutting fluid

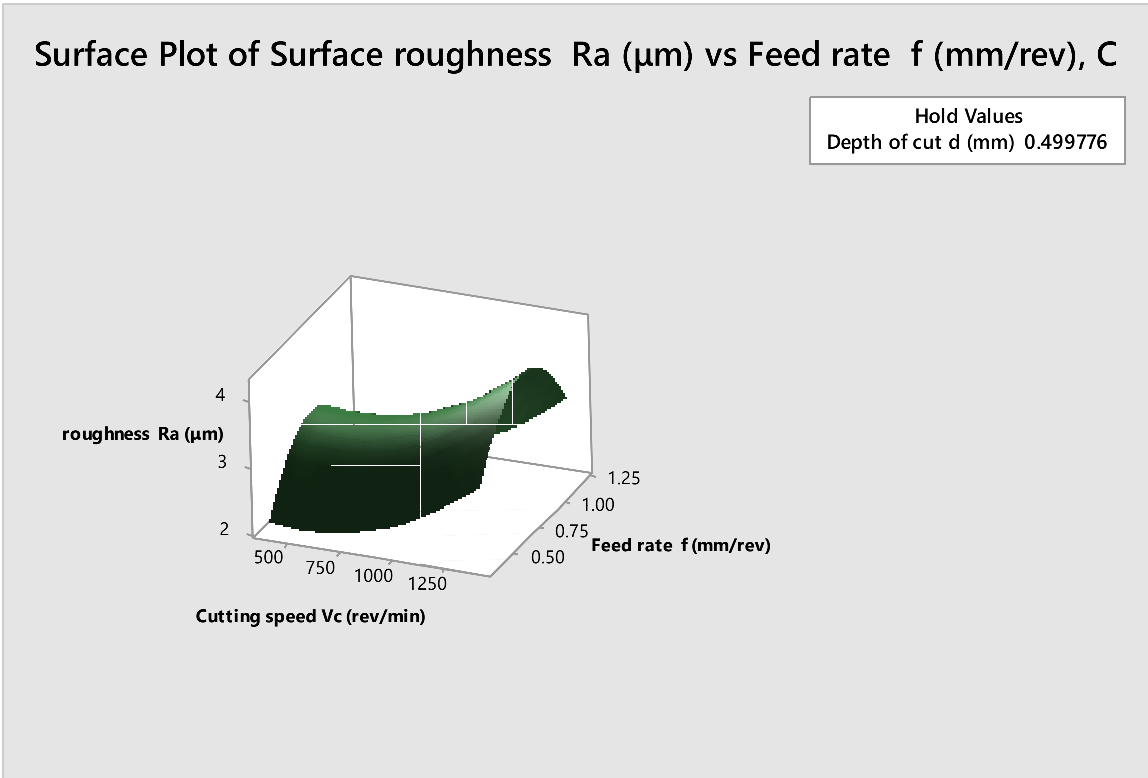


Figure 4.17: 3D surface plot of surface roughness against speed of cutting and rate of feed in wet turning with mineral oil-based cutting fluid

4.7.5 Normal Probability Plots for Energy consumption and Surface roughness in wet turning with mineral oil-based cutting fluid

The normal probability plots for Energy consumption and Surface roughness in wet turning with mineral oil-based cutting fluid are shown in Figures 4.16 and 4.17 respectively

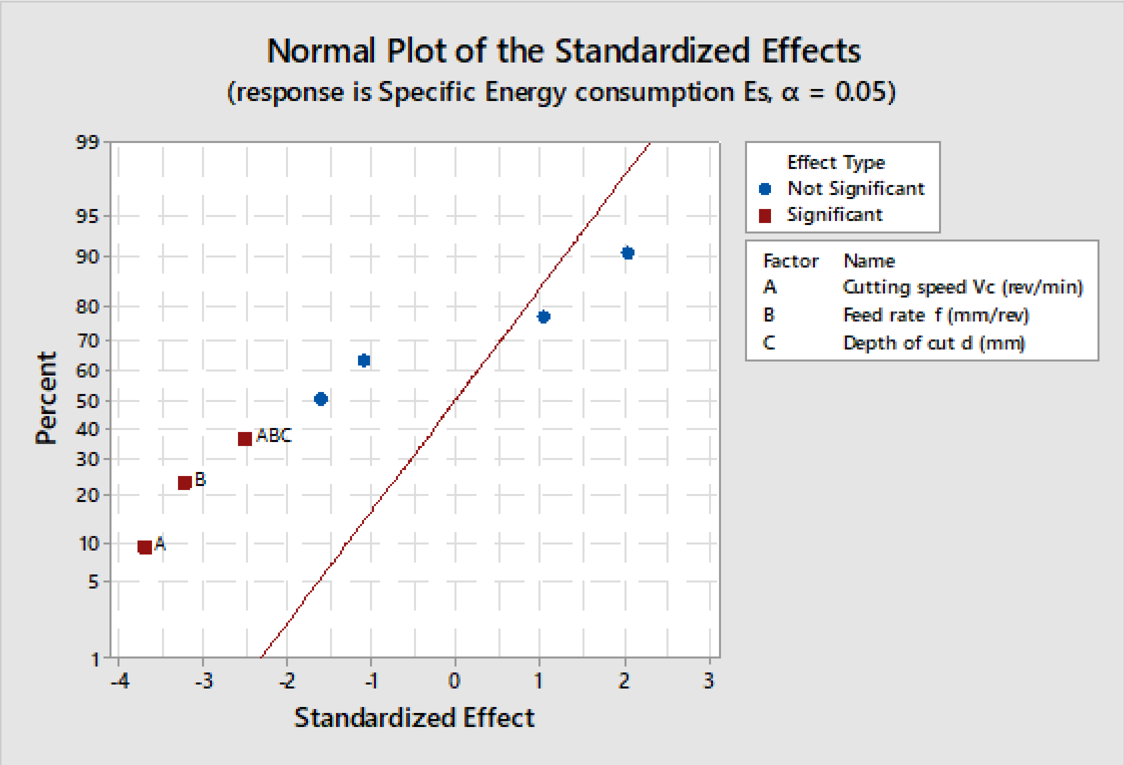


Figure 4.18: Normal Probability Plot for Energy consumption in wet turning with mineral oil-based cutting fluid

From Figure 4.18, it can be observed that speed of cutting and rate of feed are important in one hand and the combination of all the input factors at the other hand also affect energy consumption in wet turning with mineral oil-based cutting fluid significantly.

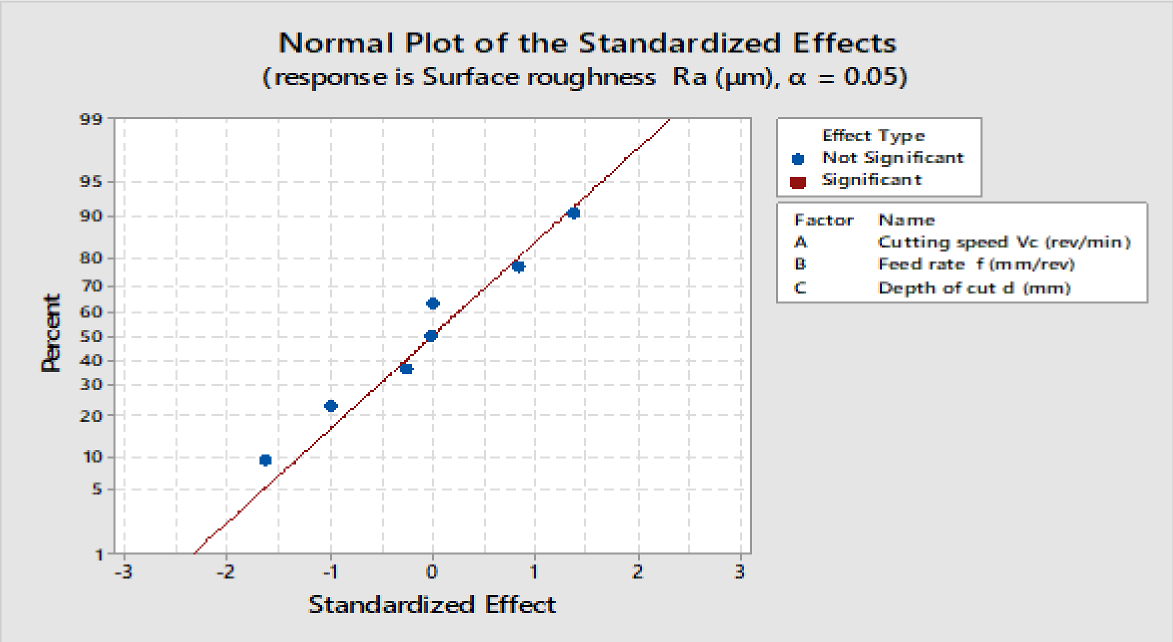


Figure 4.19: Normal Probability Plot for Surface roughness in wet turning with mineral oil-based cutting fluid

From Figure 4.19, it can be observed that in wet turning with mineral oil-based cutting fluid, all the input parameters are insignificant to the surface roughness.

4.7.6 Interaction plots in wet turning with mineral oil-based cutting fluid

Interaction plots for energy consumtion and surface roughness in wet turning with mineral oil-based cutting fluids are shown in Figures 4.20 and 4.21 respectively.

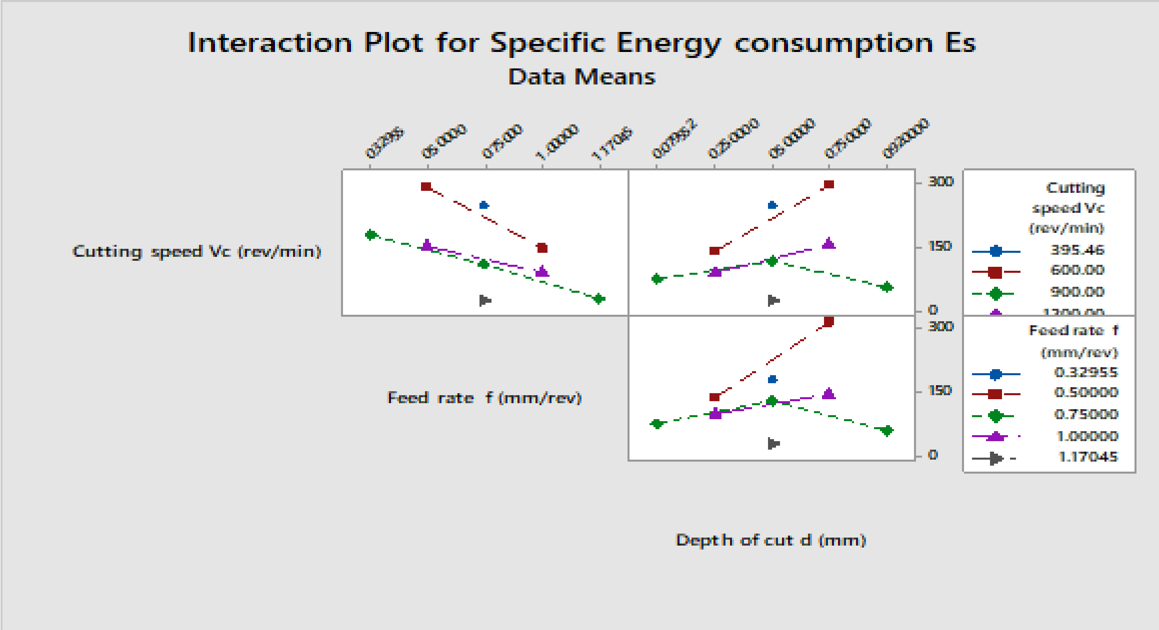


Figure 4.20: Interaction plot for specific energy consumption in wet turning with mineral oil-based cutting fluid

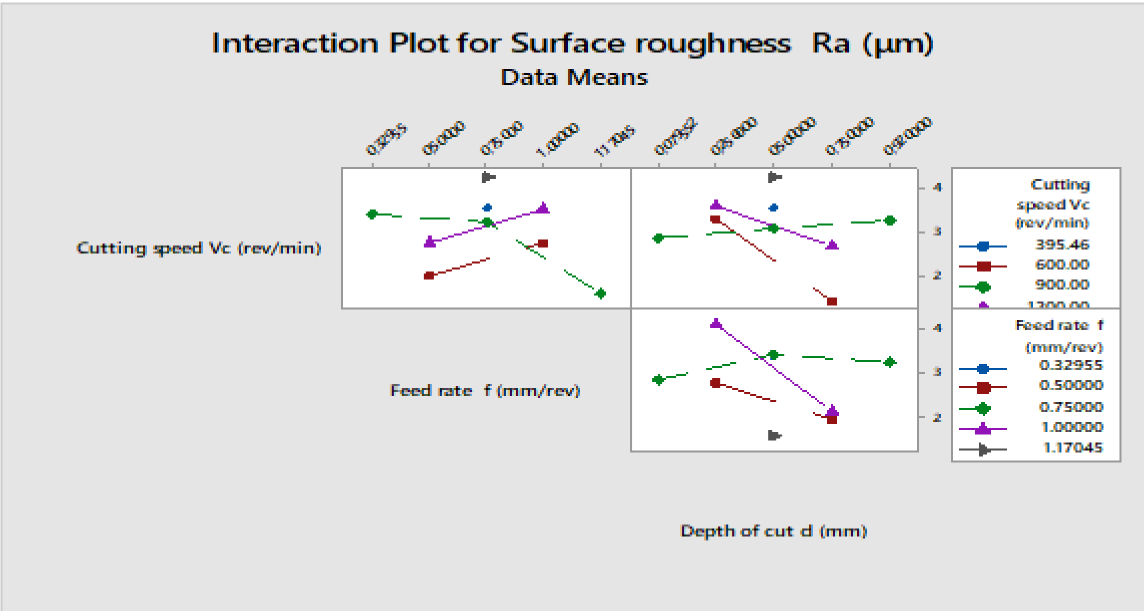


Figure 4.21: Intraction plot for surface roughness in wet turning with mineral oil-based cutting fluid

4.7.7 Regression equations in wet turning with mineral oil-based cutting fluid

In wet turning with mineral oil-based cutting fluid, the regression equation for energy consumption and the respective R-sq values are shown in equation 4.12 from figure 4.12

Energy consumption, Es = 390.6 – 0.1867 Vc – 195.9 Fr + 123.9 d 4.12

where Vc = speed of cutting, Fr = rate of feed, and d = Cutting depth

S = 58.6928, R-sq = 67.20%, R-sq (adj) =55.11%

Surface roughness Ra (μm) = 2.83 + 0.001050 Vc - 0.007 Fr - 1.465 d 4.13

R-sq = 64.80%, R-sq (adj) =50.80%

To validate the empirical regression model, the optimal process parameters obtained from the main effects' plots were used to obtain the optimal energy consumption.

From the main effects plots (Figure 4.2), the optimal process parameters are speed of cutting = 1404.54 rev/min, rate of feed = 1.17045 mm/rev, and cutting depth = 0.92mm.

Hence, Es = 13.0769 J/mm^3

From the main effects plots (Figure 4.3), the optimal process parameters are speed of cutting = 600 rev/min, rate of feed = 1.17 mm/rev, and cutting depth = 0.75mm

Hence, Ra = 2.353057μm

4.8 Analysis of Experimental results for wet turning with vegetable oil-based cutting fluid

4.8.1 ANOVA for energy consumption in wet turning with vegetable oil-based cutting fluid

The ANOVA table for energy consumption in wet turning with vegetable oil-based cutting fluid is shown in Table 4.16

Table 4.18: ANOVA for energy Consumption in wet turning with vegetable oil-based cutting fluid

Input Variables	DeOF	SOS	MnS	f-ratio	Contrbtn (%)
Speed of cutting	4	19035	4758.75	10.80	20.16
Rate of Feed	4	49525	12381.25	28.11	52.44
Cutting depth	4	22799	5699.75	12.94	24.14
Error	7	3083.40	440.49		3.26
Total	19	94442.40	4970.65		100

Table 4.18 shows that, in wet turning with vegetable oil-based cutting fluid, the percentage error obtained is 3.26%. The most important parameter is feed rate (52.44%) with depth of cut (24.14%) following, and the least significant being cutting speed (20.16%). All the input variables have significant effect since their individual contribution are higher than 0.05%.

Table 4.19: ANOVA for surface roughness in wet turning using vegetable oil-based cutting fluid

Factor	DeOF	SOS	MnS	f-ratio	Contrbtn (%)
Speed of cutting	4	0.46	0.12	1.70	3.00
Rate of feed	4	14.32	3.58	52.51	92.77
Cutting depth	4	0.18	0.04	0.65	1.14
Error	7	0.48	0.07		3.09
Total	19	15.44	0.81		100

The ANOVA for surface roughness in wet turning with vegetable oil-based cutting fluid presented in Table 4.19 reveals a percentage error of 3.09 while rate of feed of (92.77 %) specifies the most significant variable, with speed of cutting (3.00 %) following, and cutting depth (1.14 %) being the least significant. The impacts of all the variables are important since their individual contributions are above 0.05%.

Table 4.20 shows the signal to noise (S/N) ratio of experimental results in wet turning with vegetable oil-based cutting fluid.

Table 4.20: S/N Ratio Value for Experimental results in wet turning with vegetable oil-based cutting fluid

Run order	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (µm)	S/N ratio for Energy Consumption Es (db)	S/N ratio for surface roughness Ra (db)
1.	305.53	1.41	-47.950	-3.918
2.	107.903	1.15	-35.945	-12.506
3.	154.826	3.74	-45.858	-8.432
4.	62.698	4.22	-37.491	-8.165
5.	94.644	1.33	-42.056	-11.687
6.	249.738	1.57	-41.798	-10.103
7.	122.994	3.22	-39.522	-2.477
8.	41.136	3.41	-41.965	-8.432
9.	196.292	2.64	-41.879	-9.188
10.	74.082	2.18	-41.912	-8.498
11.	276.336	1.085	-48.829	-0.709
12.	126.703	3.84	-49.703	-2.984
13.	76.547	2.78	-37.394	-6.769
14.	74.913	2.56	-40.661	-1.214
15.	124.144	2.88	-41.822	-8.432
16.	124.624	2.66	-41.822	-9.367
17.	123.338	2.64	-32.284	-10.630
18.	123.335	2.94	-41.893	-9.188
19.	124.352	2.88	-37.679	-8.881
20.	125.381	2.64	-43.797	-11.457

4.8.2 Main effects plots for wet turning with vegetable oil-based cutting fluid

The main effects plots of signal to noise (S/N) ratio for energy consumption in wet turning with vegetable oil-based cutting fluid is shown in Figure 4.19.

