



**WALLAGA UNIVERSITY**  
**SCHOOL OF GRADUATE STUDIES**  
**COLLEGE OF ENGINEERING AND TECHNOLOGY**  
**DEPARTMENT OF MANUFACTURING ENGINEERING**

**Parameter Optimization in CNC Dry Turning of AISI 1060 Steel for  
Sustainable Manufacturing**

**A M.Sc. Thesis**

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**APPROVAL SHEET FOR SUBMITTING FINAL PROPOSAL**

As members of the Board of Examiners of the Final MSc. Thesis open defense, we certify that we have read and evaluated the thesis prepared by **Tesfaye Oljira** under the title **“Parameter Optimization in CNC Dry Turning of AISI 1060 Steel for Sustainable Manufacturing”** and recommend that the thesis be accepted as fulfilling the Thesis requirement for the Degree of Master of Mechanical Engineering in Manufacturing Engineering.

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# APPROVAL SHEET

This certifies that Tesfaye Oljira's research thesis, "**Parameter Optimization in CNC Dry Turning of AISI 1060 Steel for Sustainable Manufacturing**," was approved in part to satisfy the requirements for the MSC Degree of Master of Manufacturing Engineering awarded by Wallaga University's School of Graduate Studies through the College of Engineering and Technology. The topic covered in this study has never before been submitted for consideration for a degree or certificate. The support and aid obtained throughout this study have been properly recognized. Consequently, we suggest that it be approved as meeting the standards of the research thesis.

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Major advisor

Date

Signature

## **ABBREVIATIONS AND ACRONYMS**

|       |                                   |
|-------|-----------------------------------|
| AISI  | American Iron and Steel Institute |
| ANOVA | Analysis of Variance              |
| CCD   | Central Composite Design          |
| CI    | Class Interval                    |
| CNC   | Computer Numerical Control        |
| df    | Degree of freedom                 |
| DFA   | Desirability Function Analysis    |
| dc    | Depth of cut                      |
| f     | Feed rate                         |
| MRR   | Material Removal Rate             |
| RSM   | Response Surface Methodology      |
| Ra    | Arithmetic average as a height    |
| T     | Temperature                       |
| Vc    | Cutting speed                     |
| VIF   | Variance Inflation Factor         |

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## ABSTRACT

*Metal cutting is a common operation performed in modern manufacturing industries. Integration of high-precision machines like NC machines improved the issues related to downtime and human intervention as well as product quality. However, balancing quality, productivity, and sustainability in the machining industry remains a significant challenge. While metal cutting fluids can simultaneously improve productivity and quality, they also have negative impacts on machining costs and sustainability. AISI 1060 is a high-carbon steel commonly used in automotive components such as clutch discs, shafts, and axles. Dry turning of this type of steel generates an excessive amount of heat, leading to the need high cutting force and spoiling the integrity of the resulting surface. The purpose of this study is to investigate how dry turning parameters, such as feed rate, depth of cut, and cutting speed, affect productivity metrics, such as surface roughness, cutting temperature, and material removal rate (MRR), when AISI 1060 steel is CNC turned. The experiments are designed using Central Composite Design (CCD) from Design Expert software (version 13.0.5.0), and the settings are optimized for improved performance using desirability function analysis (DFA) techniques. To ascertain the significance level of factors on outcomes, an ANOVA was performed using the Response Surface Methodology (RSM) research type. With percentage contribution values of 40.6 and 54.4 for surface roughness and cutting zone temperature, respectively, the ANOVA result highlighted the significant parameters as cutting speed. The multiobjective optimization using DFA showed that the cutting speed of 128.928 m/min, feed rate of 0.150 mm/rev, and depth of cut of 1.137 mm were the optimal combinations of conditions that yield the lowest roughness of 3.966  $\mu\text{m}$ , cutting temperature of 64.9°C, and maximum MRR of 21919.191  $\text{mm}^3/\text{min}$  with a 0.586 desirability value.*

**KEYWORDS;** *Cutting fluids, Dry turning, Machining, Sustainability, Surface Roughness,*

# **CHAPTER ONE**

## **1. INTRODUCTION**

### **1.1. BACKGROUND OF THE STUDY**

These years, fabrication of product with high quality attributes at the appropriate amount and economy is challenging task facing manufacturing sectors (Padhan et al., 2020). The manufacturing sector is always looking to increase the effectiveness and caliber of its machining operations. A basic machining technique called turning is essential for creating cylindrical pieces with exact dimensions and surface qualities. The basic turning principles and setup, as shown in Figure 1.1, depict the conventional turning method, which is still widely used in small-scale manufacturing industries. Due to its favorable mechanical properties and versatility in various applications, medium carbon steel, especially AISI 1060, is extensively used in the construction, automotive, and machinery industries to create items like clutch discs, shafts, axles, water mains, wear rail, and machinery (Mia & Dhar, 2019). However, challenges persist in dry CNC turning of medium carbon steel, particularly in maintaining optimal cutting temperatures and achieving superior surface quality.

According to the current environmental protection laws, the restrictions were placed on the use of the non-friendly materials, such as traditional cutting fluids, in machining industries. In response to this, the manufacturing industries are turning their faces to introduce green approaches such as the use of nanofluids, cryogenic machining, and dry conditions. Moreover, nowadays the machining industries and researchers are looking forward to using these approaches, which are environmentally friendly and independent of the nonrenewable resources. The machining approach's efficiency is largely dependent on turning factors, such as feed rate, depth of cut, and cutting speed. These variables affect the work piece's surface polish as well as the temperature produced at the cutting contact. Inappropriate parameter settings can provide poor surface finishes, jeopardizing the integrity of the finished product, while excessive cutting temperatures can cause tool damage, shorter tool life, and worsened surface quality.

This study aims to experimentally investigate how turning parameters in dry CNC machining of medium carbon steel (AISI 1060) affect material removal rate, chip formation, and cutting temperature. Important machining parameters will be varied in this investigation, and their effects on the final surface polish and cutting temperature will be measured. Comprehending

these correlations is crucial in order to optimize the turning procedure and improve both product quality and performance. Further in this research work, the optimization of these turning parameters will be conducted using desirability function analysis, in which the range in which maximum desirability values are obtained will be suggested.

Moreover, this research focus to provide bulk information on the interaction between turning parameters and their effects on quality and production rate, ultimately providing actionable insights for improving machining processes.

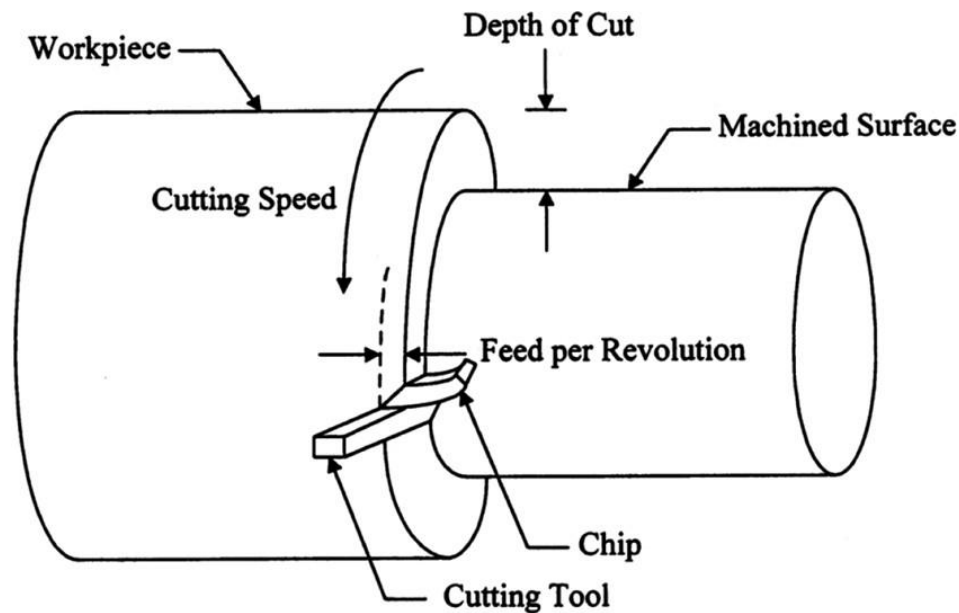


Figure 1. 1: Basic turning principle in metalworking

## 1.2 Statement of the problems

Rules about environmental protection limits use of coolant from use and promote the use of dry or near-dry machining in the metalworking industries. In addition, the problems associated with cutting fluids, such as harming the environment, increasing machining costs, affecting the operator's health, disposal concerns, fluid maintenance, and pretreatment costs, impose significant restrictions on coolant in machining (Ishfaq et al., 2021). As a result, metalworking industries are rapidly adopting cost-effective and environmentally friendly approaches are practiced in metal cutting industries (Zishanur Rahman et al., 2018). From these green approaches being implemented in metalworking industries is performing machining operations without the adoption of dry machining in place of cutting fluids. However, the machining operations carried out without coolant pose detrimental effects on surface quality, tool wear,

power consumption, production rate, and cutting zone temperature. Research indicated that the metal fabrication variables like cutting speed, feed rate, depth of cut, and cutting tool geometry influence machining performance characteristics such as rate of production and roughness cutting zone temperature, and tool wear (Abbas et al., 2023; Ahmed et al., 2023). Thus, choice of optimal process parameters in order to balance the machining performance characteristics and sustainability is still a challenging task for both metalworking industries and researchers. Several researchers have made an attempt to find optimal machining parameters that can negotiate sustainability and machining performance. (Vukelic et al., 2021) performed a dry turning experiment on AISI 1040 steel to investigate the effects of parameters on surface roughness and tool wear. They employed hybrid RSM and GA optimization tools to find optimal parameters. (Cabanac et al., 2021) carried out dry turning on AISI 1040 steel and reported that optimum surface roughness  $1.15 \mu\text{m}$  and MRR  $22\,357.5 \text{ mm}^3 \text{ min}^{-1}$  were achieved at 1200 rpm, feed of  $0.21 \text{ mm rev}^{-1}$  and depth of cut of 1.5 mm. (Zerti et al., 2017) did dry turning experiments on AISI D3 steel based on Taguchi L18 and presented the optimal surface roughness of  $0.39 \mu\text{m}$  and cutting force of 55.16 N at a cutting speed of 220 m/min, a feed rate of 0.16 mm/rev, and a depth of cut of 0.45 mm. Further, the accuracy of the optimization and data analysis tools resulted in the development of wrong prediction models and sets of optimal parameters. Thus, there is a need for a comprehensive investigation of the parametric effects of CNC dry machining on surface integrity, production rate, cutting zone temperature, and tool wear during dry turning of AISI 1060 steel and systematic selection of optimum parameters to ensure sustainability without compromising machining performance outcomes.

### **1.3. Research questions**

The following are the questions for this research;

1. How do the turning parameters affect the product quality, production rate, and temperature at the cutting zone during CNC dry turning of AISI 1060 steel?
2. What are the optimal combinations of turning parameters that improve surface quality, production rate, and minimize cutting zone temperature?
3. What are the most significant influencing parameters for surface roughness, production rate, and cutting zone temperature during CNC dry turning of AISI 1060 steel?
4. How does the predictive regression model developed by RSM for surface roughness, MRR, and tool tip temperature perform?

## **1.4. General Objectives**

The general goal in this research is to optimize the parameters in CNC dry turning of AISI 1060 steel for sustainable manufacturing.

### **1.4.1. Specific objectives**

The following are the particular goals of the current study;

- To investigate the effects of varying dry turning procedure variables on surface quality, production rate, and tool-workpiece contact point temperature.
- To choose better combinations of turning parameters for improved surface quality, production rate and reduce tool tip temperature so that contribute to sustainable metal working.
- To identify the most influential factors for product quality, rate of production, and temperature during CNC dry machining of AISI 1060 steel.
- To evaluate the performance of the predictive regression models developed for these three machining performance characteristics.
- To add a significant understanding regarding the influence of turning parameters during CNC dry turning of AISI 1060 steel on the efficiency and sustainability.

## **1.5. Significance of The Study**

This research is particularly beneficial for metalworking industries as it identifies the optimal process parameters that simultaneously enhance product quality and production rate. As reported in the literature, one of the most significant challenges in metalworking industries is selecting machining parameters that can simultaneously enhance both quality and productivity. Additionally, costs such as fluid costs, fluid maintenance, and pretreatment costs impose additional burdens on the machining industries. Thus, this work is helpful for machining industries. Secondly, this approach aims at avoiding the cutting fluids that hurt both environments and individuals' health. The machinist who works with these cutting fluids may be exposed to respiratory health problems such as hypersensitivity pneumonia, lipoid pneumonia, and occupational asthma, leading to discomfort for workers. Thus, as the dry machining tends to avoid these fluids from the machining process, the workers feel comfortable and perform their work. Finally, the disposal of these cutting fluids may have significant effect on the environment. Thus, the elimination of these fluids will contribute to sustainability by helping to synchronize the green manufacturing idea with manufacturing strategies. Also, as it contributes to adding

significant information to bulk of knowledge, it allows a researchers around the world to get an understanding of dry machining.

### **1.6. Scope of the Research**

The following are the coverages of this research work;

- CNC turning experiments was conducted on AISI 1060 steel under dry conditions using carbide inserts.
- ANOVA is conducted using the response surface methodology (RSM) study type, central composite design (CCD) is used for the experiment design, and desirability function analysis (DFA) techniques are used for a multi-objective optimization assignment.
- Predictive regression models were developed using RSM methods to forecast quality based on the roughness rate of production and temperature, correlating the selected turning parameters with the outcomes.

### **1.7. Research Motivation**

Given that AISI 1060 steel finds application areas in construction, automotive, shipbuilding, machinery parts, and nuclear power plant construction, the need for machining of this type of steel is increasing. During making a product from this type of steel, a machining operation is performed at least at one stage. Well-surfaced machined components perform well during operation in the field and hence satisfy the customers. In order to provide a better-performing product and maximize their productivity, use of a metal cutting fluid is a common practice in metal cutting industries. Despite its advantages in terms of quality product, metal cutting fluids impose negative impacts on the environments and machinist's health. Thus, there is a need for machining conditions in which quality, productivity, and environmental sustainability are simultaneously achieved. The current research is to find optimum machining conditions where these three machining pillars are simultaneously satisfied without one influencing another one. Also, it intends to achieve sustainability in metalworking, minimize the machining cost by avoiding cutting fluids from machining operations, improve the quality without compromising productivity, thus it can be treated as a forward step toward green manufacturing. Thus, the need for high-quality products, enhanced productivity to meet market needs on time, and ensuring sustainability are what motivated a researcher to carry out this research work.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1. Introduction**

In the current era of advanced technology, the need for high-performance, high-quality, green products within a short time and at a low cost is increasing. The manufacturing industries are seeking to provide their products to the markets at possible affordable cost, with high quality and quantity. The high-performance engineering products are currently increasing in application areas such as shipbuilding, aerospace, automotive industries, machinery parts, and etc. Also, the integration of high-precision machining machines, such as computer numerical control (CNC), use of cutting fluids improved the product quality and production rate. The American Iron and Steel Institute (AISI) 1060 is one of the families of medium-carbon steel widely used in automotive industry to make components like shafts, axles, clutch discs, and for the construction of different machinery parts because of its different advantageous mechanical properties (Mia & Dhar, 2019). However the primary aim of machining industries is to maximize their profit using these high-precision machines and selecting processing parameters. Most often the set of machining parameters selected for high production rate spoils the quality of the products. Despite its advantages to improve the production rate and product quality, coolants for metal cutting operations affect the health of the operators; their disposal concern again poses a significant problem to the environment; and pretreatment and fluid system maintenance also add additional cost to machining industries. Thus, this section mainly focuses on presenting the progress of knowledge regarding the dry machining of different steel grades and browsing the different optimization tools that have been employed.