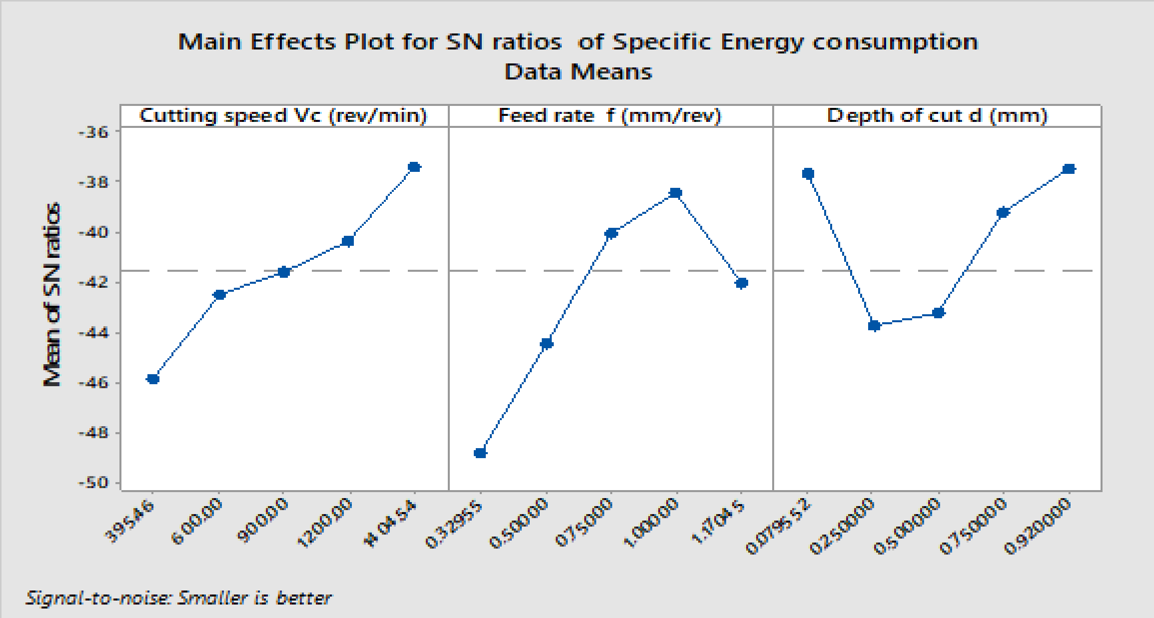


Figure 4.22: Main effects plots for S/N ratio of Energy consumption in wet turning with vegetable oil-based cutting fluid

In wet turning with vegetable oil-based cutting fluid, the optimum energy consumption can be achieved as shown in figure 4.22 using a speed of cutting of 1404.54rev/min, rate of feed of 1.0 mm/min and cutting depth of 0.92 mm.

Figure 4.23 shows the main effects plots of surface roughness in wet turning with vegetable oil-based cutting fluid.

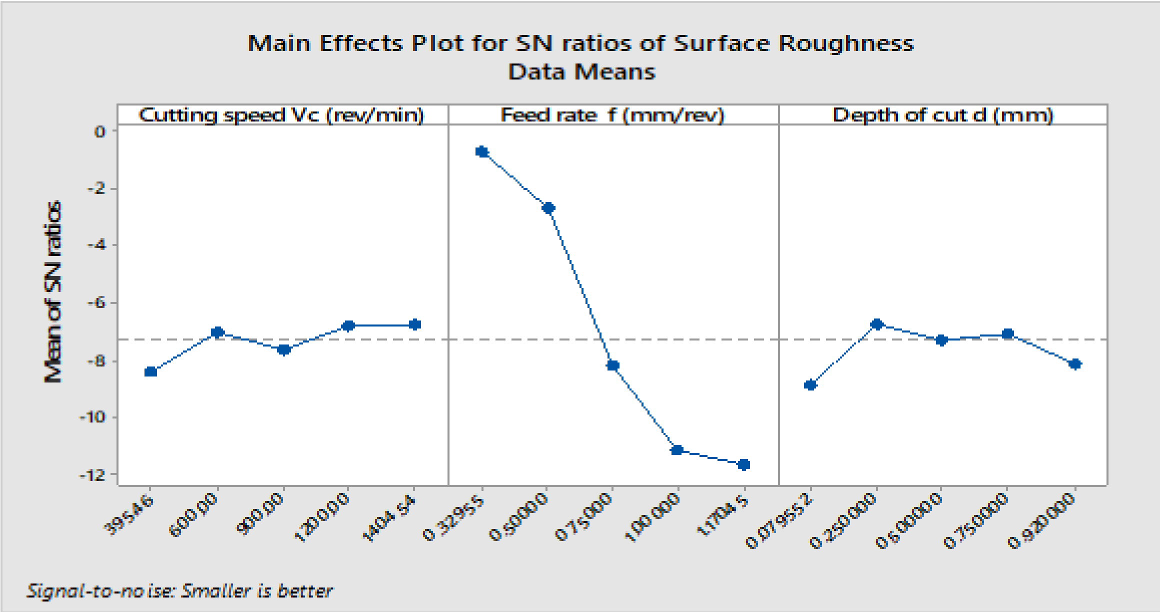


Figure 4.23: Main effects plots for S/N ratio of surface roughness in wet turning with vegetable oil-based cutting fluid

In wet turning with vegetable oil-based cutting fluid, the optimal surface roughness can be accomplished as shown in Figure 4.23 using a speed of cutting of 1200rev/min, rate of feed 0.3296mm/rev and cutting depth of 0.250mm.

4.8.3 Contour plots in wet turning with vegetable oil-based cutting fluid

The contour plots for energy consumption in wet turning with vegetable oil-based cutting fluid is shown in Figure 4.24

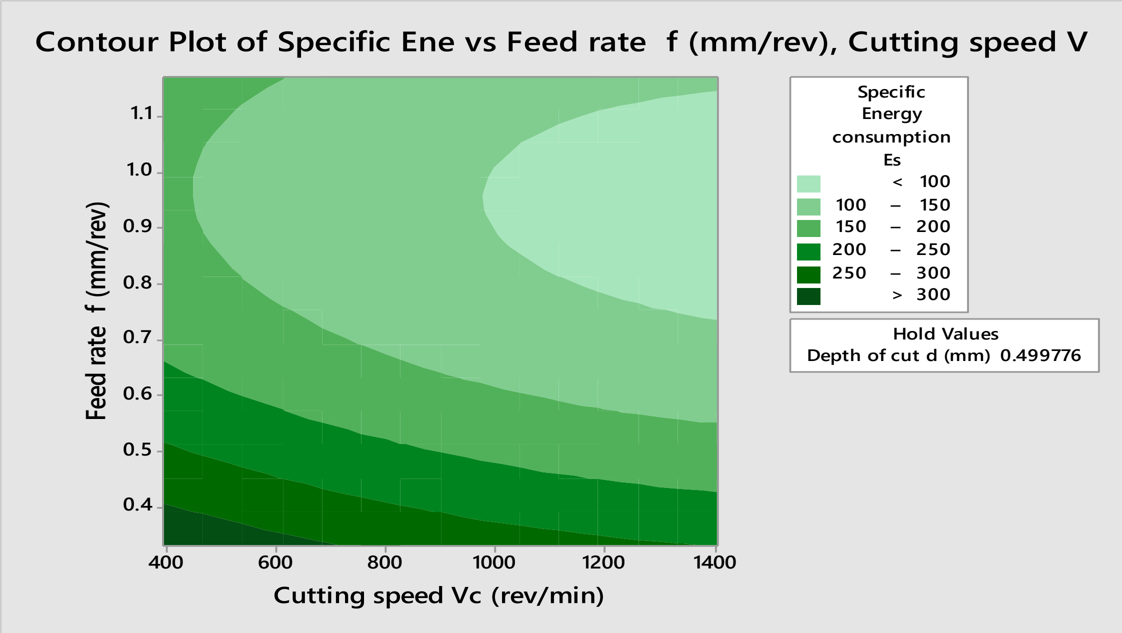


Figure 4.24: Contour plots of energy consumption with rate of feed and speed of cutting in wet turning with vegetable oil-based cutting fluid

Figure 4.24 shows the choice of rate of feed and speed of cutting to be selected when depth of cut is held at a value of 0.499 mm to accomplish minimum energy consumption. If energy consumption of less than 100 J/mm^3 must be accomplised, feed rate and cutting speed must be selected within the contour of the colour behind < 100.

The contour plots of surface roughness with feed rate and cutting speed is presented in Figure 4.25

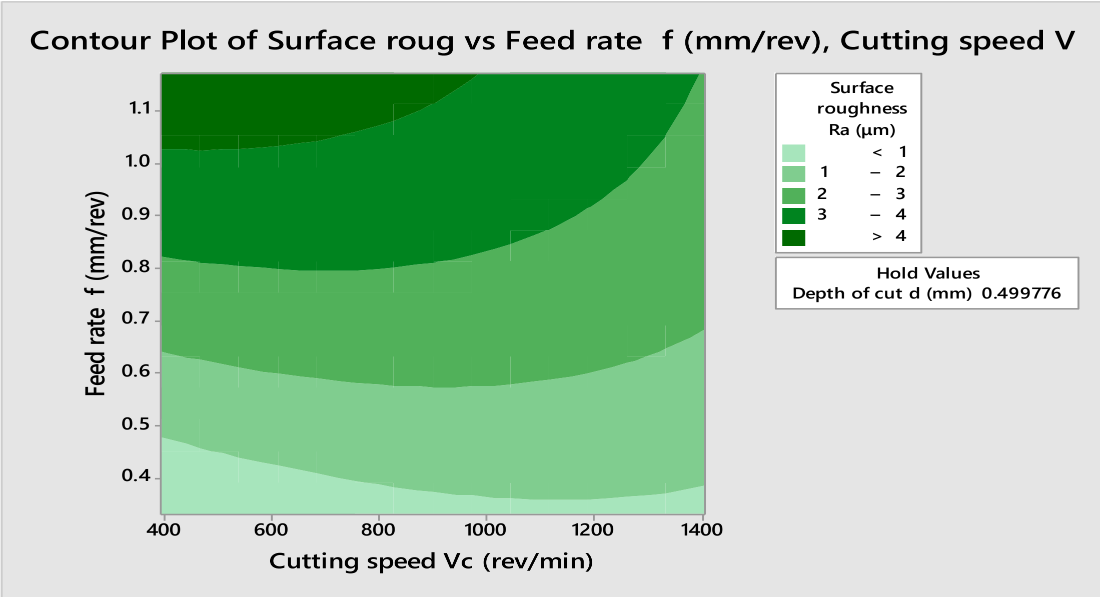


Figure 4.25: Contour plots of surface roughness with rate of feed and speed of cutting in wet turning with vegetable oil-based cutting fluid

From Figure 4.25, to accomplish a surface roughness of less than 1.00 µm, values of rate of feed and speed of cutting must be selected from the contough of the colour beind < 1 while the cutting depth is held at 0.499 mm.

4.8.4 3D surface plots for wet turning with vegetable oil-based cutting fluid

The 3D surface plots, which is contour plots in three dimension for wet turning with vegetable oil-based cutting fluid are presented in this sub-section, Figure 4.26 shows 3D plot for energy consumption while Figure 4.27 presents the 3D plot for surface roughness.

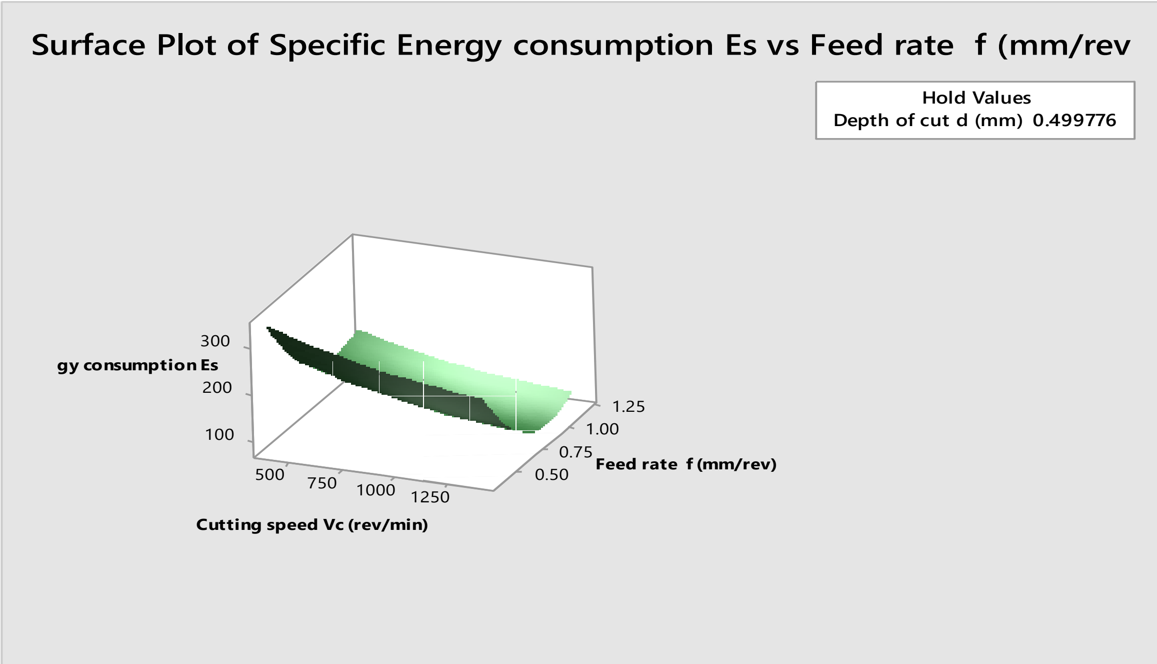


Figure 4.26: 3D surface plot for energy consumption with rate of feed and speed of cutting for wet turning with vegetable oil-based cutting fluid

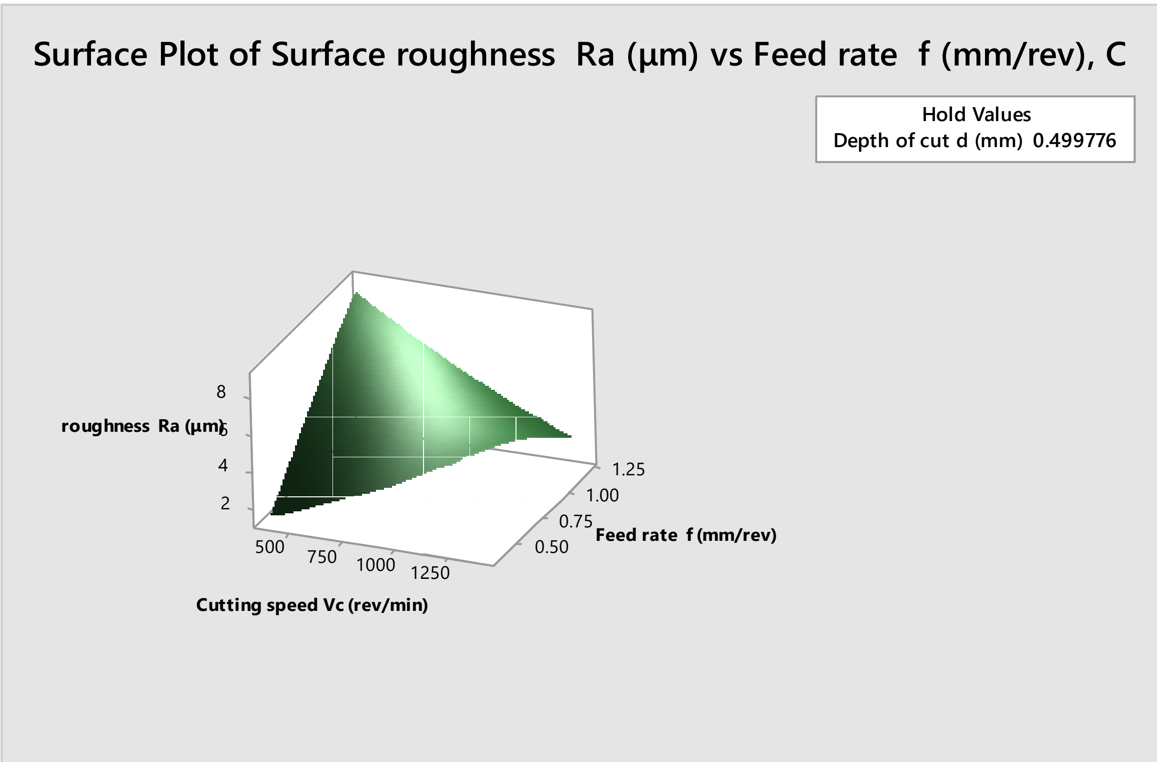


Figure 4.27: 3D surface plot for surface roughness with rate of feed and speed of cutting for wet turning with vegetable oil-based cutting fluid

4.8.5 Normal probability plots for energy consumption and surface roughness in wet turning with mineral oil-based cutting fluid

The normal probability plots for energy consumption and surface roughness in wet turning with vegetable oil-based cutting fluid are shown in Figures 4.28 and 4.29 respectively.

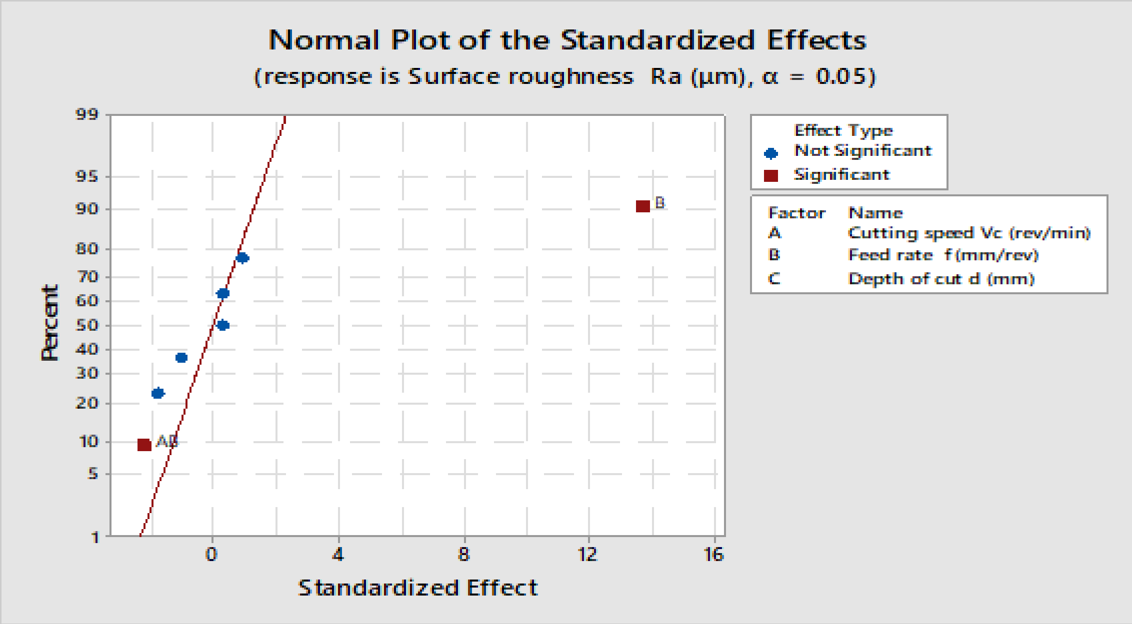


Figure 4.28: Normal Probability Plot for Energy consumption in wet turning with vegetable oil-based cutting fluid

Figure 4.28 depicts that combination of speed of cutting and rate of feed are the significant factors to energy consumption in wet turning with vegetable oil-based cutting fluid. Rate of feed is observed to be more significant.

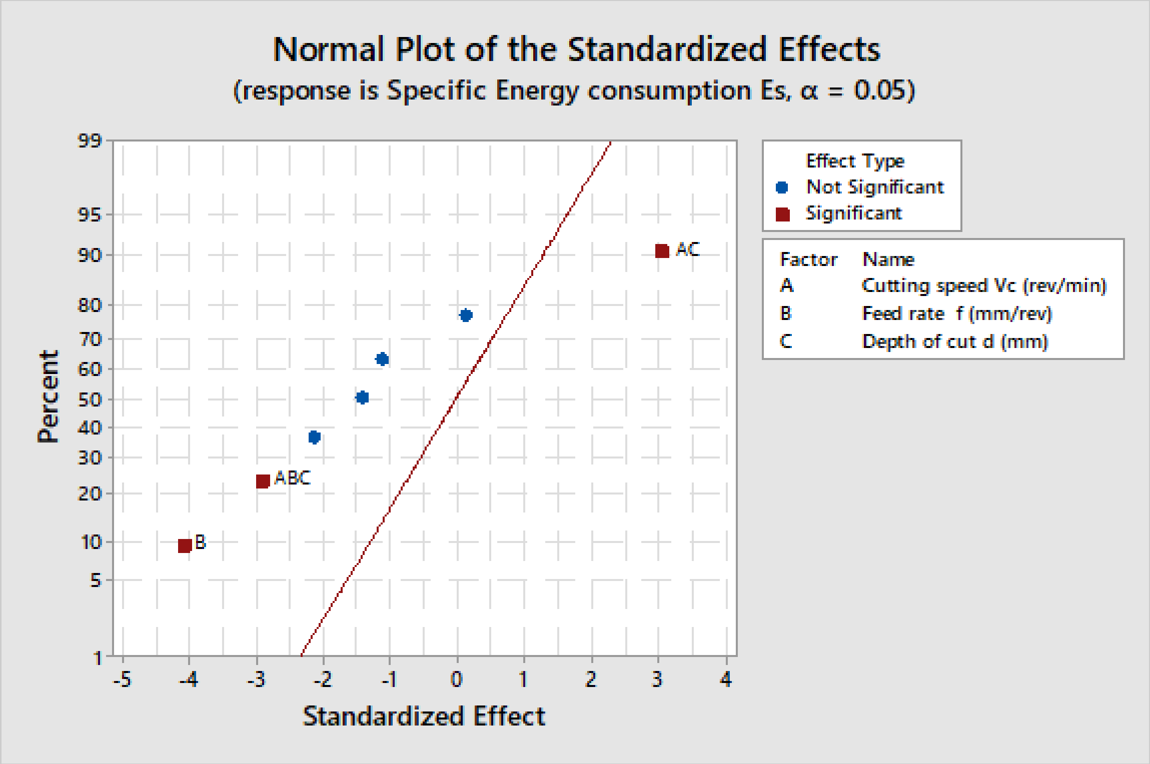


Figure 4.29: Normal Probability Plot for Surface roughness in wet turning with vegetable oil-based cutting fluid

From Figure 4.29, it can be seen that, in this cutting environment, the combination of all the three factors – speed of cutting, rate of feed and cutting depth are the significant to surface roughness in one hand, combination of speed of cutting and cutting depth are also significant in the other hand while rate of feed as a factor is also significant to surface roughness in wet turning with vegetable oil-based cutting fluid.

4.8.6 Interaction plots in wet turning with vegetable oil-based cutting fluid

Interaction plots for energy consumption and surface roughness in wet turning with vegetable oil-based cutting fluid are presented in Figures 4.30 and 4.31 respectively.

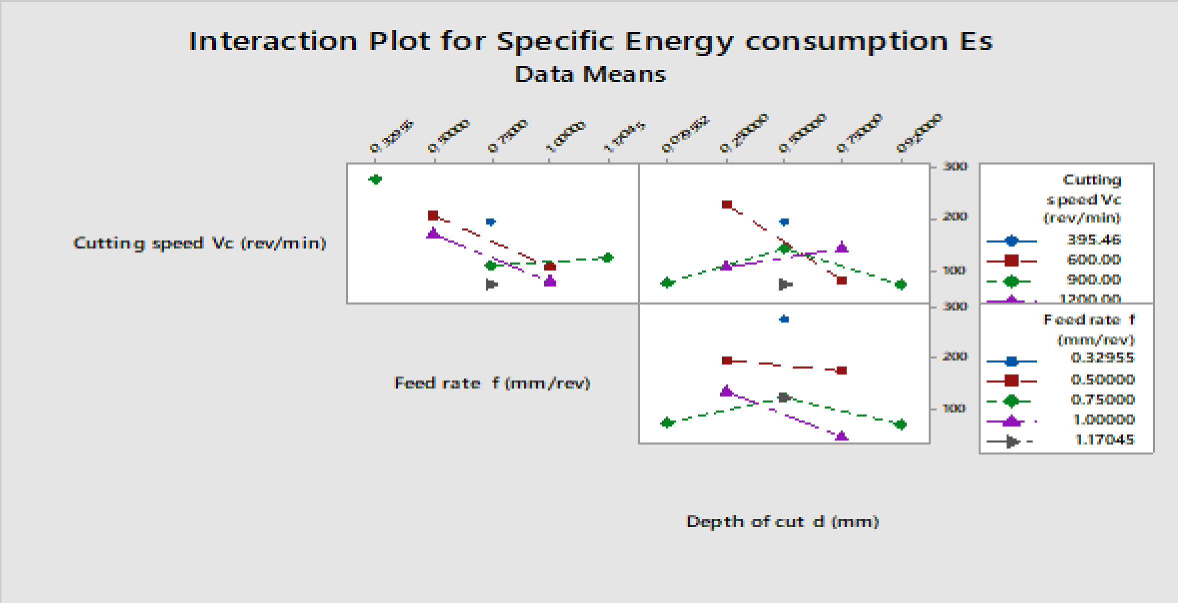


Figure 4.30: Intraction plot for energy consumption in wet turning with vegetable oil-based cutting fluid

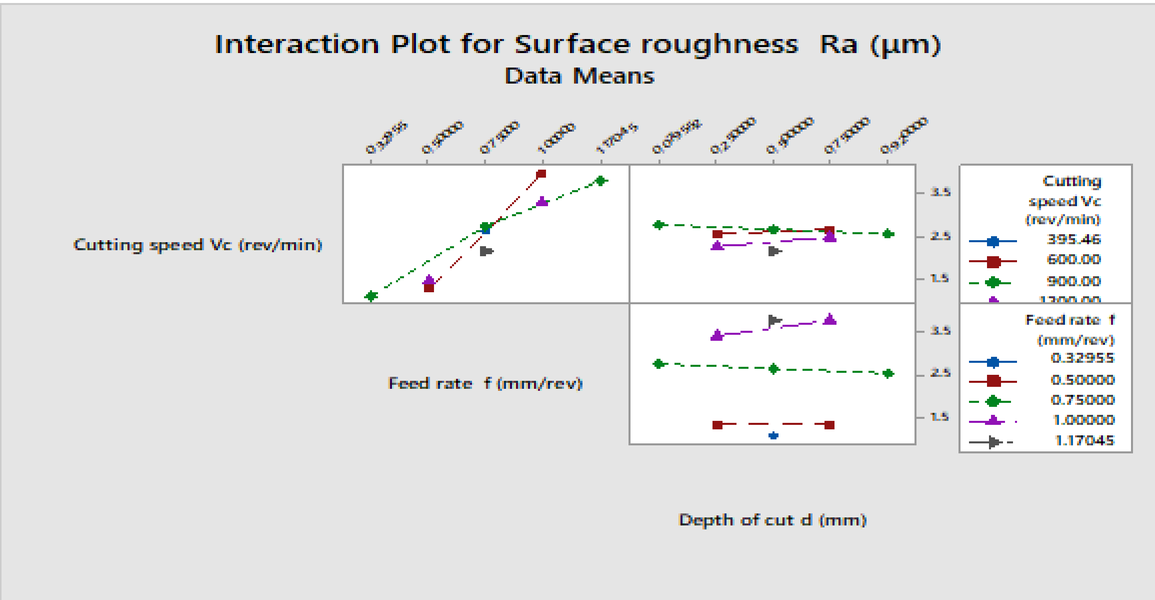


Figure 4.31: Intraction plot for surface roughness in wet turning with vegetable oil-based cutting fluid

4.8.7 Regression equations in wet turning with vegetable oil-based cutting fluid

In wet turning with vegetable oil-based cutting fluid, the regression equation for energy consumption and the respective R-sq values are shown in equation 4.14.

Specific Energy consumption Es = 377.6 - 0.0801 Vc - 183.9 Fr - 64.2 d 4.14

R-sq = 72.64%, R-sq(adj) = 61.88%

The surface roughness model for wet turning with vegetable oil-based cutting fluid with respective R-sq values is given by equation 4.15 .

Surface roughness Ra (μm) = -0.078 - 0.000438 Vc + 4.022 Fr + 0.085 d 4.15

R-sq = 91.03%, R-sq(adj) = 89.34%

The optimal values of the cutting parameters obtained from respective main effects plots were substituted in the regression equations and the optimal values were obtained as follows:

Energy consumption Es = 123 J/mm^3

Surface roughness Ra = 0.74μm

4.9 Grey Relational Analysis

4.9.1 Grey relational generating

The response values from the experimental runs – Energy consumption and surface roughness were analysed and transformed into comparable sequences using Grey Relational Analysis (GRA).

Table 4.21: Specific Energy Consumption and surface roughness data in dry turning

Run order	Speed of Cutting V_c (rev/min)	Rate of Feed Fr (mm/rev)	Cutting Depth d (mm)	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (µm)
1	600	0.5	0.25	318.03	1.34
2	600	0.5	0.75	118.01	3.81
3	600	1	0.25	270.90	5.48
4	600	1	0.75	60.04	7.92
5	1200	0.5	0.25	100.10	4.24
6	1200	0.5	0.75	247.80	4.15
7	1200	1	0.25	49.26	4.4
8	1200	1	0.75	124.74	4.17
9	395.46	0.75	0.5	195.17	5.15
10	1404.54	0.75	0.5	88.94	5.26
11	900	0.32955	0.5	293.12	4.85
12	900	1.17045	0.5	85.79	4.25
13	900	0.75	0.079552	864.21	2.07
14	900	0.75	0.92	68.39	3.7
15	900	0.75	0.5	132.50	5.05
16	900	0.75	0.5	136.03	4.87
17	900	0.75	0.5	132.30	5.15
18	900	0.75	0.5	132.18	4.88
19	900	0.75	0.5	131.01	4.76
20	900	0.75	0.5	134.50	5.48

Table 4.22: Specific Energy Consumption and surface roughness data in wet turning with mineral oil-based cutting fluid

Run order	Speed of Cutting V_c (rev/min)	Rate of Feed Fr (mm/rev)	Cutting Depth d (mm)	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (µm)
1	600	0.5	0.25	233.20	2.73
2	600	0.5	0.75	354.04	1.25
3	600	1	0.25	53.523	3.93
4	600	1	0.75	245.08	1.57
5	1200	0.5	0.25	39.908	2.85
6	1200	0.5	0.75	272.38	2.66
7	1200	1	0.25	140.52	4.36
8	1200	1	0.75	47.153	2.7
9	395.5	0.75	0.5	252.59	3.55
10	1404	0.75	0.5	27.152	4.27
11	900	0.32	0.5	180.87	3.43
12	900	1.17	0.5	28.988	1.59
13	900	0.75	0.079	75.242	2.86
14	900	0.75	0.92	58.074	3.27
15	900	0.75	0.5	124.97	3.39
16	900	0.75	0.5	124.21	3.11
17	900	0.75	0.5	121.96	3.35
18	900	0.75	0.5	122.67	3.31
19	900	0.75	0.5	124.90	3.41
20	900	0.75	0.5	124.92	3.15

Table 4.23: Specific Energy Consumption and surface roughness data in wet turning with vegetable oil-based cutting fluid

Run order	Speed of Cutting V_c (rev/min)	Rate of Feed Fr (mm/rev)	Cutting Depth d (mm)	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (µm)
1	600	0.5	0.25	305.59	1.41
2	600	0.5	0.75	107.90	1.15
3	600	1	0.25	154.83	3.74
4	600	1	0.75	62.698	4.22
5	1200	0.5	0.25	94.644	1.33
6	1200	0.5	0.75	249.738	1.57
7	1200	1	0.25	122.994	3.20
8	1200	1	0.75	41.136	3.40
9	395.46	0.75	0.5	196.292	2.64
10	1404.54	0.75	0.5	74.082	2.18
11	900	0.33	0.5	276.336	1.09
12	900	1.17	0.5	126.703	3.84
13	900	0.75	0.08	76.547	2.78
14	900	0.75	0.92	74.913	2.56
15	900	0.75	0.5	124.144	2.88
16	900	0.75	0.5	124.624	2.66
17	900	0.75	0.5	123.338	2.64
18	900	0.75	0.5	123.335	2.94
19	900	0.75	0.5	124.352	2.88
20	900	0.75	0.5	125.38	2.64

Table 4.23: Specific Energy Consumption and surface roughness data in wet turning with vegetable oil-based cutting fluid

Run order	Speed of Cutting V_c (rev/min)	Rate of Feed Fr (mm/rev)	Cutting Depth d (mm)	Specific Energy consumption Es (J/mm^3)	Surface roughness Ra (µm)
1	600	0.5	0.25	305.59	1.41
2	600	0.5	0.75	107.90	1.15
3	600	1	0.25	154.83	3.74
4	600	1	0.75	62.70	4.22
5	1200	0.5	0.25	94.64	1.33
6	1200	0.5	0.75	249.74	1.57
7	1200	1	0.25	122.99	3.2
8	1200	1	0.75	41.14	3.4
9	395.46	0.75	0.5	196.29	2.64
10	1404.54	0.75	0.5	74.082	2.18
11	900	0.33	0.5	276.34	1.085
12	900	1.17	0.5	126.70	3.84
13	900	0.75	0.08	76.55	2.78
14	900	0.75	0.92	74.91	2.56
15	900	0.75	0.5	124.14	2.88
16	900	0.75	0.5	124.62	2.66
17	900	0.75	0.5	123.34	2.64
18	900	0.75	0.5	123.34	2.94
19	900	0.75	0.5	124.35	2.88
20	900	0.75	0.5	125.38	2.64

4.9.2 Multi response optimization and data processing

Energy consumption (E_S) and Surface roughness (Ra) are the responses in the turning experiment being considered. The results obtained are as presented in Tables 4.21 to 4.23. Adopting the works of Slavek and Jovic (2012), Ertuguru *et al.*, (2016), and Sreenivasulu and Rao (2012); the response values were applied directly without the Signal – to – Noise (S/N) being calculated. To obtain the optimal turning performance, “the smaller – the – better” criterion was adopted for optimising both energy consumption and surface roughness. The sequence is then normalised using equation 2.9. For the smaller the better

$$X_i^*(k) = \frac{\max Xi(k) - Xi(k)}{\max Xi(k) - \min Xi(k)}$$

According to Agu *et al.*, (2019), Grey Relational Analysis (GRA) optimisation procedure involves three stages. Firstly, calculation of grey relational generation (GRG) is done followed by calculation of grey relational coefficient (GRC) and lastly calculation of grey relational grade (GRD).

4.9.3 GRG calculation

Calculation of grey relational generation (GRG) of individual response is done using their respective S/N ratio values. The smaller, the better criterion is used.

$$GRG\ (the\ smaller\ the\ better) = \frac{\bar{y} - y}{\bar{y} - \underline{y}}$$

Where $\bar{y}$ = maximum value of S/N ratio

$\underline{y}$ = minimum value of S/N ratio

y = S/N ratio of run being considered

For example, the GRG for the energy consumption of experimental runs 1 – 5 in dry turning are calculated as follows:

From Table 4.14,

$\bar{y}$ = -33.849

$\underline{y}$ = -58.732

$$\therefore Run\ 1, X_1(m) = \frac{-33.849+50.049}{-33.849+58.732} \qquad = 0.651$$

$$\therefore Run\ 2, X_2(m) = \frac{-33.849+41.489}{-33.849+58.732} \qquad = 0.305$$

$\therefore Run\ 3, X_3(m) = \frac{-33.849+48.656}{-33.849+58.732}$ $= 0.595$

$\therefore Run\ 4, X_4(m) = \frac{-33.849+35.569}{-33.849+58.732}$ $= 0.069$

$\therefore Run\ 5, X_5(m) = \frac{-33.849+40.009}{-33.849+58.732}$ $= 0.248$

4.9.4 Grey relational coefficient

Grey relational coefficient (GRC) is then calculated using equation 2.11 i.e.

$$\xi i(k) = \frac{\Delta \min + p\Delta \max}{\Delta xi(k) + p\Delta \max}$$

Where Δ min = minimum value of GRG

Δ max = maximum value of GRG

p = distinguishing coefficient is between 0 -1 but usually set at 0.5.

The GRC of energy consumption for experimental runs 1 – 5 in dry turning are calculated as follows:

From Table 4.24

Δ max = 1.000

Δ min = 0.000

ρ = 0.5 distinguishing coefficient

Δ xi(k) = Actual value of S/N ratio for the run i

Run 1, GRC $= \frac{(1.00 - 0.00)\ 0.5}{(1.00 - 0.651) + 0.5}$ $= 0.589$

Run 2, GRC $= \frac{(1 - 0.00)\ 0.5}{(1.00 - 0.305) + 0.5}$ $= 0.4184$

Run 3, GRC $= \frac{(1 - 0.00)\ 0.5}{(1.00 - 0.595) + 0.5}$ $= 0.552$

Run 4, GRC $= \frac{(1.00-0.00)\ 0.5}{(1.00\ -\ 0.069)+0.5} \quad = 0.349$

Run 5, GRC $= \frac{(1.00-0.00)\ 0.5}{(1.00\ -\ 0.248)+0.5} \quad = 0.399$

4.9.5 Grey relational grade

Grey relational grade (GRD) is then computed for each experimental run by taking the average of GRC of energy consumption and surface roughness for that experimental run and similarly for all the runs.

Examples are given as follows for runs 1 – 5 of dry turning .

For run 1,

GRC for Energy consumption = 0.589

GRC for surface consumption = 0.333

∴ Grey relational grade GRG $= \frac{0.418\ +0.548}{2} = 0.461$

Similarly,

Run 2, GRG = $= \frac{0.418\ +0.548}{2} = 0.483$

Run 3, GRG = $= \frac{0.553\ +0.707}{2} = 0.630$

Run 4, GRG = $= \frac{0.349\ +\ 1.000}{2} = 0.675$

Run 5, GRG = $= \frac{0.399\ +\ 0.587}{2} = 0.493$

The results for Grey relational generation (GRG), Grey relational coefficient (GRC) and Grey relational grade (GRD) for the 20 experimental runs for energy consumption and surface roughness for dry turning, wet turning with mineral oil-based cutting fluid and wet turning with vegetable oil-based cutting fluid are shown in Tables 4.24, 4.25 and 4.26 respectively.