##### **2.1.1. The Surface Quality**

The most frequent request from customers for machined products is always surface quality. One typical metric allows us measure the performance of items is surface roughness. Surface quality is essential for machine parts to work properly (Chen et al., 2018). Lower roughness of surfaces is preferable to increase friction amongst parts that mate, particularly as they rotate and come into touch. It becomes essential for moving the components with an intense friction force as the degradation of the joint surfaces develops and heat is generated when the surface roughness of two mating parts rises. These events lead to parts heating up and wearing down more quickly,

which shortens the equipment's lifetime and causes loss of energy and vibration (Kumar et al., 2018). The irregularity of a treated surface with tiny peaks and valleys spaced at fairly brief intervals is referred to as surface roughness. Surface texture affects a mechanical item's longevity as well as durability and is strongly linked to factors including fit, resilience to wear, fatigue capacity, touch rigidity, motion, and noise (Liu et al., 2017). There are four roughness variables namely average height (Ra), mean square (Rq), ten-point height (Rz), and peak height (Rt) to indicate irregularities of the overall profile, surface height distribution's standard deviation, difference between peaks and valleys of several height, and vertical distance through line being detected, respectively. However, average height (Ra), commonly involved for quality control is used in this research as well. Though there are many different techniques to measure the surface roughness of a product, there are two main categories of measurements: contact and non-contact type measurement techniques (Chen et al., 2018).

In their work to optimize surface roughness in turning of AISI 1060 steel with Al<sub>2</sub>O<sub>3</sub> and TiC-coated (WNMA 080408) inserts using Taguchi methods, Chowdhury et al., 2019 used a Mitutoyo SJ-301P contact-type portable device to measure surface roughness.

### **2.1.2. Productivity In Machining**

One of the very vast manufacturing process in metal shaping sectors is machining, that involve cutting metal to obtain the required geometry and dimensions of the product. Machining processes included turning, milling, drilling, shaping, planing, boring, tapping, and the like. The productivity of a machining industry depends on how much material has been removed from a workpiece per unit time (Kaladhar, 2019). Thus, the metal cut from the work part in a given time is called the material removal rate (MRR). This shows that the productivity of the machining industries depends on the MRR of the operation. Always, machining organizations seek to maximize their profit by enhancing the material removal rate of each operation, which directly relies on the setting of cutting settings such as cut speed, depth of cut, and feed rate. Therefore, the material removal rate is the product of the processing parameters; specifically, for turning operations, it is the multiple of cutting speed, feed rate, and depth of cut. Therefore, several researchers used the following formula to calculate the material removal rate for the turning operations (Du et al., 2020);

$$MRR = VC \times f \times dc \quad (2.1)$$

Where MRR is material removal rate in  $\text{mm}^3/\text{min}$ ,  $V_c$  is cutting speed in  $\text{m}/\text{min}$ ,  $f$  is feed rate in  $\text{mm}/\text{rev}$ , and  $d_c$  is depth of cut in  $\text{mm}$ .

### **2.1.3. Heat Generated in Machining**

Machining operations involve engagement of tool and workpart. Due to this contact between these two moving materials, there is high friction that leads to the generation of a high amount of heat between cutter and part being cut and cutter-chip interface. Three sources of heat originate in the metal cutting industry: the major shear zone, the chip tool interface, and the tool work-piece interaction (Kursus et al., 2022) (Storchak et al., 2021). From these three heat sources in metal cutting operations, the primary shear zone covers a major portion of the generation of heat in the operation. This generated heat or temperature spoils the quality of the product in several ways. As instance, increased temperature at cutting zone develops built up edge (BUE) at cutter-part interface or the phenomena in which the tool materials welded to the workpiece. This situation requires a higher cutting force and deteriorates the surface quality of the finished part. Also, the increased heat at tip of cutter initiates flank wear of the tool, leading to tool dullness that may result in the worst surface roughness and a low MRR even at higher energy consumption. Thus, machining industries were using several techniques to minimize heat generation and to dissipate the generated heat at the cutting zones. The coolants was the primary method employed by industries lower the heat generation at cutter-part contact point (Padmini et al., 2015). Traditional coolants such as vegetable oils poses a negative impact on both environments and human health; thus, researchers have been involved in using nanofluids having higher heat dissipation capacity with minimum quantity lubrication (Kumar et al., 2016). However, the expense of these advanced coolant raised the need for dry machining that ensures both the sustainability and reduces the environmental burden of cutting fluid disposal along with the avoided cost of these fluids. Thus, machining under dry conditions to reduce the effects of these fluids on the environment, reduce health problems, and reduce cost is regarded as the green strategy in metalworking industries. Researchers have used different techniques to model and measure the heat at contact area to investigate the impacts of machining parameters on the temperature. (Belloufi et al., 2018) conducted experiments on AISI 1060 steel to model the cutting temperature using a fuzzy logic system. They indicated that the developed fuzzy model was efficient and economical for predicting the cutting zone temperature while turning the AISI1060 steel. (Storchak et al., 2021) presented several cutting-edge temperature measurement

techniques, such as thermal balance, change of chip color, change of metallographic structure, thermocouple, infrared emission, etc., and suggested that the infrared thermometer is most widely used in industrial applications.

#### **2.1.4. Turning Parameters and Optimizations**

In machining operations, there are a lot of input variables or independent variables that need to be controlled in order to see their effects on outcomes called dependent parameters like surface quality, tool rear, and material removal rate. Most often, performance of part, the productivity of the machining organization, machining costs, tool wear, and other performances are dependent on these parameters. A few of these parameters are cutting speed, feed rate, depth of cut, tool nose, cutting angle, tool geometry, and the like. In many cases, the cutting speed, depth of cut, feed rate, and tool nose were usually investigated as they have significant impacts on the machining performance.

Cutting speed is the rotational speed of either workpiece or tool based on the type of operation being performed. In the case of turning operations, cutting speed is the rotational speed of the tool in revolutions per minute and can be computed based on the basic formula given below:

$$N = \frac{v}{\pi D_o} \quad (2.2)$$

Where N is rotational speed in rev/min, v is cutting speed in m/min, and D<sub>o</sub> is the original diameter of the workpiece to be turned in mm.

Feed rate is the travel rate of the either tool or workpiece depending on the type of operation, and typically in turning operation it is the travel rate of the tool into the rotating workpiece and can be converted in to mm/min by the formula;

$$f = fN \quad (2.3)$$

Where fr is feed rate in mm/min, N is rotational speed in rev/min and f is feed in mm/rev.

Numerous researchers investigated the effects of these parameters, considering them as input parameters to see how they influence the outcomes. (Zerti et al., 2017a) investigated the effects of edge angle, nose radius, cutting speed, feed rate, and depth of cut on surface roughness and forces during turning of AISI D3 steel using the Taguchi optimization method. (Chowdhury, Debnath, Kamruzzaman, Nuruzzaman, & Mia, 2019) employed Taguchi optimization techniques to choose better variable setting in turning AISI 1060 steel, considering parameters such as cutting speed, feed rate, and depth of cut. (Vukelic et al., 2021) implemented genetic algorithm optimization approach to optimize surface quality, MRR and tool wear considering cutting

speed, feed rate, depth of cut, and tool nose as independent parameters. (Panday et al., 2018) used RSM to perform multi-objective optimization of surface roughness, chip thickness ratio, and temperature while cutting speed, depth of cut, and feed rate were regarded as turning parameters.

## **2.2. Review of the Literatures**

This section mainly focuses on presenting systematically the progress of research on different steel grades and to browsing the different optimization tools that have been employed.

The Researcher (Rajput & Datta, 2019) provided a detailed review on sustainability and green manufacturing and indicated that the primary aim of green manufacturing strategies is to spare the resources and minimize the product cost in parallel with decreasing waste and environmental pollution.

The researcher (Lee et al., 2019) conducted a bibliographical survey on the research on sustainability to suggest future research directions based on the growth rate of the research topics. The authors provided that sustainability in any field of research is the future research trend linked with digital transformation.

The researcher (Chetan et al., 2015) conducted a literature review on the sustainable approaches employed in metalworking industries, pointing out the different problems associated with the cutting fluid used in machining and suggesting that sustainable techniques should be biodegradable and eco-friendly, such as the use of mist or minimum quantity lubrication set-up and compressed air.

The researchers (Malek & Desai, 2020) presented a comprehensive literature on sustainability in manufacturing industries and highlighted that sustainability in manufacturing industries pivoted on economic, environmental, and social aspects and marked that as future research that many studies are required to balance these three pivotal in sustainable manufacturing strategies.

A detailed the negative impacts of cutting fluids on the environment and a skin disease associated with these fluids was conducted by researchers (Ishfaq et al., 2021) and pointed out that about 17% of product costs are related to the cutting fluid. The authors suggested that the need for sustainable manufacturing and sustainability depends on three pivots, namely social, economic, and environmental.

A researcher (Liew et al., 2017) browsed that the cooling methods and different cutting fluids used in machining of steels and indicated that despite improving the manufacturing

performances, the conventional cutting fluids add environmental burdens in addition to increasing manufacturing cost, the use of nanofluids is recommended for their higher cooling capacity. However, the authors suggested that the use of these fluids is costly; thus, future researchers should focus on the optimization of machining settings for dry machining for higher performance.

Researchers (Sivaiah & Chakradhar, 2018) performed a comparison study on MQL, dry, wet, and cryogenic cooling techniques for turning 17-4 PH stainless steel and reported that, from health and environment perspectives, cryogenic cooling techniques were the most promising techniques for machining this type of steel.

The researcher (Alemayoh et al., 2023) studied the impacts of turning parameters on the surface roughness material removal rate and temperature while performing dry CNC turning on AISI 1030 carbon steel. Cutting speed was identified as the most important factor among all parameters, and the grey relational analysis method based on Taguchi design optimization revealed that the ideal cutting parameters for improved performance were 90 m/min, 0.25 mm depth of cut, and 0.15 mm/rev feed rate.

The researcher (Kumar Bagal et al., 2019) experimented using AISI 4140 steel under dry conditions using carbide insert and optimized the parameters for surface roughness and tool wear using coupled Taguchi and DFA methods. The optimum surface roughness of 2.518 mm and tool wear of 0.239 mm were reported based on the optimization results.

The researcher (Vukelic et al., 2021) performed a turning experiment under dry conditions on AISI 1040 steel to examine the effects of cutting parameters on surface quality, MRR, and average tool wear and simultaneously optimized these performance characteristics using a genetic algorithm. The GA optimization revealed that 0.1 mm/rev, 307 m/min, 2.04 mm, and 1.6 mm were the optimum combinations of feed rate, cutting speed, depth of cut, and tool radius, respectively.

The researcher (Cabanac et al., 2021) optimized surface roughness and MRR while performing dry turning operations using TiN-coated carbide inserts on AISI 1040 steel, considering feed, depth of cut, speed, and tool radius as input parameters. The RAM optimization based on Box Behnken design suggested that 200 rpm speed, 0.21 mm rev<sup>-1</sup> of feed, 1.5 mm of depth of cut, and 1.2 mm of nose radius were optimum combinations of parameters for better performance.

The researcher (Abbas et al., 2023) employed four different optimization algorithms to optimize cutting force, temperature, surface roughness, and MRR while turning AISI 1045 steel under dry conditions and reported that Weighted Value Gray Wolf Optimizer (WVGWO) performed better than all others, yielding surface roughness of 0.719  $\mu\text{m}$  and MRR of 4460.25  $\text{mm}^3/\text{min}$  at 0.050  $\text{mm}/\text{rev}$ , 156.5  $\text{m}/\text{min}$ , and 0.57  $\text{mm}$  of feed rate, speed, and depth of cut, respectively.

The researcher (Zerti et al., 2017a) used Taguchi optimization methods to optimize the parameters for surface roughness, tangential force, specific force, and power while turning AISI D3 steel under dry conditions. Based on Taguchi optimization roughness of 0.39  $\mu\text{m}$ , cutting force 55.16 N, specific cutting force of 3049.63  $\text{MPa}$ , and 202.25 W cutting power were reported as optimal performances.

The researcher (Kebblouti et al., 2017) performed turning operation under dry conditions on AISI 52100 steel using PVD (TiCN-TiN) coated cermet cutter for evaluation of impacts of the variables and optimize surface roughness and MRR simultaneously by desirability function analysis approach. The optimal values of surface roughness of 0.54  $\mu\text{m}$  and MRR of 11.629  $\text{cm}^3/\text{min}$  were reported as having a desirability value of 0.698.

The researcher (Du et al., 2020) used multiple genetic algorithm optimization methodology to optimize the surface roughness and energy consumption while performing dry turning experiments on 304 stainless steel. The cutting speed of 210  $\text{m}/\text{min}$ , 0.062  $\text{mm}/\text{rev}$ , and depth of 1.750  $\text{mm}$  were reported as combinations of optimal parameters for speed, feed, and depth respectively.

The researcher (Nguyen et al., 2023) performed multi-objective optimization for surface roughness and cutting force when turning AISI 4340 steel using five different machine learning algorithms. Better settings suggested for better performances were 0.02  $\text{mm}/\text{rev}$  of feed rate, between 0.62 and 0.79  $\text{mm}$  of depth of cut, 72.92 and 75.11  $\text{m}/\text{min}$  of cutting speed, and 0.4  $\text{mm}$  of tool nose.

The researcher (Bagaber & Yusoff, 2018) examined the energy usage and surface roughness in dry turning of AISI316 steel and employed the Box-Behnken design (BBD) methods to perform multiobjective optimization. The optimization result revealed that energy usage decreased by 6.78% and surface roughness by 13.89% at the optimized combination of parameters.

The researcher (Bagaber & Yusoff, 2017) did a dry-turning experiment on stainless steel 316 using an uncoated carbide insert and employed response surface methodology to optimize

surface roughness, tool wear, and energy consumption. The optimization resulted in a minimization of energy usage by 14.94%, surface roughness by 4.71%, and tool wear by 13.98%(Sartal et al., 2020) indicated that the increasing concept of sustainability even in the so-called Industry 4.0 sectors.

The researcher (Sharif et al., 2017) carried out the literature review on lubrication strategies in metalworking while mentioning that the cutting fluid does not only imposes a threat to the environment but is also costly as their disposals are restricted and explored that dry, MQL, and cryogenic cooling techniques are sustainable while suggesting future research works are required to optimize these processes to make them functionally applicable.

(Panday et al., 2018) implemented the near-dry lubrication system with soluble oil and coated carbide inserts in the cutting of AISI 1060 steel to examine the effects of parameters on tool chip contact heat, quality of surface, and ratio of chip. The multiobjective optimization using RSM showed that the minimum Ra of 2.189  $\mu\text{m}$ , interface temperature of 563.766  $^{\circ}\text{C}$ , and maximum chip thickness ratio of 0.694 were achieved at optimum combinations of parameters: feed of 0.10 mm/rev, speed of 41 m/min, and 0.5 mm depth of cut (Paul et al., 2018) studied the effects of turning parameters while dry turning of AISI 1060 steel on specific energy and back force. High feed rate and moderate depth of cut in combination with positive rake angle were suggested as optimum for both criteria selected.

The researcher (Rivki et al., n.d.) Used the integrated Taguchi RSM approach to optimize cutting parameters for cutting point temperature and cutting force while performing dry turning on AISI 1060 steel. Based on desirability analysis, they reported that a temperature of 471.85  $^{\circ}\text{C}$  and a cutting force of 394.80 N were obtained at optimum values of parameters at a cutting speed of 93 m/min, a feed of 0.1 mm/rev, and a depth of cut of 1.0 mm.

The researcher (Mia & Dhar, 2019) experimented on AISI 1060 steel considering feed rate, cutting speed, and hardness as input parameters and surface roughness as output response under both dry and high-pressure coolant and applied support vector regression (SVR) and combined RSM and GA to optimize surface roughness. The genetic algorithm-based optimization showed a smaller superiority than RSM; however, in coolant free and coolant supported cutting 161m/min, 0.10mm/rev, and 43HRC speed, feed and hardness respectively were reported as optimum parameters.

From the literature report, it is clear that the future research directions are to toward exploring the combination of dry turning with innovative cutting tools or integrating artificial intelligence with optimization techniques to improve machining performance further.