Table 4.23: Results of Grey Relational Analysis for Dry Turning

Run order	Grey relational Generation		Grey relational coefficient		
	Es	Ra	Es	Ra	GRD
1.	0.651	0.000	0.589	0.333	0.461
2.	0.305	0.588	0.418	0.548	0.483
3.	0.595	0.793	0.553	0.707	0.630
4.	0.069	0.000	0.349	1.000	0.675
5.	0.248	1.648	0.399	0.587	0.493
6.	0.564	0.636	0.534	0.599	0.557
7.	0.000	0.669	0.333	0.602	0.468
8.	0.324	0.639	0.425	0.581	0.503
9.	0.481	0.758	0.490	0.674	0.582
10.	0.206	0.770	0.386	0.685	0.536
11.	0.623	0.724	0.570	0.644	0.607
12.	0.194	0.650	0.383	0.588	0.485
13.	1.000	0.245	1.000	0.398	0.699
14.	0.115	0.572	0.361	0.539	0.450
15.	0.345	0.747	0.433	0.667	0.548
16.	0.206	0.770	0.386	0.685	0.536
17.	0.623	0.724	0.570	0.644	0.607
18.	0.194	0.650	0.383	0.588	0.485
19.	1.000	0.245	1.000	0.398	0.699
20.	0.115	0.572	0.361	0.539	0.450

Table 4.25: Results for Grey Relational Analysis for Wet turning with mineral oil-based cutting fluid

Run order	Grey relational generation		Grey relational coefficient		GRD
	Es	Ra	Es	Ra	
1.	0.296	0.783	0.415	0.697	0.556
2.	0.869	0.850	0.792	0.769	0.780
3.	0.898	0.615	0.830	0.565	0.698
4.	0.264	0.932	0.405	0.881	0.643
5.	0.025	0.196	0.339	0.383	0.361
6.	0.640	1.017	0.582	1.035	0.808
7.	0.150	0.671	0.370	0.603	0.487
8.	0.594	0.812	0.552	0.727	0.640
9.	0.592	0.742	0.551	0.660	0.605
10.	0.585	0.802	0.546	0.717	0.632
11.	0.738	0.822	0.657	0.737	0.697
12.	1.000	0.000	1.000	0.333	0.667
13.	0.000	1.000	0.333	1.000	0.667
14.	0.837	0.636	0.755	0.579	0.667
15.	0.587	0.793	0.548	0.707	0.627
16.	0.594	0.817	0.552	0.732	0.642
17.	0.215	0.627	0.389	0.573	0.481
18.	0.594	0.752	0.552	0.669	0.610
19.	0.397	0.674	0.453	0.605	0.529
20.	0.857	0.186	0.777	0.380	0.579

Table 4.26: Results of Grey Relational Analysis for wet turning with vegetable oil-based cutting fluid

Run order	Grey relational generation		Grey relational coefficient		GRD
	Es	Ra	Es	Ra	
1.	0.899	0.272	0.832	0.407	0.620
2.	0.210	1.000	0.388	1.000	0.694
3.	0.779	0.655	0.694	0.591	0.643
4.	0.299	0.632	0.416	0.576	0.496
5.	0.561	0.931	0.532	0.878	0.705
6.	0.546	0.796	0.524	0.711	0.617
7.	0.416	0.150	0.461	0.370	0.416
8.	0.556	0.655	0.530	0.591	0.561
9.	0.551	0.719	0.527	0.640	0.583
10.	0.553	0.660	0.528	0.595	0.562
11.	0.950	0.000	0.909	0.333	0.621
12.	1.000	0.193	1.000	0.383	0.691
13.	0.293	0.514	0.414	0.507	0.461
14.	0.481	0.043	0.491	0.343	0.417
15.	0.548	0.655	0.525	0.591	0.558
16.	0.543	0.734	0.525	0.653	0.589
17.	0.000	0.841	0.333	0.759	0.546
18.	0.552	0.719	0.527	0.640	0.584
19.	0.310	0.693	0.420	0.619	0.520
20.	0.661	0.911	0.596	0.849	0.722

The higher the Grey relational grade value, the better the multiple response characteristics. Consequently, higher Grey relational grade is desired to achieve optimal performance. In dry turning, the highest value of Grey relational grade recorded was 0.699 for experimental run nos 13 and 19. In wet turning with mineral oil-based cutting fluid, the highest value of Grey relational grade recorded was 0.808, for experimental run no 6. In wet turning with vegetable oil-based cutting fluid, the highest value of Grey relational grade recorded was 0.722 for experimental run no 20. These implies that experiments 13,6 and 5 have the optimal parameters for dry, wet with mineral oil-based cutting fluid and wet with vegetable oil-based cutting fluid turning experiments respectively.

Furthermore, more analysis was then conducted to determine the optimal levels for each of the input variables - depth of cut, cutting speed and feed rate under various cutting environment. Thus, the average of the Grey relational grade for each level of the turning variables was summarised as presented in Tables 4.27 to 4.29. These were calculated by taking the average of each level of input factors, namely, cutting speed, feed rate, and depth of cut. These results indicate the level of correlation between the reference sequence and the obtained sequence. Hence, the optimal levels of the process variables are designated by the levels with the highest average of grey relational grades, for each of the input variables.

Response Tables

Tables 4.27 to 4.29 reveal the means of the signal to noise (S/N) ratios for the selected variables at the five levels. The highest of the values obtained for each parameter appear in bold and those values with their corresponding parameters are used to plot the main effects plots of Figures 4.32 to 4.34.

Table 4.27: Response Table for Grey Relational Grade in dry turning

S/No	Parameter	Level 1	Level 2	Level 3	Level 4	Level 5
1.	Cutting Speed	**0.58205**	0.562238	0.556665	0.505054	0.53554
2.	Feed rate	**0.60708**	0.498539	0.559179	0.568753	0.48537
3.	Depth of cut	**0.69916**	0.512894	0.554398	0.55439	0.44973

Table 4.28: Response Table for Grey Relational Grade in wet turning with mineral oil-based cutting fluid

S/No	Parameter	Level 1	Level 2	Level 3	Level 4	Level 5
1.	Cutting Speed	0.60514	**0.669239**	0.616545	0.57394	0.63163
2.	Feed rate	**0.69684**	0.626523	0.603871	0.61666	0.66667
3.	Depth of cut	**0.66667**	0.52545	0.606896	0.71773	0.66659

Table 4.29: Response Table for Grey Relational Grade in wet turning with vegetable oil-based cutting fluid

S/No	Parameter	Level 1	Level 2	Level 3	Level 4	Level 5
1.	Cutting Speed	0.58339	**0.613104**	0.57087	0.574713	0.56162
2.	Feed rate	0.32955	0.659072	0.554139	0.528744	**0.69126**
3.	Depth of cut	0.07955	0.595847	**0.597618**	0.591969	0.41688

The main effect plots for the means of Grey relational grade are shown in Figures 4.32 – 4.34.

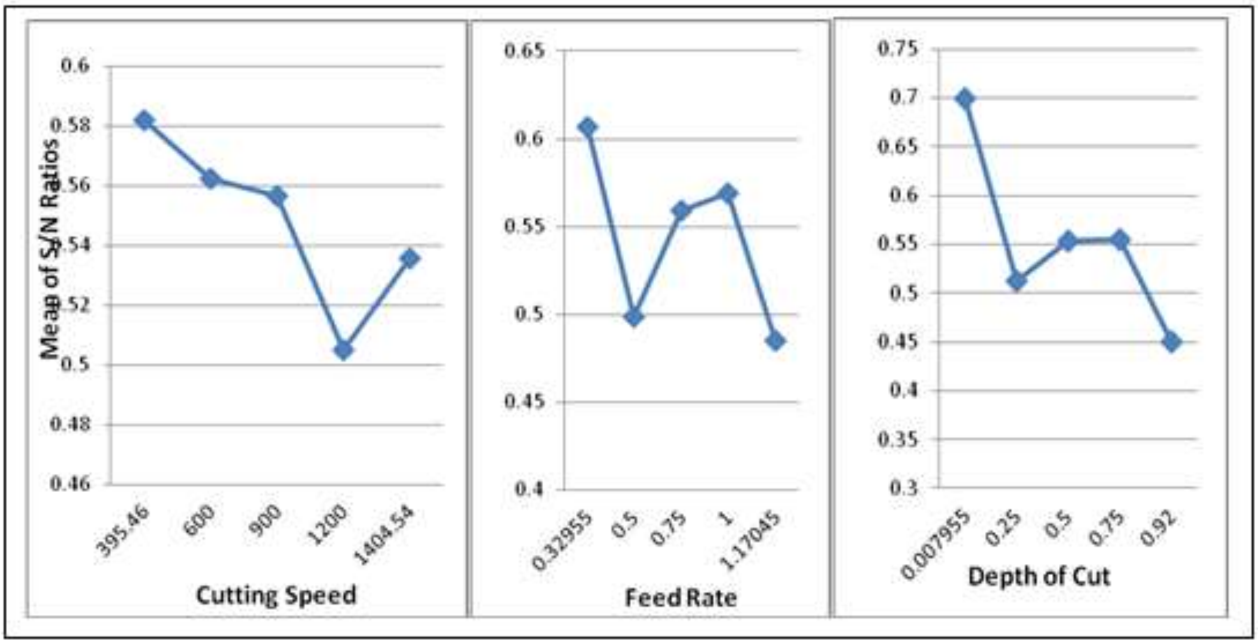


Figure 4.32: Main effect plot Grey relational analysis for dry turning

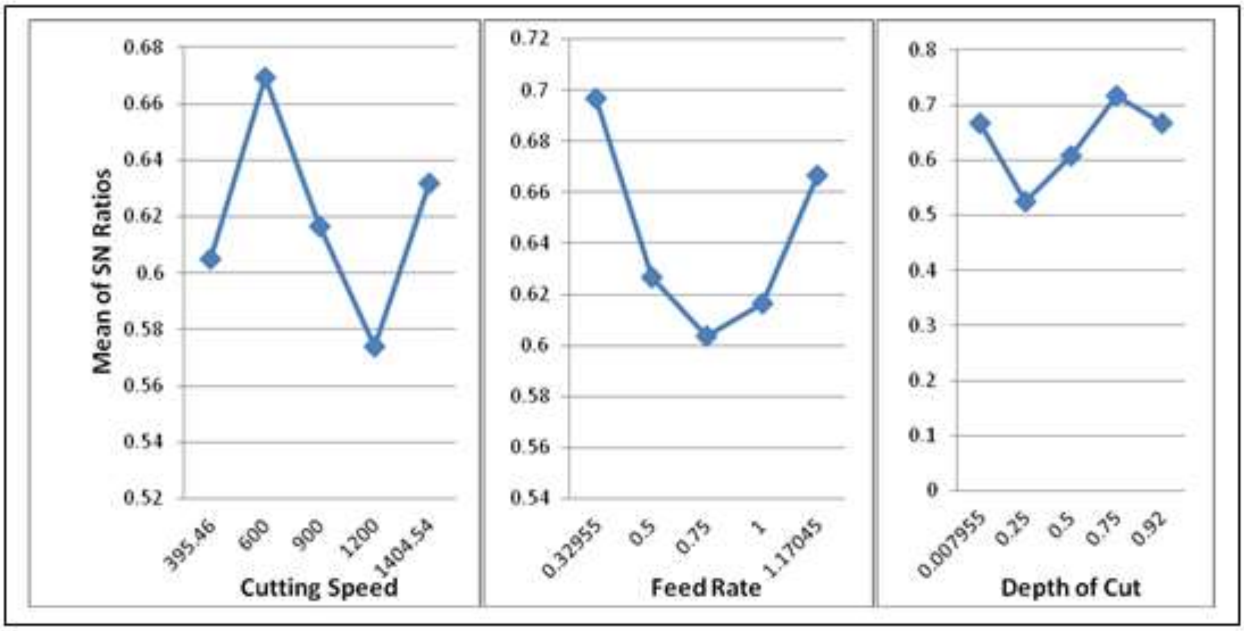


Figure 4.33: Main effect plot Grey relational analysis for wet turning with mineral oil-based cutting fluid

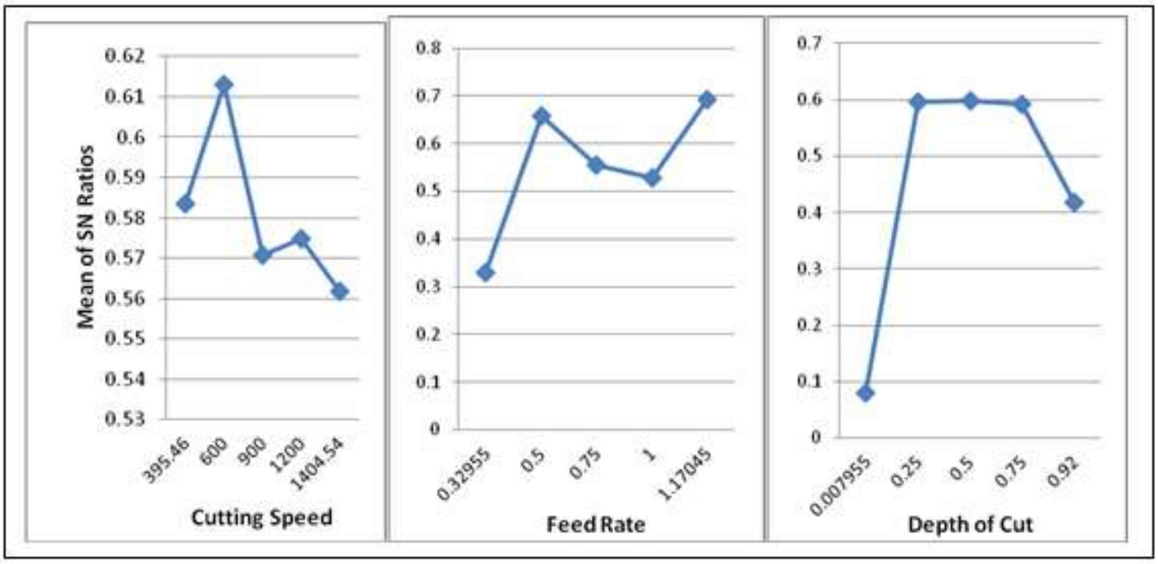


Figure 4.34: Main effect plot grey relational analysis for wet turning with vegetable oil-based cutting fluid

From Figure 4.32, the optimal level of parameters for both responses in dry turning are speed of cutting of 395.46 rev/min, rate of feed of 1.17045mm/rev and cutting depth of 0.5mm. From Figure 4.33, the optimal level of parameters in wet turning with mineral oil-based cutting fluid are speed of cutting of 600 rev/min, rate of feed of 0.32955mm/rev and cutting depth of 0.007955mm. From Figure 4.34, the optimal level of parameters in wet turning with vegetable oil-based cutting fluid are speed of cutting of 600 rev/min, rate of feed of 0.5mm/rev and cutting depth of 0.25mm.

4.10 Analysis of Variance (ANOVA) for both Energy Consumption and Surface Roughness

The ANOVA tables for both responses in various cutting environment are shown in Tables 4.30– 4.32. The purpose of ANOVA is to investigate the degree of importance of each of the factors- Speed of cutting, Rate of feed and Cutting depth on combined responses – Energy consumption and Surface roughness. This agrees with the submission of Balsubramanian and Genepathy (2011).

Table 4.30: ANOVA for Energy consumption and Surface roughness in dry turning

Input variables	**DeOF**	**SOS**	**MnS**	**f-ratio**	**Contribution (%)**
Speed of Cutting	4	**0.02825**	0.007063	9.848108	22.1847
Rate of feed	4	0.03817	0.009543	13.30627	29.97487
Cutting depth	4	0.0559	0.013975	19.48705	43.89823
Error	7	0.00502	0.000717		3.942202
Total	19	0.12734	0.006702		100

Table 4.30 shows a percentage error of 3.94% with cutting depth (43.898%) indicating the most significant variable, followed by rate of feed (29.975%) and speed of cutting (22.185%) which is the least significant factor. The effects of all the variables are important since their individual contributions are higher than 0.05%.

Table 4.31: ANOVA for Energy consumption and Surface roughness in wet turning with mineral oil-based cutting fluid

Input variables	DeOF	SOS	MnS	f-ratio	Contribution (%)
Speed of Cutting	4	**0.04863**	0.012158	1215.75	24.36739
Rate of Feed	4	0.04087	0.010218	1021.75	20.47903
Cutting Depth	4	0.11	0.0275	2750	55.1185
Error	7	7E-05	1E-05		0.035075
Total	19	0.19957	0.010504		100

Table 4.31 shows a percentage error of 0.035% with depth of cut (55.119%) indicating the most significant parameter, followed by cutting speed (24.367%) and feed rate (20.479%) which is the least significant factor. The effects of all the variables are significant since their individual contributions are higher than 0.05%.

Table 4.32: ANOVA for Energy consumption and Surface roughness in wet turning with vegetable oil-based cutting fluid.

Input variables	DeOF	SOS	MnS	f-ratio	Contribution (%)
Cutting speed	4	0.00068	0.000169	22.35377	0.448731
Feed rate	4	0.0501	0.012525	1654.245	33.2074
Depth of cut	4	0.10004	0.02501	3303.208	66.30874
Error	7	5.3E-05	7.57E-06		0.03513
Total	19	0.15087	0.007941		100

Table 4.32 shows a percentage error of 0.035% with depth of cut (66.309%) indicating the most significant variable, with feed rate following (33.204%) and cutting speed

(0.449%) which is the least important factor. The effects of all the variables are significant since their individual contributions are higher than 0.05%.

4.10.1 Regression Analysis of Energy consumption and Surface roughness

GRA results were then used to obtain Regression models for each response by means of Design expert statistical software. In dry turning, the Empirical models obtained are as follows:

(a) Models for dry Turning

Specific Energy consumption $E_{S} = 639 - 0.103Vc - 184Fr - 447d$ 4.13

R- sq = 65.41%, R-sq(adj) = 53.29%

Surface Roughnes $Ra = 2.15 - 0.00034Vc + 2.17Fr + 2.15d$ 4.14

R-sq = 74.29%, R-sq (adj) = 60.77

Where Vc = Speed of cutting, Fr = Rate of feed and d = Depth Cutting depth.

(b) Models for wet cutting using mineral oil-based cutting fluid

Specific Energy consumption $E_{S} = 390.6 - 0.186Vc - 195.9Fr + 123.9d$ 4.15

R- sq = 67.20%, R-sq(adj) = 55.11%

Surface Roughness $Ra = 2.83 + 0.001050Vc + 0.007Fr - 1.465d$ 4.16

R-sq = 64.8%, R-sq(adj) = 50.80

Where Vc = Speed of cutting, Fr = Rate of feed and d = Cutting depth.

(c) Models for wet cutting using vegetable oil-based cutting fluid

Specific Energy consumption $E_{S} =$ 677.6 – 0.0801Vc – 183.9Fr – 64.2d 4.17

S = 0.152501, R- sq = 78.4%, R-sq(adj) = 59.08%

Surface Roughness Ra = -0.078 – 0.000438Fr + 4.022 + 0.085d 4.18

R-sq = 91.03%, R-sq(adj) = 89.34

Where Vc= Speed of cutting, Fr = Rate of feed and d = Cutting depth.

To validate the empirical regression model, the optimal process variables obtained from the main effects' plots were used to obtain the calculated optimal values of energy consumption and surface roughness.

From the main effects plot of Figure 4.32, the optimal process parameters in dry turning are Speed of cutting (Vc) =395.46 rev/min, Rate of feed (Fr) = 0.32755 mm/rev, Cutting depth (d) = 0.007955 mm.

From eq 4.13, Energy consumption $E_{S} =$ 639 – 0.103Vc – 184Fr – 447d

= 639 – 0.103 (395.46) – 184 (0.32955) – 447(0.007955)

= 527.1796 J/mm^3

From eq 4.14 Surface roughness Ra = 2.15 – 0.00034Vc + 2.17Fr + 2.15d

= 2.15-0.00034(395.46)-2.17(0.32955) +2.15(0.007955)

= 1.47116μm

From the main effects plot of Figure 4.33, the optimal process parameters in wet cutting using mineral oil-based cutting fluid are Cutting Speed (Vc) = 600 rev/min, feed rate (Fr) = 0.32955 mm/rev and depth of cut (d) = 0.5 mm.

From equation 4.14, Energy consumption Es=390.6- 0.1867 CS - 195.9 FR + 123.9 DOC

=390.6-0.1867(600)-195.9(0.32955) +123.9(0.5)

= 306.9364 J/mm^3

From equation 4.15, Surface roughness Ra = 2.83+0.001050CS-0.007FR-1.4565DOC

= 2.83+0.00105(600)-0.007(0.32955)-1.465(0.5)

= 2.358943μm

From the main effect plot of Figure 4.34, the optimal process s in wet cutting using vegetable oil-based cutting fluid are Cutting speed = 600rev/min, Feed rate = 1.17045 mm/rev, depth of cut = 0.5mm.

From equation 4.16, Specific Energy consumption E_S =377.6-0.0801Vc–183.9Fr - 64.2d

Hence, E_S = 377.6 - 0.00801(600) -183.9(1.17045) - 64.2(0.25)

= 141.50 J/mm^3

From equation 4.18,

Surface roughness Ra = - 0.078 - 0.000438 Vc + 4.022 Fr+ 0.085 d

= - 0.078 – 0.000438(600) +4.022(1.17045) +0.085(0.5)

= 4.388 μm

4.11 Confirmation Test

Regression equations for cutting variables which include speed of cutting, rate of feed and cutting depth were obtained from regression analysis using design expert statistical software. The calculated results from the equations generated, the experimental values and the percentage errors are calculated and presented in Table 4.28.

$$Percentage\ error\ (E) = \frac{Experimental\ (Ex)\ value - calculated\ (Cc) value}{Experimental\ (Ex) value}\ x\ 100$$

Table 4.33: **Confirmation test and percentage errors**

Cutting Environment	Response	Calculated value	Experimental value	Percentage Error (%)
Dry	Specific energy consumption (J/mm^3)	527.18	520.28	1.31
	Surface roughness(μm)	1.47	1.44	2.08
Wet with mineral oil based cutting fluid	Specific energy consumption (J/mm^3)	306.94	310.56	1.18
	Surface roughness(μm)	2.36	2.42	2.54
Wet with vegetable oil-based cutting fluid	Specific energy consumption (J/mm^3)	141.50	138.76	1.96
	Surface roughness(μm)	4.30	4.28	2.51

All the R^2 values obtained for energy consumption and surface roughness concur with regression models for both responses in the three cutting environments. According to Montgomery *et al*., (1998), R^2 is a value of correlation coefficient in any multiple linear regression analysis and should be within 0.8 and 1.0.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The research is categorised into five subdivisions which include characterisation of Jathropha vegetable oil, formulation of oil in water cutting fluids, determination of optimal process variables for minimum energy consumption and minimum surface roughness in orthogonal turning of AISI 304 alloy steel, determination of optimal combined process variables and generation of regression equations for the energy consumption and surface roughness in orthogonal turning of AISI 304 alloy steel in dry and wet environments.

The physiochemical properties and fatty acid profile of Jatropha vegetable oil was determined and its suitability for formulation of oil in water cutting fluid was ascertained. The oil was then used as a base for formulation of oil in water emulsion cutting fluids and characterised. The formulated cutting fluid had a pH value of 8.65 and viscosity of 2.32mm^2/s. It was found to be corrosion resistant and also show long-time stability with milky colour.

Orthogonal turning investigations were conducted on A1S1304 alloy steel using tungsten coated carbide tool insert in dry and wet environments with mineral oil-based and vegetable oil-based cutting fluids. The selected cutting variables were based on the configuration of the lathe used. The depth of cut used were 0.25 and 0.5mm, cutting speeds used were 600 and 1200 rev/mm, while feed rate of 0.5 and 1.0 mm/rev were also used. The investigation of the Orthogonal turning of A1S1304 alloy steel in dry, wet with mineral oil-based cutting fluid and wet with vegetable oil-based cutting fluid results in establishments of the following:

1. The optimal turning parameters for energy consumption are

   (a) Dry turning: speed of cutting of 1404.5rev/mm, rate of feed of 1.11 mm/rev and cutting depth of 0.92mm.

   (b) Wet turning with mineral oil-based cutting fluid: speed of cutting of 1404.5rev/mm, rate of feed of 1.17mm/rev and cutting depth of 0.92mm.

   (c) Wet turning with vegetable oil-based cutting fluid: speed of cutting of 1404.5rev/mm, rate of feed of 1.00mm and depth of cut of 0.92mm.

2. The optimal process variables for surface roughness are:

   (a) Dry turning: speed of cutting of 900rev/mm, rate of feed of 0.5mm/rev and cutting depth of 0.08mm.

   (b) Wet turning with mineral oil-based cutting fluids: speed of cutting of 600rev/mm, rate of feed of 1.17mm/rev and cutting depth of 0.75mm.

   (c) Wet turning with vegetable oil-based cutting fluid: speed of cutting of 1200rev/mm, rate of feed of 0.33mm/rev and cutting depth of 0.25mm.

3. The optimal combined turning parameters using the Grey relational analysis are:

   (a) Dry turning: speed of cutting of 395.46rev/mm, rate of feed of 1.17mm/rev and cutting depth of 0.5mm.

   (b) Wet turning with mineral oil-based cutting fluid: speed of cutting of 600rev/mm, rate of feed of 0.33mm/rev and cutting depth of 0.01mm.

   (c) Wet turning with vegetable oil-based cutting fluid: speed of cutting of 600rev/mm, rate of feed of 0.5mm/rev and cutting depth of 0.25mm

4. The regression models generated from the Grey rotational analysis are as follows:

   (a) Dry turning:

      i. Energy consumption $Es = 639 - 0.103Vc - 1.84Fr - 447d$

ii. Surface roughness Ra = 2.15 – 0.00034Vs + 2.17Fr + 2.45d

(b) Wet turning with mineral oil-based cutting fluid:

i. Energy consumption Es = 390.6 – 0.1867Vs – 195.9Fr + 123.9d

ii. Surface roughness Ra = 2.83 + 0.001050Vs + 0.007Fr – 1.465d

(c) Wet turning with vegetable oil-based cutting fluid

i. Energy consumption Es = 397.6 – 0.0801Vs – 183.9Fr – 69.2d

ii. Surface roughness Ra = - 0.098 – 0.000438Vs + 4.02Fr + 0.085d

This study has shown that Jathropha vegetable oil is suitable for formulation of metal cutting fluids which is environmentally friendly. In orthogonal turning of AISI 304 alloy steel, minimum energy consumption of 141.50J/mm^3 was recorded in wet environment with vegetable oil-based cutting fluid and minimum surface roughness of 1.47μm was accomplished in dry turning.

5.2 Recommendations

Further works can be done in the areas listed as follows:

i the quality of energy consumption and surface roughness during orthogonal turning of AISI 304 alloy steel using the formulated cutting fluids with the same cutting conditions, and different cutting tools should be studied.

ii energy consumption and surface roughness values while carrying out orthogonal turning of other materials / alloy steel using the formulated cutting fluids should be investigated.

iii Investigation should also be carried out to establish and optimize the relationship existing between energy consumption, material removal rate (MRR) and surface roughness during orthogonal turning.

5.3 Contribution to Knowledge

This research has been able to establish the following:

1. Jathropha vegetable oil from Zaria, Kaduna State, Nigeria having poly unsaturated fatty acid in excess of 70% has been characterised, formulated and used as an alternative cutting fluid for turning AISI 304 alloy steel. The formulated cutting fluid reduced energy consumed from 527.18 J/mm^3 in dry turning to 141.50J/mm^3 using Jathropha vegetable oil-based cutting fluid.

2. The study has also generated regression models for minimum energy consumption and surface roughness in orthogonal turning. The models for dry turning are as follows:

   i Specific Energy consumption $E_S = 639 – 0.103Vc – 184Fr – 447d$

   ii Surface Roughness $Ra = 2.15 – 0.00034\ Vc + 2.17\ Fr + 2.15d$.

   For wet turning with mineral oil-based cutting fluid, the models are as follows

   iii Specific Energy consumption $E_S = 390.6 – 0.1867Vc – 195.9\ Fr + 123.9\ d$

   iv Surface Roughness $Ra = 2.83 + 0.001050\ Vc + 0.007\ Fr – 1.465d$.

   The models for wet turning with vegetable oil-based cutting fluids are as follows

   v Specific Energy consumption $E_S = 377.6 - 0.0801\ Vc – 183.9\ Fr - 64.2d$

   vi Surface Roughness $Ra = - 0.078 – 0.000438\ Fr + 4.022\ Fr + 0.085d$

Optimum cutting variables were also generated from multi-response analysis. These are

For dry turning, cutting speed Vc =395.46rev/min, Feed rate Fr = 1.10745mm/rev, Depth of cut d = 0.5mm.

For wet turning with mineral oil-based cutting fluid, cutting speed Vc = 600rev/min, Feed rate Fr = 0.32955mm/rev, Depth of cut d = 0.00095mm.

For wet turning with vegetable oil-based cutting fluid, cutting speed Vc = 600rev/min, Feed rate Fr = 0.5 mm/rev, Depth of cut d = 0.25mm.

These values when substituted in equations 4.13 to 4.18 as appropriate for dry, wet with mineral oil and wet with vegetable oil turning operations respectively, are useful in accomplishing minimum energy consumption and surface roughness.

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APPENDICES

APPENDIX A: JATROPHA CURCAS

(a) Jatropha curcas l. plant; (b) J. cursas L. fruits; (c) J.curcas L. fresh seeds; Z
(d) Hexane extract of J. curcas L. seed oil

APPENDIX B

Experimental procedure for the parameters of Jathropha vegetable oil tested

(i) Specific gravity

Specific gravity or Relative density is the heaviness of a substance compared to that of water. It is the ratio of the mass of a substance to the mass of an equal volume of water. The procedure used in determining the property is as follows:

a. A 50ml picometer bottle was thoroughly washed with detergent and water
b. The bottle was then dried in an oven at 100^0C
c. By means of electric digital weighing machine, the bottle was weighed.
d. The bottle was then filled with water, weighed and recorded.
e. The bottle was emptied, filled with oil sample and then weighed.

The calculation of the specific gravity is as follows:

a. Weight of empty bottle (A) = 25.173g
b. Weight of bottle with oil (B) = 75.543g
c. Weight of bottle with water (C) = 30.162

Specific gravity = $\frac{weight\ of\ oil}{weight\ of\ equal\ volume\ of\ water}$

$= \frac{B-A}{C-A}$

$= \frac{75.543-25.173}{80.162-25.173}$

= 0.916

(ii) Acid value

A 95ml of Diethyl other was mixed with 25ml also and 1ml phenolphthalein solution (1%). It was then neutralized carefully with few drops of 0.1M KOH. 0.5ml of oil was then dissolved in the neutral solution and titrated with aqueous O.M. KOH and constantly shaked until pink colour persisted for 15 seconds Acid value of Jathropher oil was calculated as:

Acid volume mg/KOH/g = $\frac{\text{Titre value X 0.1M KOHX}}{weight\ of\ sample\ (2)}$

$$= \frac{0.8\ x\ 0.1\ x\ 56.10}{0.572}$$

$$= \quad 7.85\text{mg/KOH/g}$$

(iii) Free fatty acid

The free fatty acids are usually derived from triglycerides or phospholipids. When they are not attached to other molecules, they are known as “free” fatty acids or uncombine fatty acids.

Free fatty acid = $\frac{acid\ value}{2}$

$$= \frac{7.85}{2}$$

$$= 3.923$$

(iv) Viscosity

Viscosity is a measure of resistance of a fluid to flow. The viscosity of the jathopha oil was determined by means of viscometer as follows:

a. The viscometer was heated to 40^0c
b. The viscometer was filled with oil sample until the mark above the upper bulb is reached

c. The time taken for the oil to be decanted from the upper to the lower bulb of the tube was noted and recorded. The Kinematic viscosity of the oil was then calculated as:

Viscosity = $\frac{volume\ decanted}{time\ taken}$

(v) Saponification value

Saponification value is the ability of the oil to form soap. This property varies from one oil to the other. The procedure used is as follows:

a. 2g of jathropha oil was weighed accurately and poured into a comical flask which can resist the action of an alkali.
b. 25ml of alcoholic potassium hydroxide (KOH) solution was added to the oil, heated and allowed to boil continuously for 30minutes. The content was swirl at different intervals.
c. The excess alkali was determined while the solution was still hot by titrating it with 0.5M HCL use 0.5ml of phenolphthalein as indicator.
d. A blank experiment was performed at the same time upon the same quantity of KOH under the same experimental conditions.

The saponification value was then calculated as follows:

Blank titre value (B) = 41.6; sample litre value (S) = Molarity of HCL = 0.5; molecular mass of KOH = 56.1

Saponification value = $\frac{(B-S)X\ 0.5\ X\ 56.10MG}{weight\ of\ sample\ (2)}$

$= \frac{(41.6-38.23)x\ 28.05}{0.5}$

= 189.33

(vi) Flash point

The flash point of oil is the lowest temperature at which vapour of the oil will ignite when exposed to an ignition source.

The cup of the flash point tester was filled with a sample of jathropha oil, placed in the tester and the temperature increased rapidly at the initial stage up to 150^0C. Thereafter, the temperature was increased gradually while the vapour above the surface of the test sample was ignited by a flame from the tester to see if it will ignite. If it fails to ignite, the temperature was further increased and test repeated until the vapour formed is strong enough to ignite. The temperature at which the vapour burst into flame is the flash point. For test sample of the Jathropha oil, the flash point was found to be 219^0c

(vii) Pour point

The pour point of a liquid is the temperature below which the liquid loses its flow characteristics.

The oil sample was poured in a 100ml beaker and placed in a refrigerator. At intervals of 5 minutes, the oil sample was inspected by positioning the beaker horizontally for 5 seconds. The process continues until the oil could not flow while the beaker remains in horizontal position for 5 seconds. Then, a thermometer is used to read the oil temperature. 3^0C below this temperature is the pour point of the oil. For the Jathropha oil, the pour point is -7^0C.

(viii) Moisture content

Moisture content is the quantity of water contained in a material such as oil. The moisture content of the Jathropha oil was measured using the following procedure.

An empty petri dish was weighed (A)

Sample of the oil was poured in the petri dish and weighed (B)

The petri dish with oil was then position in the oven and the weight checked at intervals of 5 minutes. When the weight becomes constant, the weight was recorded (C).

Moisture content = $\frac{B-A}{C-A}$ X 100%

The moisture content of the Jathropha oil was found to be 89%

(ix) pH value

pH is a scale used in specifying how acidic or basic a water-based solution is. In determining the pH value of the oil, the procedure used is as follows:

a. The pH meter was calibrated using buffer solutions 4, 7 and 9, and distilled water.
b. An, appreciable quantity of Jathropha oil sample was then placed in a beaker and the probe of the ph meter dipped into it.
c. The meter reading was ten noted and recorded. The pH value of Jathropha vegetable oil was found to be 5.09.

(x) Iodine value

Iodine value or Iodine number is a measure of the degree of unsaturation of oil. The procedure involved in determination of Iodine value is as follows:

a. 0.5ml of oil sample was added to 0.5ml of chloroform ($CHCl_3$) in a 250ml conical flask.
b. 25ml Wig's solution was properly mixed and allowed to stand in the dark for an incubation period of 30 minutes with occasional shaking.

c. After30 minutes, 10ml or 15% Potassium Iodide (KI) was added and thoroughly shaked. Then, 10ml of distilled water was added and stirred thoroughly to mix with the solution.
d. The solution obtained was finally titrated against 0.1M Sodium Thiosulphate (NaS_2O_3) solution until yellow solution turns almost colourless.
e. Few drops of starch were added as an indicator until the bluish colour turns almost colourless.

Blank titre in ml (B) = 72.5; Sample titre in ml (S) = 37.1

Iodine value of Jathropa oil = 113.4g/100g of KOH

Appendix C1: Certificate of Characterisation of AISI 304 Alloy steel

SPECTRO

AMETEK
MATERIALS ANALYSIS DIVISION

Measure Date Time	Method Name	Type	Type Corr Sample Name
7/8/2019 2:25:22 PM	Fe-30-DP	Unknown	

Client	Coupon Identification	Test Requistion No	Specimen No	Test Operator
Engr. Kabiru Olaiya				SERAH

Meas.	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co
	%	%	%	%	%	%	%	%	%	%
1	0.0605	0.410	1.36	0.0377	0.0175	18.06	0.279	8.33	<0.00100	0.201
2	0.131	0.406	1.37	0.0384	0.0178	18.02	0.277	8.33	<0.00100	0.198
<x>	0.0957	0.408	1.36	0.0380	0.0176	18.04	0.278	8.33	<0.00100	0.199

Meas.	Cu	Nb	Ti	V	W	Pb	Sn	As	Ca	Sb
	%	%	%	%	%	%	%	%	%	%
1	0.331	<0.0040	0.0037	0.0721	0.0264	<0.0020	0.0076	<0.0020	0.00028	<0.0020
2	0.327	<0.0040	0.0039	0.0737	0.0261	<0.0020	0.0081	0.0035	0.00082	<0.0020
<x>	0.329	<0.0040	0.0038	0.0729	0.0263	<0.0020	0.0078	0.0027	0.00055	<0.0020

Meas.	Se	Ta	B	N	Fe
	%	%	%	%	%
1	<0.0020	<0.0200	0.0013	0.0418	70.7
2	<0.0020	<0.0200	0.0013	<0.0400	70.7
<x>	<0.0020	<0.0200	0.0013	0.0409	70.7

MIDWAL ENGINEERING

Appendix C2: Certificate of MIDWAL Laboratory

International Accreditation Service

CERTIFICATE OF ACCREDITATION

This is to signify that

MIDWAL ENGINEERING SERVICES LTD
ELEGANZA MALL, IKOTA, LEKKI
101245, LAGOS, NIGERIA

Testing Laboratory TL-603

has met the requirements of the IAS Accreditation Criteria for Testing Laboratories (AC89), has demonstrated compliance with ISO/IEC Standard 17025:2005, *General requirements for the competence of testing and calibration laboratories*, and has been accredited, commencing September 4, 2014, for the test methods listed in the approved scope of accreditation.

Patrick V. McCullen
Vice President, Chief Technical Officer

C.P. Ramani, P.E.
President

ilac-MRA

IAS ACCREDITED

(see attached scope of accreditation for fields of testing and accredited test methods)

Print Date: 09/11/2014

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This accreditation certificate supersedes any IAS accreditation certificate bearing an earlier date. The certificate becomes invalid upon suspension, cancellation or revocation of accreditation.
See the IAS Accreditation Listings on the web at www.iasonline.org for current accreditation information, or contact IAS directly at (562) 364-8201.