### 2.3. Summary of Review of the Literatures

Table 2. 1: Summary of the review of the literatures

| S/No | References                 | Type of operation and Equipment used                          | Optimization techniques and focus                          | Major findings                                                                               | Summary of the studies                                            |
|------|----------------------------|---------------------------------------------------------------|------------------------------------------------------------|----------------------------------------------------------------------------------------------|-------------------------------------------------------------------|
| 1.   | (Alemayoh et al., 2023)    | Dry CNC turning on AISI 1030 carbon steel                     | Taguchi methods, Ra, MRR and T                             | Vc of 90 m/min, d c of 0.25 mm, fr 0.15 mm/rev reported as optimum.                          | Studied Ra, MRR and temperature in AISI 1030 steel.               |
| 2.   | (Kumar Bagal et al., 2019) | Dry turning of AISI 4140 steel                                | Coupled Taguchi and DFA methods for Ra and tool wear       | Ra of 2.518 $\mu$ m and tool wear of 0.239 mm were reported as optimum.                      | Investigated on AISI 4140 while focusing on Ra and tool wear only |
| 3.   | (Vukelic et al., 2021)     | Under dry conditions on AISI 1040 steel                       | GA optimization methods for Ra, MRR, and average tool wear | f of 0.1 mm/rev, Vc of 307 m/min, dc of 2.04 mm, and 1.6 mm tool nose were optimum reported. | Studied turning of AISI1040 steel.                                |
| 4.   | (Du et al., 2020)          | Dry turning of 304 stainless steel.                           | MOGA for Ra and energy consumption                         | Vc of 210 m/min, f of 0.062 mm/rev, dc of 1.750 mm were optimum.                             | Studied turning of 304 stainless steel.                           |
| 5.   | (Paul et al., 2018)        | Dry turning of AISI 1060 steel using uncoated carbide inserts | Taguchi methods for specific energy and back force.        | High feed rate and moderate depth of cut were suggested for optimum performance.             | Focused only on specific energy and back force;                   |

|    |                          |                                                                                     |                                                                           |                                                                                                                                                                          |                                                                   |
|----|--------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|
|    |                          |                                                                                     |                                                                           |                                                                                                                                                                          | no study on Ra, MRR, or temperatures.                             |
| 6. | (Panday et al., 2018)    | Near dry turning of AISI 1060 steel with WC, and Co-coated carbide tools.           | RSM optimization for Ra, chip thickness ratio and temperature.            | Achieved Ra of 2.189 $\mu\text{m}$ , temperature of 563.766 $^{\circ}\text{C}$ , and chip ratio of 0.694 at 0.10 mm/rev of $f$ , 41 m/min of $V_c$ , and 0.5 mm of $d_c$ | Missed study in dry and study of MRR and tool wear.               |
| 7. | (Rivki et al., n.d.)     | Dry turning of AISI 1060 steel with tungsten carbide inserts                        | integrated Taguchi RSM approach to optimize cutting force and temperature | Optimum of 471.85 $^{\circ}\text{C}$ and a cutting force of 394.80 were obtained at 93 m/min, a feed of 0.1 mm/rev, and a depth of cut of 1.0 mm.                        | Missing study on Ra, MRR and tool wear.                           |
| 8. | (Mia & Dhar, 2019)       | Performed turning on AISI1060 steel under both dry and HPC                          | Employed SVR and RSM-GA optimization for surface roughness.               | Found that speed of 161 m/min, feed rate of 0.10 mm/rev, and hardness of 43 HRC were optimum conditions for both dry and high pressure coolant conditions.               | Ignored effects of parameters on MRR, tool wear, and temperatures |
| 9. | (Chowdhury et al., 2019) | Dry turning of AISI1060 steel using $\text{Al}_2\text{O}_3$ and TiC-coated inserts. | Employed Taguchi optimization to optimize surface roughness               | Achieved minimum Ra at 143.26 m/min of $V_c$ , 0.50mm of $d_c$ , and 0.10 mm/rev of feed rate                                                                            | No study on MRR, tool wear, and temperature.                      |

## **2.4. Research Gap**

In the manufacturing field of study Research on metalworking, specifically the machining of steel, is becoming an increasing and hot topic as advances in research on metalworking help machining industries maximize their profit and delivery quality and reliable products to the market.

The influence of machining parameters on various performance indicators including surface roughness, MRR, tool-workpiece interface temperature, tool wear, cutting force, power consumption, and chip thickness ratio, have been the subject of numerous studies. These studies have optimized these parameters for improved performance. However, there are few studies on the dry turning of the steels, specifically on the dry turning of AISI 1060 steel and advanced optimization of turning parameters. Moreover, Previous studies primarily focused on single-response optimization, but there is a need for multi-objective optimization that includes not only surface roughness but also MRR and tool-work interface temperature. For instance, the optimizations performed were mainly focused on a single response while ignoring the effects of parameters on other responses. The researcher (Mia & Dhar, 2019) optimized only surface roughness; (Rivki et al., 2018) focused only on cutting force and temperature; and (Paul et al., 2018) optimized specific energy and back force. Also, apart from optimization carried out for individual responses separately, many studies used traditional optimization techniques such as Taguchi methods that may affect the optimization quality. Further, most of the studies have been focused on the turning cutting fluids assisted, which adds additional costs to the machining industries and environmental and safety burdens. In order to transform the machining industries into green manufacturing strategies, the use of coolant must be restricted in the machining shops; thus, much more work is required to search the machining settings where quality of product, productivity, and environmental safety are simultaneously ensured. Therefore, the current research address the effects of machining parameters while DRY turning of AISI 1060 steel and perform multiobjective optimization of quality of surface, MRR, and tool-work interface temperature using a desirability function analysis approach to contribute to sustainability in metalworking industries. Thus as the previous studies largely ignore the environmental impact of using cutting fluids, this research focus on dry turning to contribute to green manufacturing.

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1. Materials

##### 3.1.1. American Iron and Steel Institute (AISI) 1060 steel

The steel designation protocols given by the American Iron and Steel Institute describe the steel with four-digit numbers as 10XX. The first two digits represent the type of steel, i.e., in this case, 10 shows the material categorized under plain carbon steel, and the second two digits refer to the percentage of carbon. AISI 1060 is indeed a high-carbon steel (with 0.60% carbon), but high-carbon steel typically contain carbon between 0.60% to 1.00% and can be utilized for even higher strength applications where rigidity and hardness are required as well as wear-resistant parts, like cutting tools, blades, and springs.

Due to its advantageous mechanical qualities and adaptability in a variety of applications, medium carbon steel, more especially AISI 1060, is utilized extensively in the construction, automotive, and machinery industries to create items like clutch discs, shafts, axles, water mains, wear rail, and machinery (Mia & Dhar, 2019). For making these parts from this type of steel, machining is required at least at one stage in manufacturing industries. However, as the carbon composition in steel raises, obviously the strength of the steel increases, and it is very difficult to machine this kind of steel. Thus, machining generates high heat, needs a higher cutting force, and hence increases machining costs. In order to lessen the heat produced at contact areas, which can also cause damage to the cutting tool, machining businesses frequently utilize cutting fluids while machining this type of steel.

However, the philosophy of green manufacturing strategies being implemented by industries avoided the use of these coolants because of its negative impacts on both the environment and machinist's health. In light of this framework, researchers across the world turned their attention to finding novel machining approaches in which sustainability is ensured without spoiling the quality attribute and productivity of the machining industry. One of the approaches is to find the machining setting during conducting operations under dry conditions by implementing optimization techniques.

Thus, this work uses AISI 1060 to conduct turning experiments under dry conditions in CNC lathe machines. The round AISI 1060 steel with 40mm diameter and 1000mm length, the

material make up of which is illustrated in Table 3.1 from the spectroscopy test and compared with the reference was obtained and used for the experimental purpose. The figure 3.4 shows the photograph of the Spectro and spectro test conducted for the chemical composition analysis of the sample selected for the experimentation.

Table 3. 1: The chemical composition of the AISI 1060 steel using the Spectro test

| Material  | Cr   | Ni    | Mn   | C    | Mo        | Si       | Cu  | S    | P     | Ni       | Fe   | W    |
|-----------|------|-------|------|------|-----------|----------|-----|------|-------|----------|------|------|
| AISI 1060 | 0.12 | 0.051 | 0.65 | 0.61 | Max 0.003 | Max 0.15 | 0.1 | 0.14 | 0.058 | Max 0.40 | 98.1 | 0.04 |



Figure 3. 1: The round AISI 1060 steel bar prepared before cut into specimen for each experimental run.