11-04577

APPENDIX D: Contour plots for Energy consumption

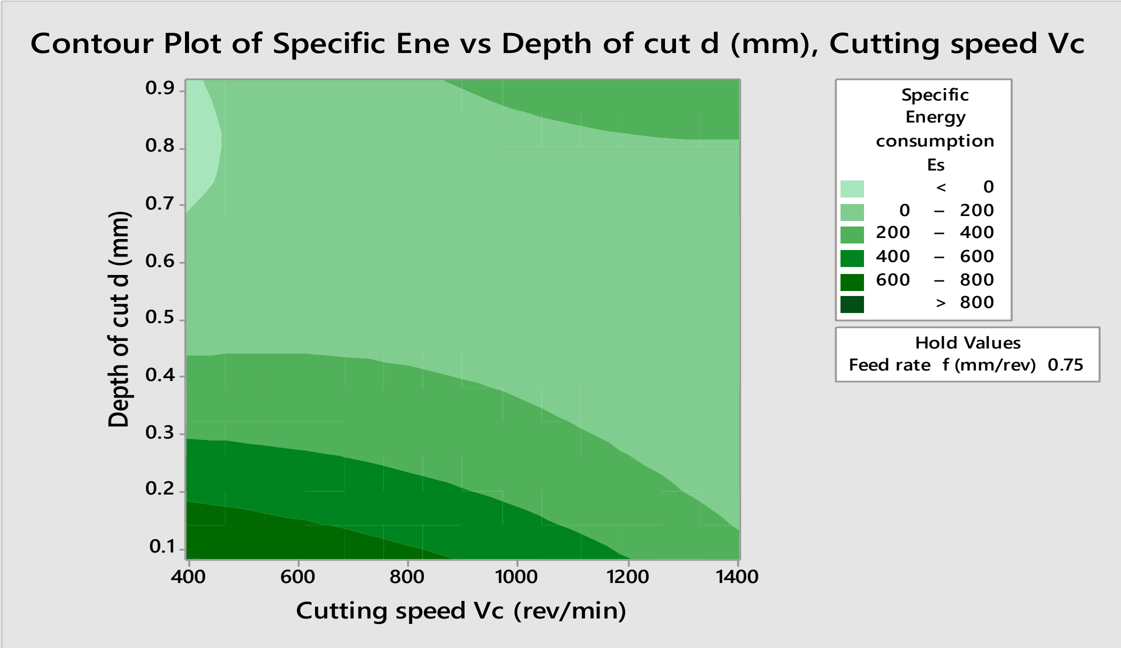

Figure D1: Contour plot of specific energy consumption(Es) versus depth and cutting speed in dry cutting

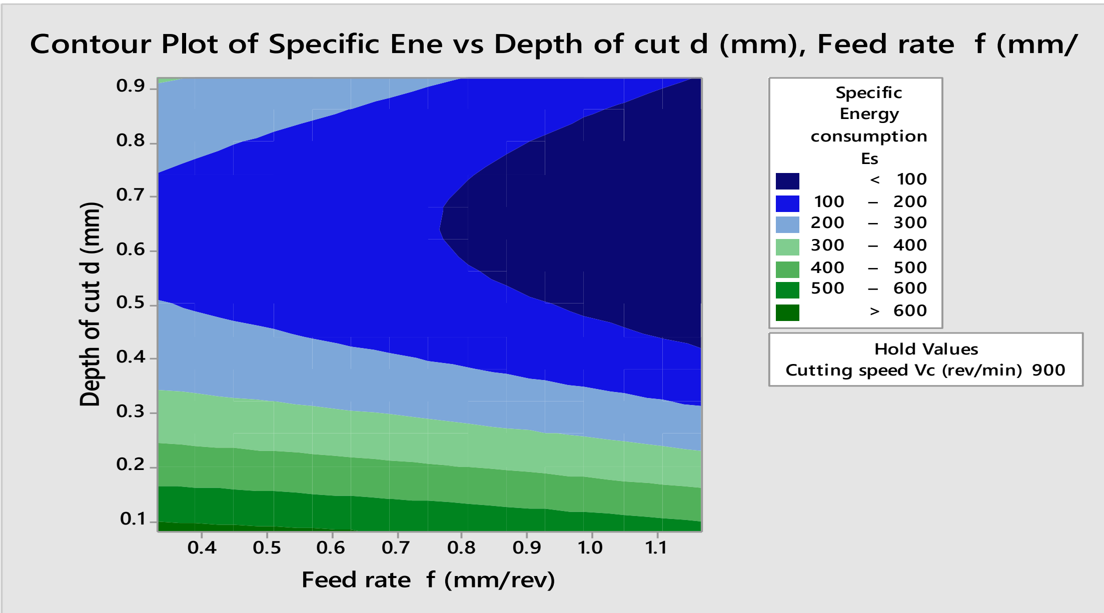

Figure D2: Contour plot of specific energy consumption(Es) versus depth of cut and feed rate in dry cutting

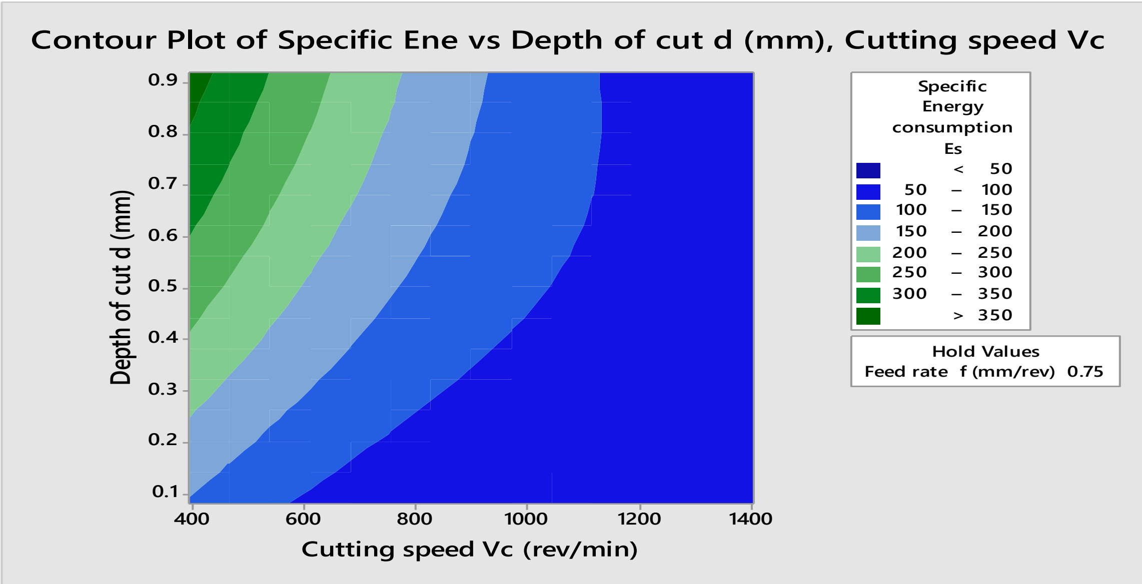

Figure D3: Contour plot of specific energy consumption(Es) versus depth of cut and cutting speed in wet cutting with mineral oil-based cutting fluid

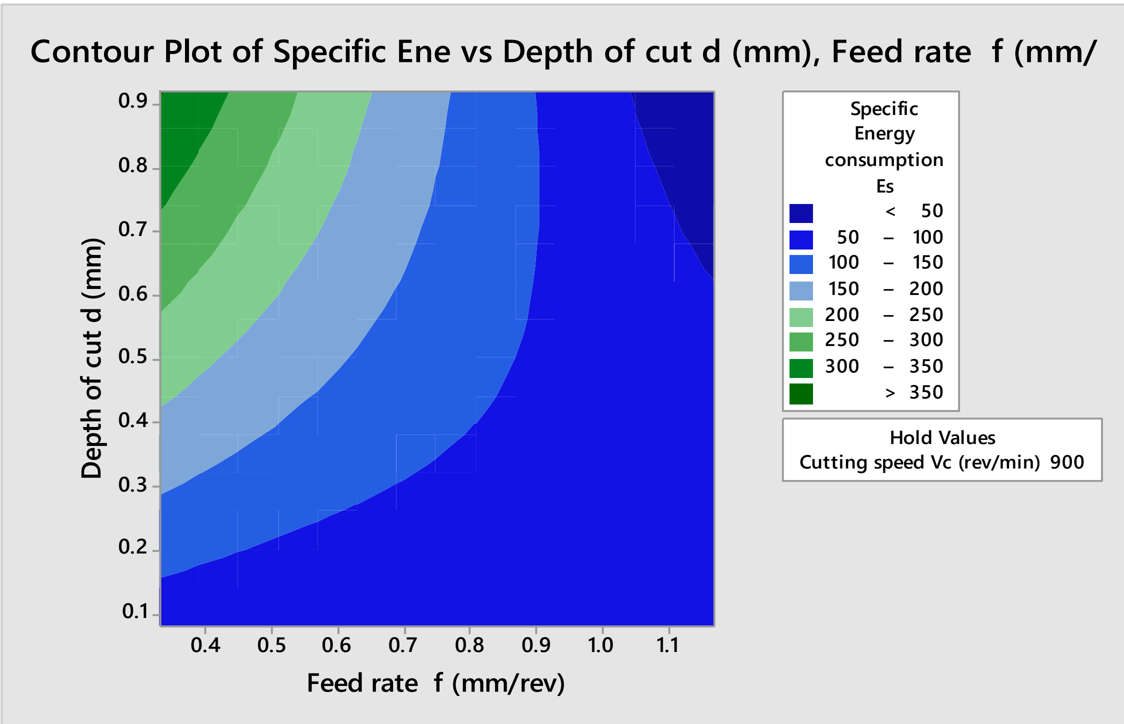

Figure D4: Contour plot of specific energy consumption(Es) versus depth of cut and feed rate in wet cutting with mineral oil-based cutting fluid

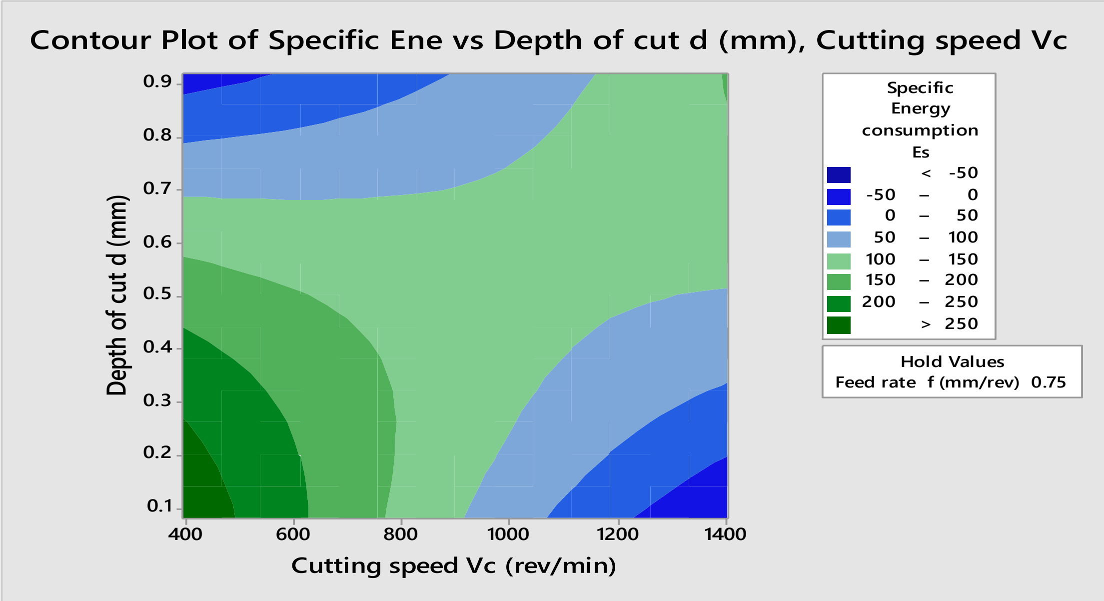

Figure D5: Contour plot of specific energy consumption(Es) versus depth of cut and cutting speed in wet cutting with vegetable oil-based cuttin fluid

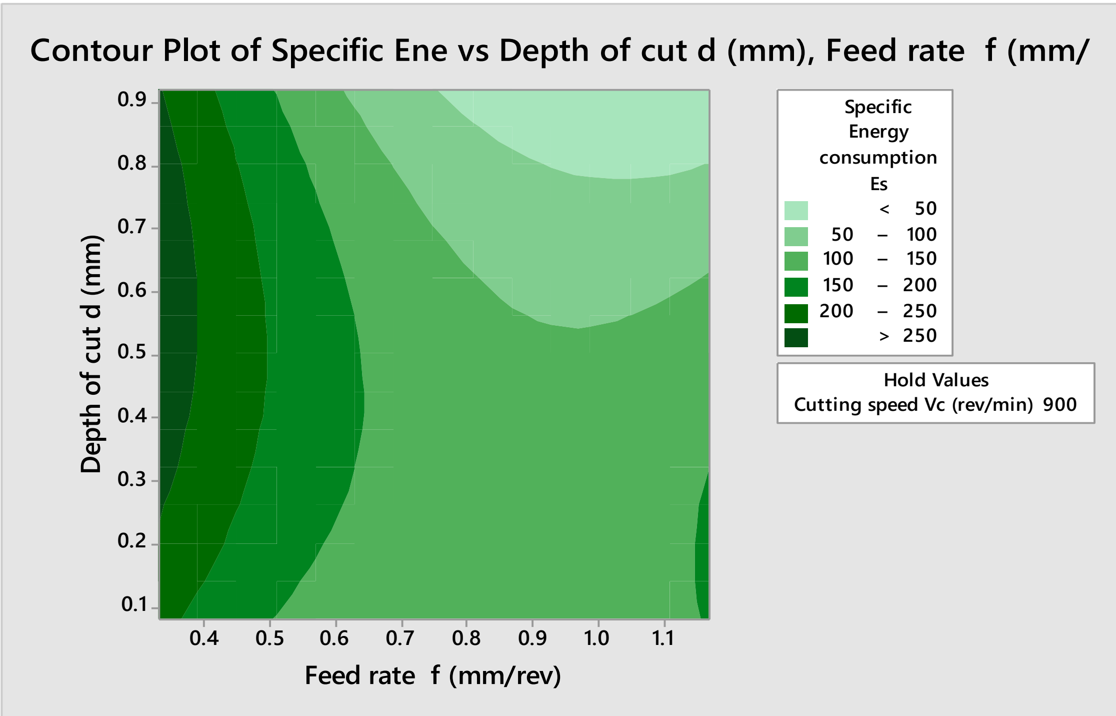

Figure D6: Contour plot of specific energy consumption(Es) versus depth of cut and feed rate in wet cutting with vegetable oil-based cuttin fluid

APPENDIX E: Contour plots for surface roughness

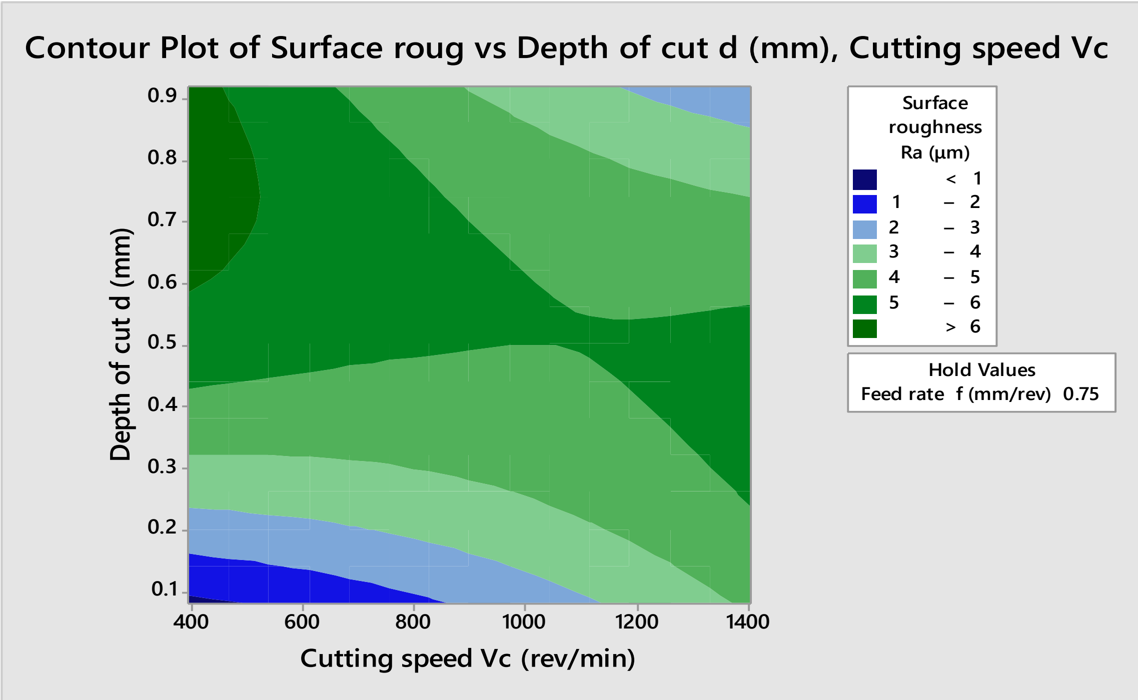

Figure E1: Contour plot of surface roughness versus depth of cut and cutting speed in dry cutting

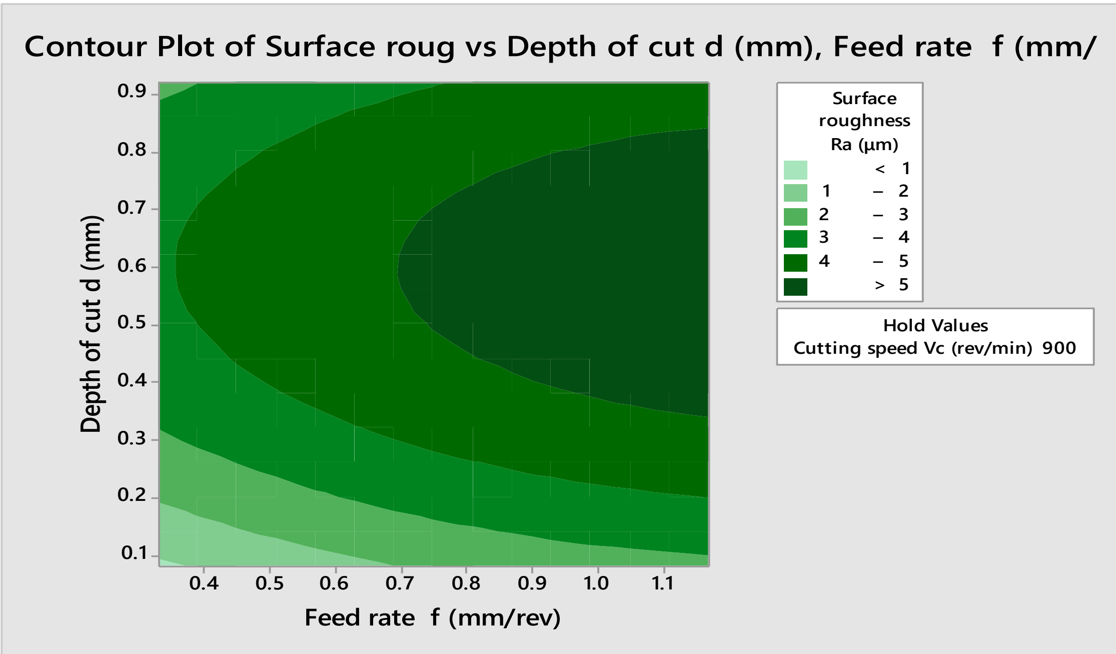

Figure E2: Contour plot of surface roughness versus depth of cut and feed rate in dry cutting