Figure 3. 2: The round AISI 1060 steel sample



Figure 3. 3: The experimental samples after machined



Figure 3. 4: The Spectro test conducted for the Sample

### 3.1.2. Carbide Insert Cutting Tools

Inserts are frequently employed as they reasonably priced and suitable enough to be used in a variety of cutting tasks, including as turning, boring, threading, milling, and even drilling.

Commonly, there are three basic tool failure modes in machining operations: fracture failure, due to the application of excessive cutting force at the tool tip, the tool may fracture because of the brittleness characteristics of the tool; failure brought on by a temperature increase at the tool tip that weakens the tool and causes plastic deformation and sharpness loss; and gradual wear brought on by the tool's deterioration over time. The first two tool failure modes are undesirable, as they are called premature tool failure. Gradual tool wear is the expected tool wear in machining and can occur at two main locations: the rake flank.

As the rake face and chip engaged the typical form of wear termed as crater occur, while flank wear happened on flank portion of tool. Several phenomena, such as abrasion, plastic deformation, chemical reactions, and diffusion, cause gradual wear of the cutting tool.

In order to establish the basic properties required from tool material, such as hot hardness, toughness, and resistance to wear, cutting tool materials are made differently and categorized into five as; Cast cobalt alloys, Ceramics, High-speed steel and low alloy steels, Synthetic diamond and cubic boron nitride, and Cemented carbides, cermet, and coated carbides.

Cemented carbides are hard cutting tool materials made of tungsten carbide (WC) using powder metallurgy methods and cobalt (Co) as binder added. Tungsten carbide (WC) alone is vulnerable

to rapid wear when machining steel due to its tendency to form carbides with elements in the steel, such as iron. The addition of titanium carbide (TiC) and tantalum carbide (TaC) improves the wear resistance by providing more stable carbide formations.

Moreover, the incorporation of titanium carbide (TiC) and tantalum carbide (TaC) reduced the facilitated wear of the tool while machining. Therefore the cemented carbide consisting of WC-TiC-TaC-Co can be able to machine steel at a cutting speed of 100 m/min–300 m/min.

Therefore, for cutting the workpiece selected in this research, i.e., AISI 1060 steel, a cemented carbide insert purchased from the market and used. Despite the fact that many shapes of this type of insert are there, rhombus shapes shown in th Figure 3.5 are easily available, and used for this work.

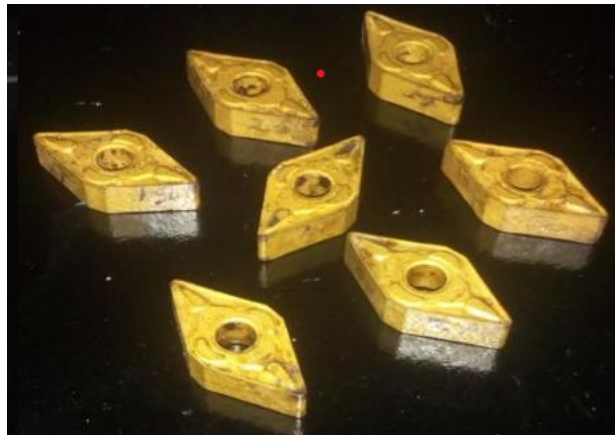


Figure 3. 5: The rhombus shaped cutting inserts used for turning experiments

### 3.1.3. Computer Numerical Control (CNC) Lathe Machine

Modern manufacturing industries aim to upgrade their productivity, improve the quality of their product, reduce the machine downtime during tool changing, minimize human intervention in machining operations, reduce the cost of the product, and hence satisfy their customers. The emergence of numerical control machines such as CNC lathe machines , milling machines, and drilling machines made their objectives successful. Today, machining industries have introduced these machines into their operations, reduced the human intervention in operations, and saved their cost while improving the quality of the manufactured products.

Numerical control (NC) is a kind of automated control in which a program with encoded numbers controls an apparatus's mechanical functions. For the current work, the turning of the samples was carried out on CNC lathe machines shown in Figure 3.6

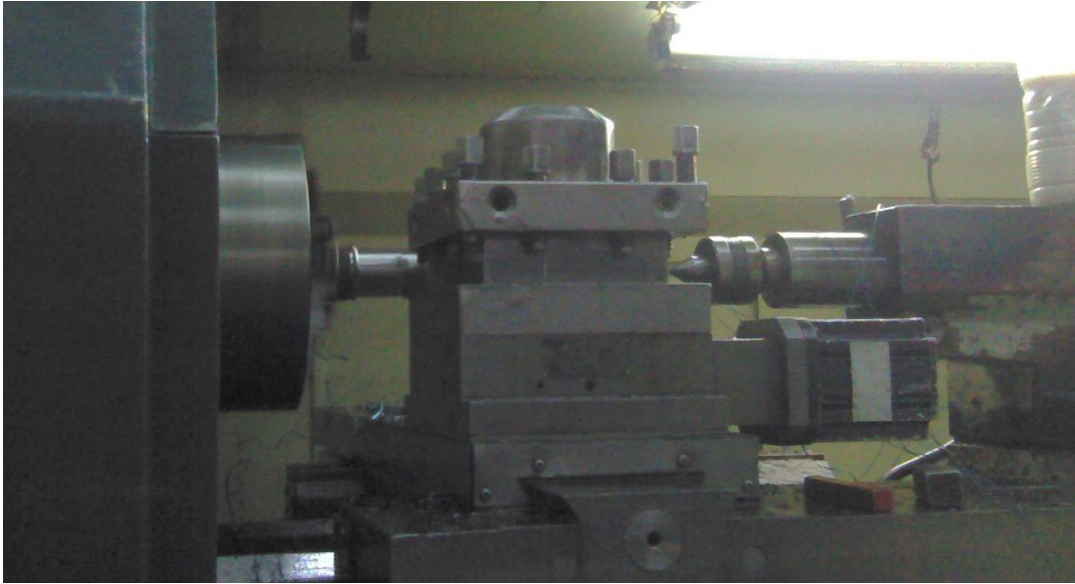


Figure 3. 6: The CNC lathe machine used for turning Experiments

#### 3.1.4. Surface Roughness Measuring Device

Most widely, surface roughness which termed as the difference in height of surface variation relative to the reference line. Surface roughness is recorded following a profile line or multiple parallel lines of the sample. Based on ANSI, Ra is the arithmetic average as a height indicator of surface roughness (Stepien, 2015).

When the fine-scale and atomic structure of a surface is required to be investigated, engineers and physicists in the real world employ many methods for measuring surface roughness. Based on how they operate, many techniques of assessing roughness are categorized. These categories include fluid methods, mechanical stylus methods, optical methods, microscopy methods, and scanning probe microscopy (SPM) methods.

In the current study, a mechanical stylus instrument that records and amplifies the vertical movement of the stylus pushed by the sample surface is selected to evaluate surface roughness. The photography and the surface roughness testing procedure is shown in the figure 3.7. As the stylus moves across the surface of the object that is being measured, the transducer measures the surface variation with the starting point or the surface average value. After that, the electrical signal that was created and captured the stylus's downward motion is controlled, increased, converted to digital form, and shown (Farkas & Drégelyi-Kiss, 2018). The result is shown by the instrument using organic light-emitting diode (OLED) display screen technology.



Figure 3. 7: The surface roughness testing procedure

### 3.1.5. Cutting Zone Temperature Measuring Device

The most known temperature measuring techniques in metal industries are thermocouples, Thermal cameras, infrared thermography, infrared thermometers, and tool-chip thermocouples. Thermocouples are Direct measurements of temperatures close to the cutting zone are made possible by thermocouples that are incorporated within the cutting tool or substrate (Astakhov & Outeiro, 2019).

Thermal camera measures the tool and workpiece's distribution of temperatures is recorded by non-invasive infrared imaging devices.

The working of the devices involves focusing the ejected rays from the samples and guiding these rays to a detector usually termed a thermopile. These rays the translated to heat in the device, which is consequened with heat modification to electricity, which can be detected (Pereira Guimarães et al., 2022).