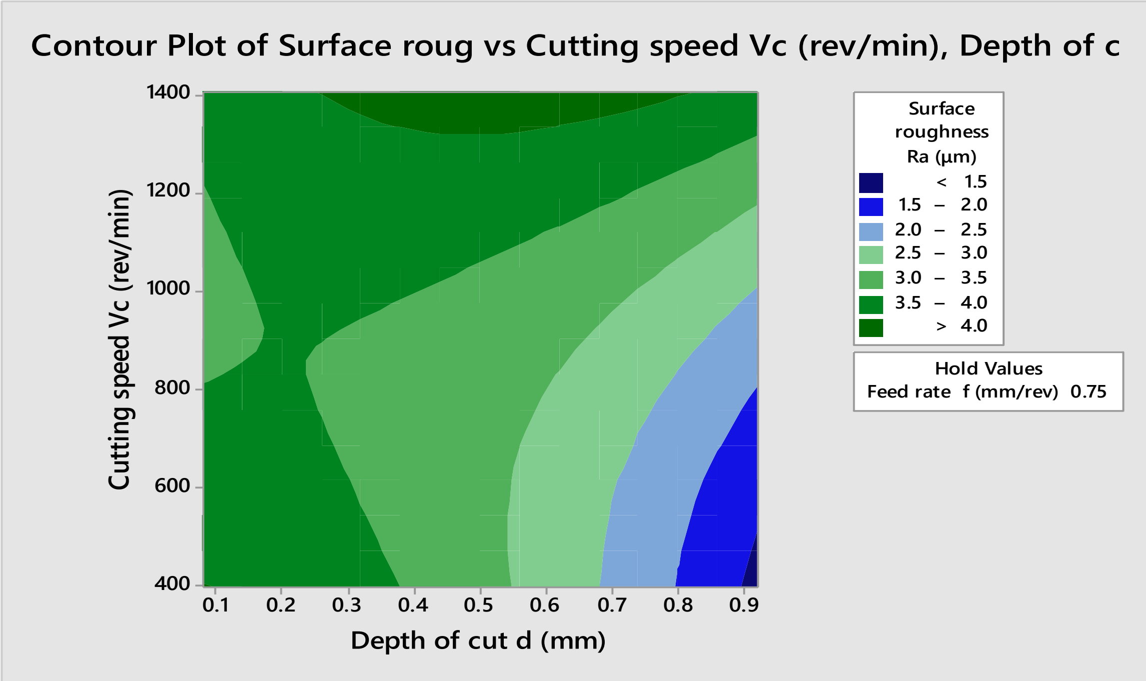

Figure E3: Contour plot of surface roughness versus cutting speed and depth of cut in wet cutting with mineral oil-based cutting fluid

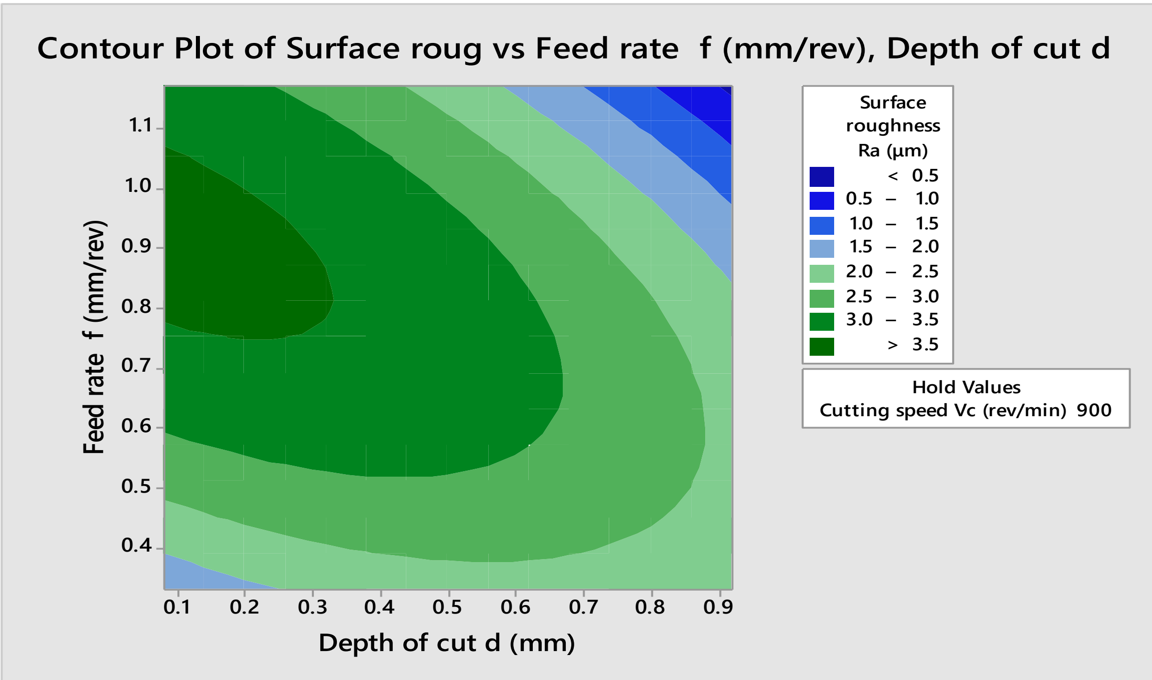

Figure E4: Contour plot of surface roughness versus feed rate and depth of cut in wet cutting with mineral oil-based cutting fluid

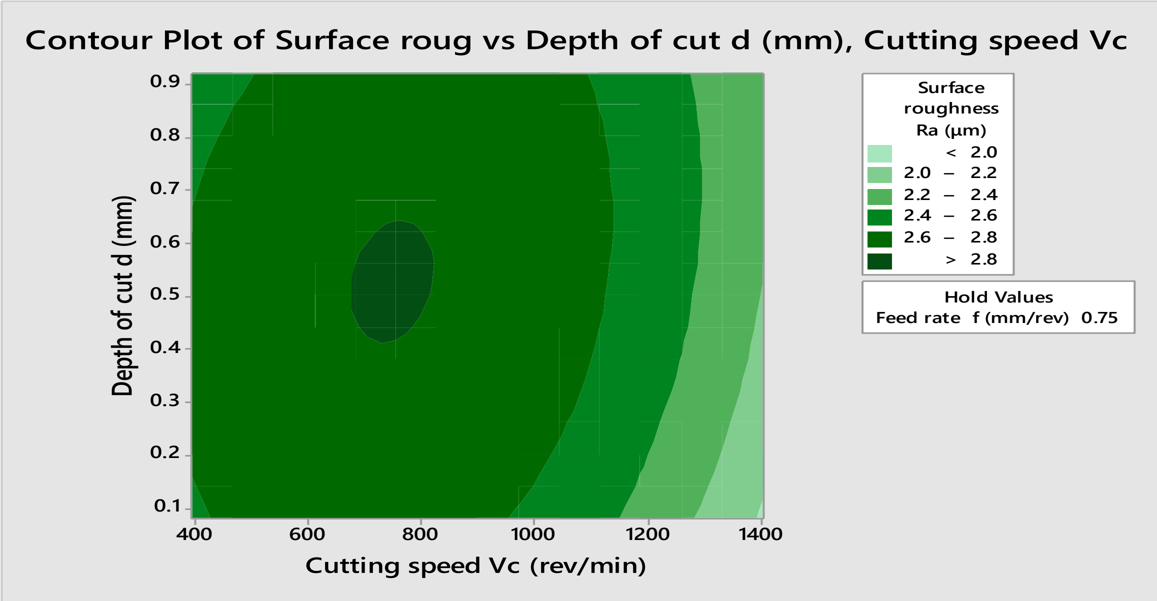

Figure E5: Contour plot of surface roughness versus depth of cut and cutting speed in wet cutting with vegetable oil-based cutting fluid

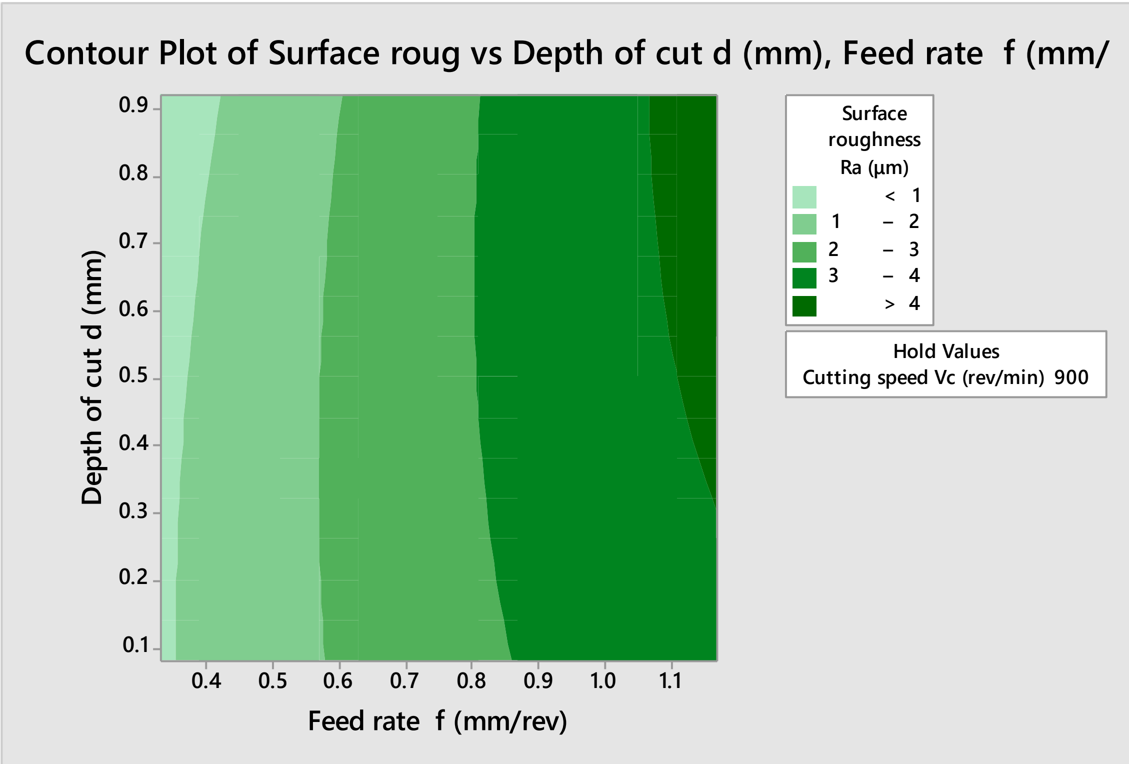

Figure E6: Contour plot of surface roughness versus depth of cut and feed rate in wet cutting with vegetable oil-based cutting fluid

APPENDIX F: Surface plots for Energy consumption

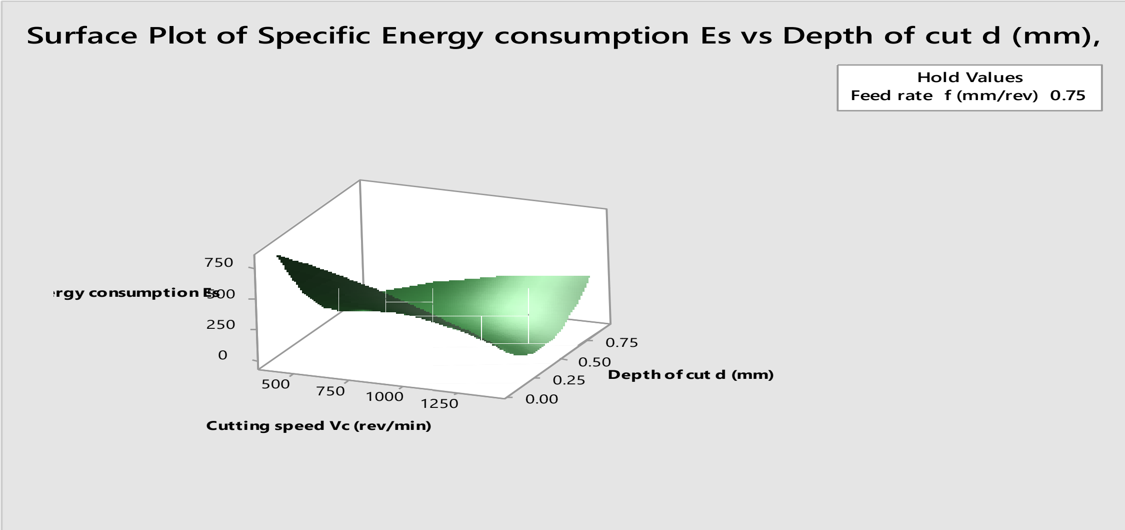

Figure F1: Surface plot of Energy consumption versus cutting speed and depth of cut in dry cutting

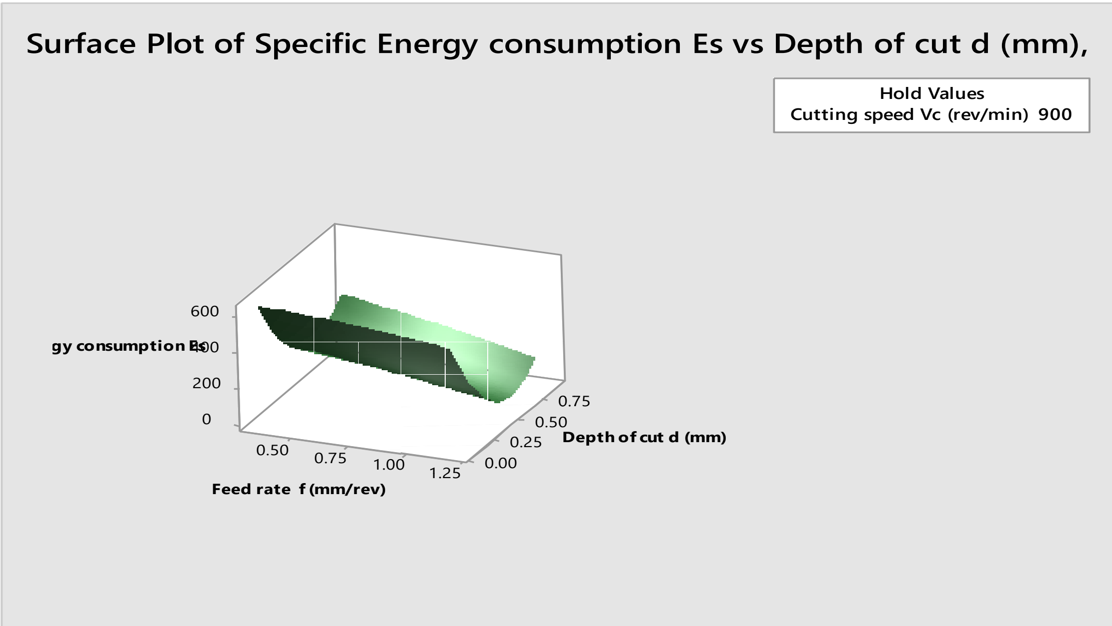

Figure F2: Surface plot of Specific energy consumption versus depth of cut and feed rate in dry cutting

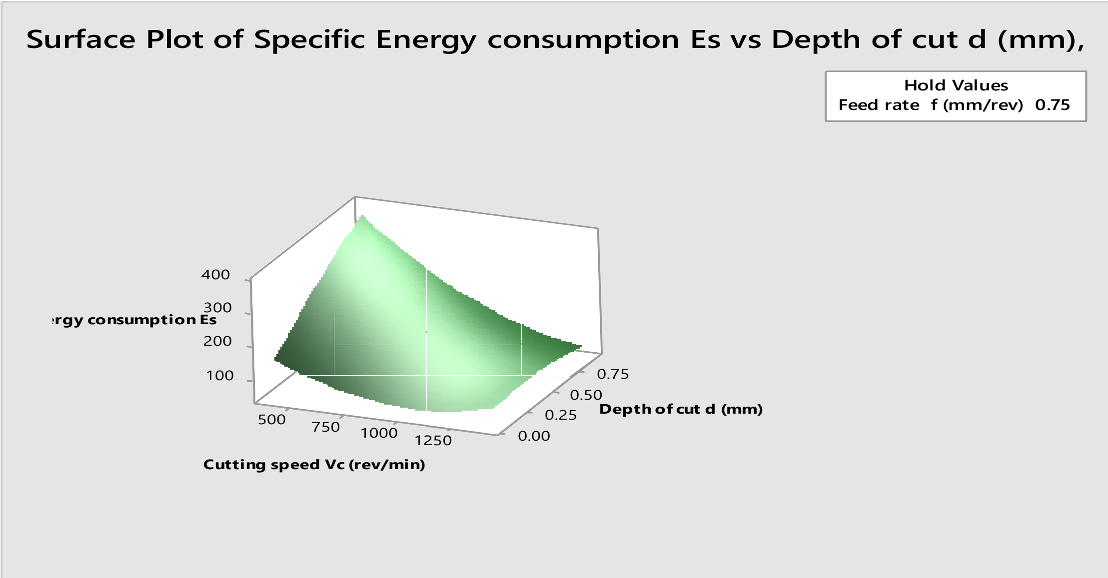

Figure F3: Surface plot of Specific energy consumption versus cutting speed and depth of cut in wet cutting with mineral oil-based cutting fluid

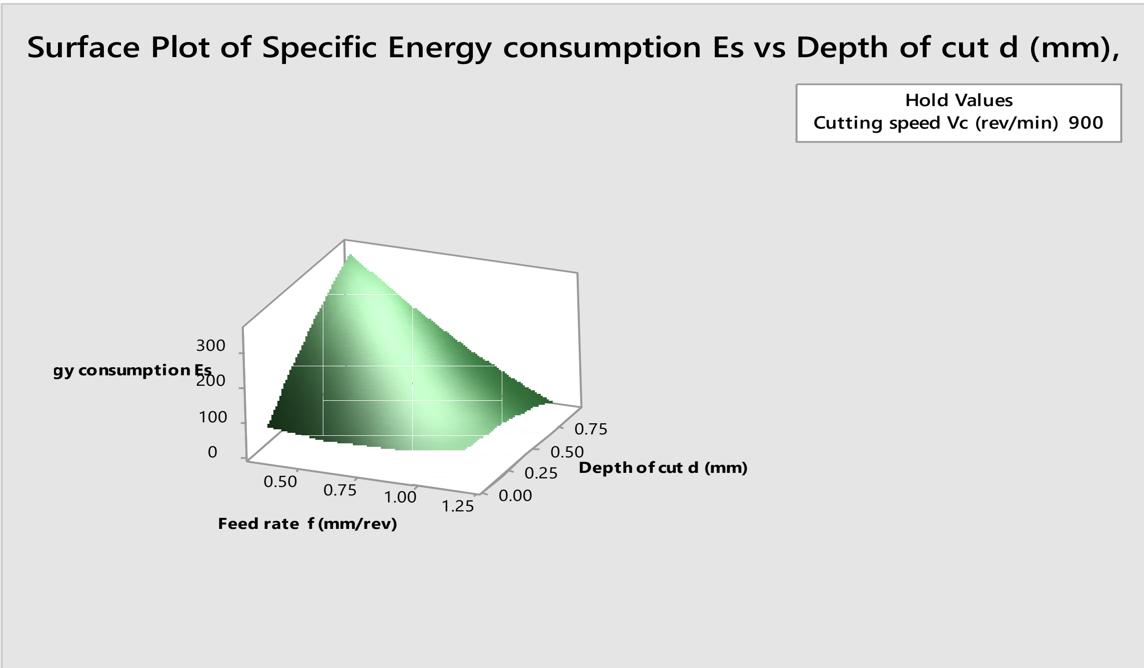

Figure F4: Surface plot of Specific energy consumption versus feed rate and depth of cut in wet cutting with mineral oil-based cutting fluid