In this research, cutting zone temperature was measured using Thermal camera shown in the Figure 3.8. The Thermal camera made in ESTONIA, Model E30bx B1.1 with serial number of 4902s282 and part number 49001-1901 was employed in this work. The device parameters are illustrated in the Table 3.2.



Figure 3. 8: The thermal Camera used for measurement of temperature at cutting zone.

Table 3. 2: The Thermal Camera parameters

|                         |              |
|-------------------------|--------------|
| Emissivity              | Steel (0.07) |
| Object Distance         | 1mt          |
| Relative Humidity       | 2percent     |
| Atmospheric Temperature | 20 °c        |
| Reselected Temperature  | 20 °c        |

The temperature measurement was conducted with three rounds for each experimental run. The first measurement round was conducted at the beginning of the experimentation while the cutting tool engaged with the specimen being machined as the contact zone becomes hot as indicated in Figure 3.9a. The second round measurement took place in the middle of the turning operation when the cutting zone temperature was expected to be high as indicated in Figure 3.9b. The final measurements were carried out when cutter and machined component disengaged upon the completion of the operation shown in Figure 3.9c. For these three round measurements, three cutting zone temperature records were taken and the averaged values were used for analysis.

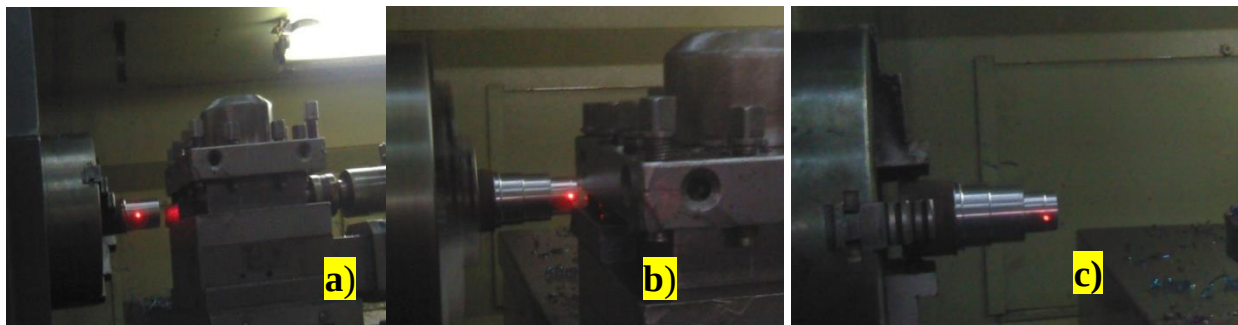


Figure 3. 9: The cutting zone temperature measuremets were taken at three rounds.

The temperature measuring thermal camera displays the temperature at the spot point indicated with the red spot point and indicates the temeperature at the point. Accordingly, the temperatyure was measured at three distiniect point and the averaged values were used for analysis. The Figure 3.10 shows the temperature result displayed using a thermal camera for a single experimental run at the three positions and the same goes for all experiments. Figure 3.10a, the temperature of the sample during the bigginning of the experiment, Figure 3.10b shows the measurement at the middle of the experiment, and Figure 3.10c indicates the temperature at the instant of the operation is completed.

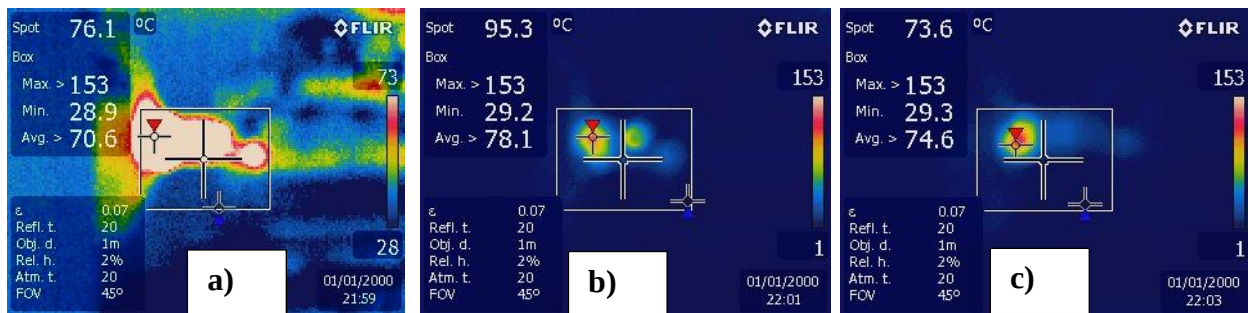


Figure 3. 10: The Cutting zone temperature Measuremet using a thermal Camera.

### 3.2. Research Design

Researchers develop an overall tactic to carry out research. It involves several methodologies and techniques aimed at collecting data, analyzing the data, visualizing the interaction between independent and dependent variables in research, testing formulated hypotheses, and answering the research questions. A good research design helps a researcher perform tasks in the research effectively and within a planned time frame. Thus, the general research framework and procedures to be followed in this research are illustrated as a flow chart in Figure 3.11.