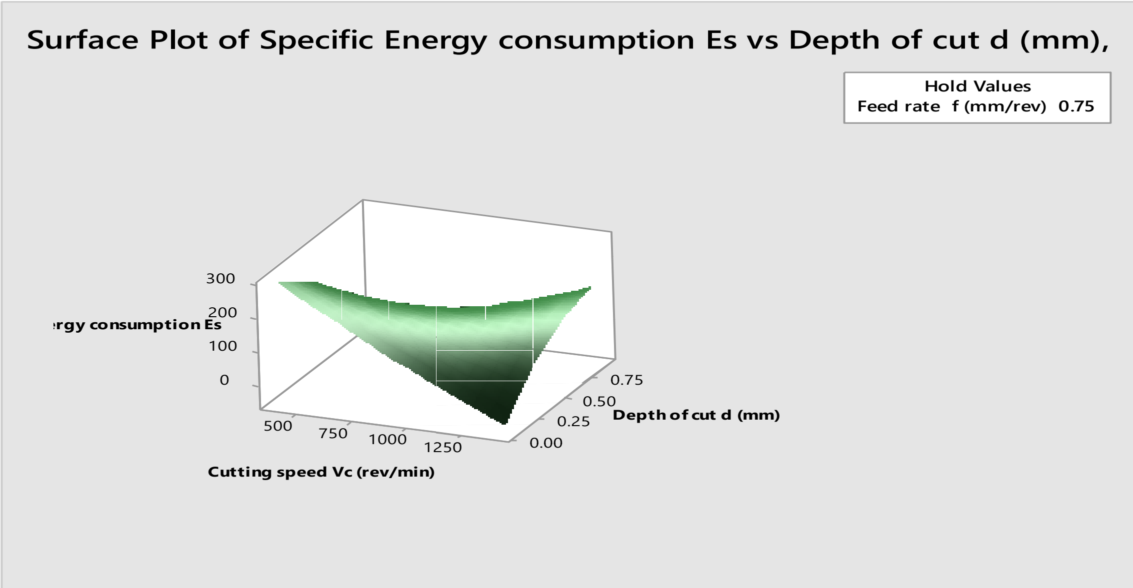

Figure F5: Surface plot of Specific energy consumption versus cutting speed and depth of cut in wet cutting with vegetable oil-based cutting fluid

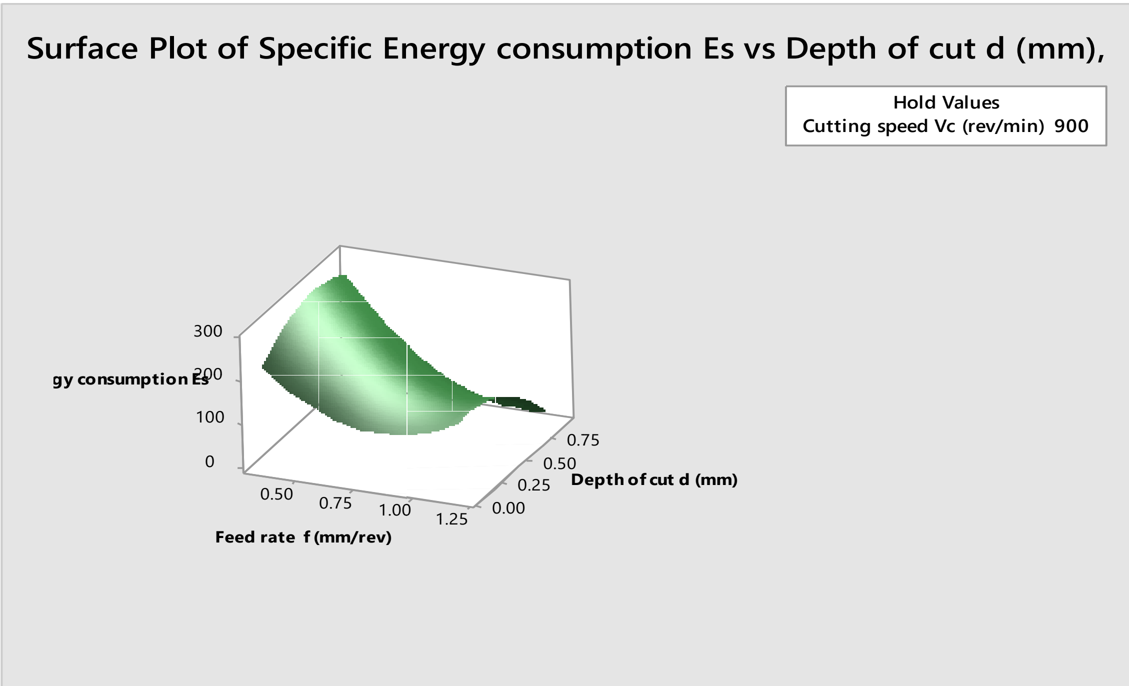

Figure F6: Surface plot of Specific energy consumption versus feed rate and depth of cut in wet cutting with mineral oil-based cutting fluid

APPENDIX G: Surface plots for Surface Roughness

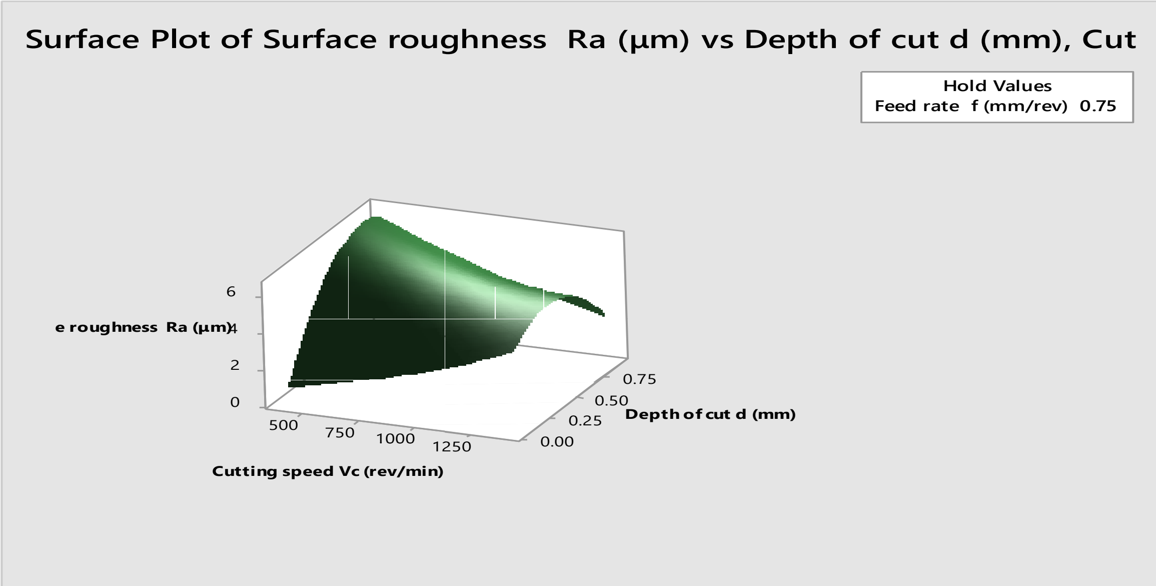

Figure G1:Surface plot of surface roughness versus cutting speed and depth of cut in dry cutting

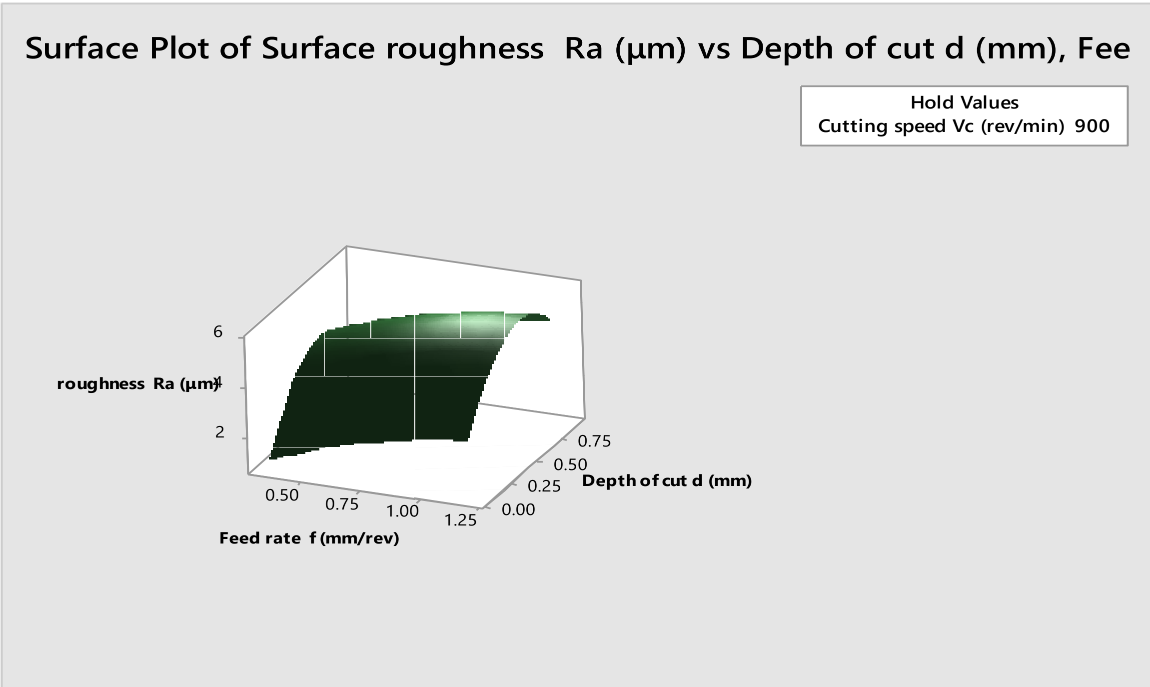

Figure G2:Surface plot of surface roughness versus feed rate and depth of cut in dry cutting

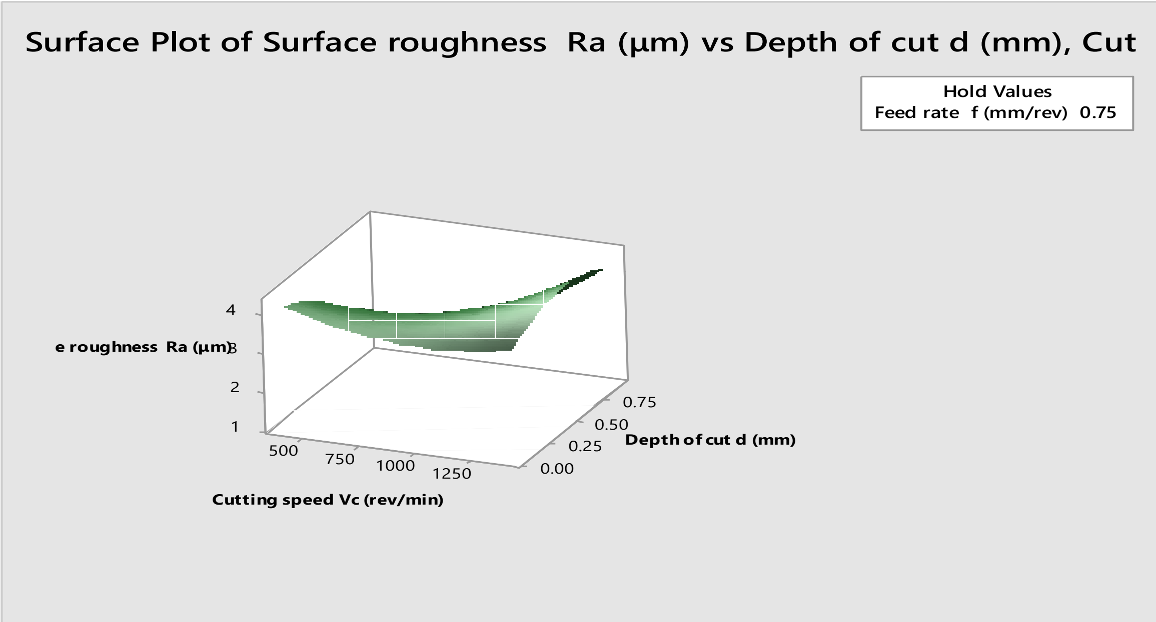

Figure G3: Surface plot of Surface Roughness versus cutting speed and depth of cut in wet cutting with mineral oil-based cutting fluid

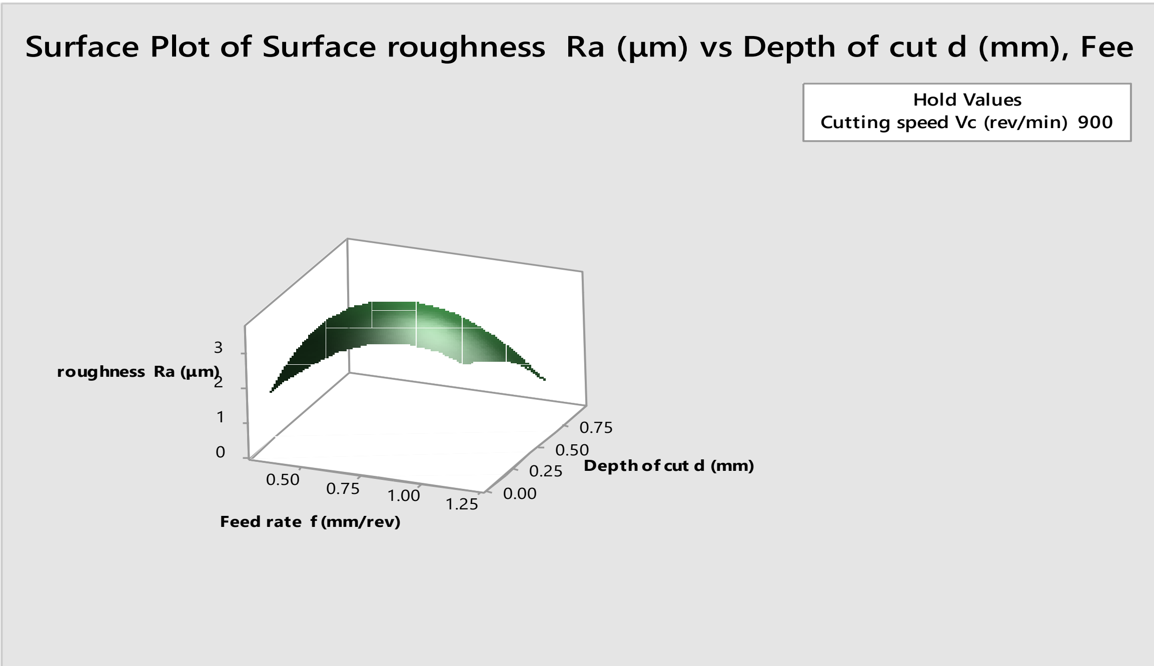

Figure G4: Surface plot of Surface Roughness versus feed rate and depth of cut in wet cutting with mineral oil-based cutting fluid

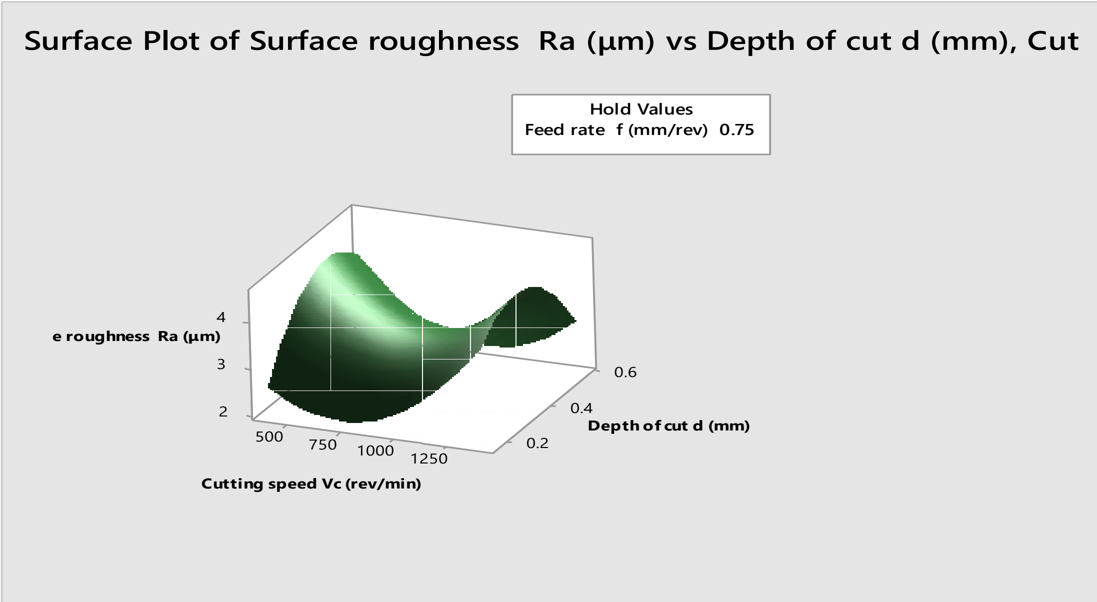

Figure G5: Surface plot of Surface Roughness versus depth of cut and of cutting speed in wet cutting with vegetable oil-based cutting fluid

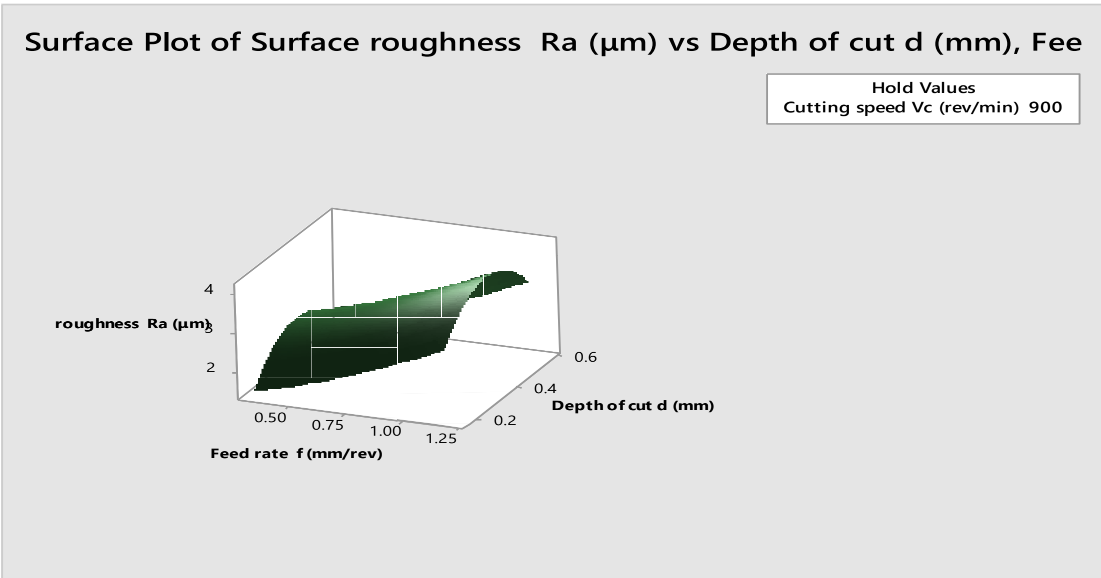

Figure G6: Surface plot of Surface Roughness versus depth of cut and feed rate in wet cutting with vegetable oil-based cutting fluid