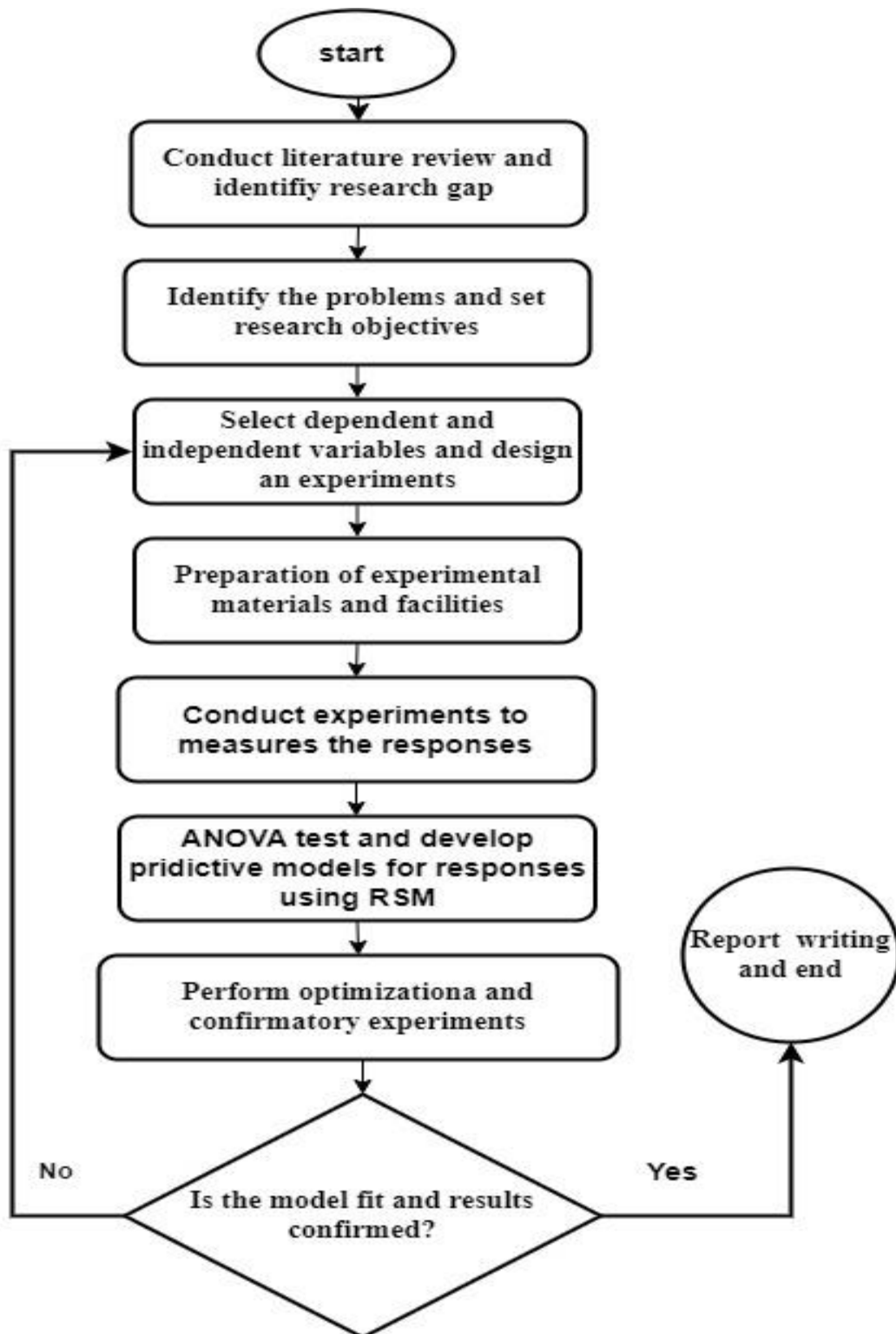


Figure 3. 11; General research methodology flow chart

### 3.2.1. Experimental Design

The investigation were planned with the help of Design Expert software version 13.0.5.0. A CCD is a popular experimental design used in response surface methodology. These consists, factorial, center, and star points. A CCD is a commonly used design type under the randomized response surface methodology study type. Therefore, in this research, randomized, full factorial, central, and face-centered experiments are designed based on composite design (CCD) from design experiments. All three factors consist of three factorial levels. A CCD is regularly employed methods in design of experiments. Factorial designs with center points and star points are called central composite designs. Surface roughness, MRR, and cutting temperature are the dependent input variables, whereas feed, depth, and speed in cutting are the independent input factors. The American Society for Metals (ASM) handbook and the best values documented in the literature are the bases for choosing the ranges of these independent cutting parameters (Chowdhury et al., 2019 (Mia & Dhar, 2019)). Table 3.3 illustrates that for all three variables, the highest factorial level is +1 and the lowest factorial level is -1. The software calculated the values of intermediate levels of 0 by interpolation methods.

Table 3. 3: The factorial levels of turning parameters

| Parameters    | Symbol         | Units  | Levels |     |      |
|---------------|----------------|--------|--------|-----|------|
|               |                |        | +1     | 0   | -1   |
| Cutting speed | V <sub>c</sub> | m/min  | 90     | 120 | 150  |
| Depth of cut  | D <sub>c</sub> | Mm     | 0.5    | 1   | 1.5  |
| Feed rate     | F              | mm/rev | 0.05   | 0.1 | 0.15 |

Thus, total of 30 experimental runs are to be performed as planned experimental matrix shown in Table 3.4 below. Twenty (28) non-center points and two (2) center points with one replicates of axial points and factorial points are selected for this experimental design.

Table 3. 4: Experimental design matrix

| Run | A:Cutting speed<br>(m/min) | B:Feed rate<br>(mm/rev) | C:Depth of<br>cut (mm) | Surface<br>roughness<br>Ra ( $\mu\text{m}$ ) | Cutting<br>temperature<br>T( $^{\circ}\text{C}$ ) |
|-----|----------------------------|-------------------------|------------------------|----------------------------------------------|---------------------------------------------------|
| 1   | 120                        | 0.1                     | 1                      |                                              |                                                   |
| 2   | 90                         | 0.05                    | 1.5                    |                                              |                                                   |
| 3   | 90                         | 0.15                    | 1.5                    |                                              |                                                   |
| 4   | 90                         | 0.05                    | 0.5                    |                                              |                                                   |
| 5   | 120                        | 0.15                    | 1                      |                                              |                                                   |
| 6   | 120                        | 0.1                     | 0.5                    |                                              |                                                   |
| 7   | 120                        | 0.15                    | 1                      |                                              |                                                   |
| 8   | 150                        | 0.1                     | 1                      |                                              |                                                   |
| 9   | 90                         | 0.05                    | 1.5                    |                                              |                                                   |
| 10  | 150                        | 0.05                    | 1.5                    |                                              |                                                   |
| 11  | 150                        | 0.05                    | 0.5                    |                                              |                                                   |
| 12  | 150                        | 0.05                    | 1.5                    |                                              |                                                   |
| 13  | 90                         | 0.15                    | 0.5                    |                                              |                                                   |
| 14  | 150                        | 0.15                    | 1.5                    |                                              |                                                   |
| 15  | 120                        | 0.1                     | 1                      |                                              |                                                   |
| 16  | 120                        | 0.1                     | 1.5                    |                                              |                                                   |
| 17  | 150                        | 0.1                     | 1                      |                                              |                                                   |
| 18  | 90                         | 0.15                    | 1.5                    |                                              |                                                   |
| 19  | 90                         | 0.15                    | 0.5                    |                                              |                                                   |
| 20  | 120                        | 0.1                     | 0.5                    |                                              |                                                   |
| 21  | 120                        | 0.1                     | 1.5                    |                                              |                                                   |
| 22  | 150                        | 0.15                    | 0.5                    |                                              |                                                   |
| 23  | 90                         | 0.1                     | 1                      |                                              |                                                   |
| 24  | 120                        | 0.05                    | 1                      |                                              |                                                   |
| 25  | 150                        | 0.05                    | 0.5                    |                                              |                                                   |
| 26  | 90                         | 0.1                     | 1                      |                                              |                                                   |
| 27  | 150                        | 0.15                    | 1.5                    |                                              |                                                   |
| 28  | 120                        | 0.05                    | 1                      |                                              |                                                   |
| 29  | 90                         | 0.05                    | 0.5                    |                                              |                                                   |
| 30  | 150                        | 0.15                    | 0.5                    |                                              |                                                   |

## CHAPTER FOUR

### RESULT ANALYSIS AND DISCUSSION

#### 4.1. Introduction

This work uses hard steel AISI 1060 steel as a workpiece for turning using a CNC lathe machine. The turning experiments were designed using CCD using Design Expert software version 13.0.5.0. The total of 30 randomized, full factorial, central, and face-centered experiments are designed based on a CCD from design experiments. To investigate the impact of cutting parameters like depth of cut, feed rate, and speed on machining performance metrics like surface roughness and heat at contact, the experiments performed without the use of any cutting fluids. For the experiment, a round bar of AISI 1060 steel measuring 40 mm in diameter and 600 mm in length was acquired from the Addis Machine and Spare Parts Manufacturing Industry in Ethiopia. The surface roughness was tested using a mechanical stylus instrument that records and amplifies the vertical movement of the stylus pushed by the sample surface is selected to measure the surface roughness. The Thermal camera made in ESTONIA, Model E30bx B1.1 with serial number of 4902s282 and part number 49001-1901 was employed in this work for cutting zone temperature measurement. For every experimental run, the contact point and quality of surface were measured three times, and the averaged results were analyzed. The table 4.1 shows the results of the surface roughness and cutting zone temperature after averaging.

Table 4. 1: The values of the surface roughness and cutting zone temperature

| Run | A:Cutting speed<br>(m/min) | B:Feed rate<br>(mm/rev) | C:Depth of<br>cut (mm) | Surface<br>roughness<br>Ra ( $\mu\text{m}$ ) | Cutting<br>temperature<br>T( $^{\circ}\text{C}$ ) |
|-----|----------------------------|-------------------------|------------------------|----------------------------------------------|---------------------------------------------------|
| 1   | 120                        | 0.1                     | 1                      | 3.04                                         | 68.1                                              |
| 2   | 90                         | 0.05                    | 1.5                    | 3.54                                         | 69.2                                              |
| 3   | 90                         | 0.15                    | 1.5                    | 3.17                                         | 76.3                                              |
| 4   | 90                         | 0.05                    | 0.5                    | 3.61                                         | 65.2                                              |
| 5   | 120                        | 0.15                    | 1                      | 3.3                                          | 65.41                                             |
| 6   | 120                        | 0.1                     | 0.5                    | 3.87                                         | 66.2                                              |
| 7   | 120                        | 0.15                    | 1                      | 3.2                                          | 67.9                                              |

|    |     |      |     |      |         |
|----|-----|------|-----|------|---------|
| 8  | 150 | 0.1  | 1   | 4.7  | 66      |
| 9  | 90  | 0.05 | 1.5 | 3.47 | 69.4    |
| 10 | 150 | 0.05 | 1.5 | 3.98 | 67.5    |
| 11 | 150 | 0.05 | 0.5 | 3.7  | 62.98   |
| 12 | 150 | 0.05 | 1.5 | 4.1  | 68.01   |
| 13 | 90  | 0.15 | 0.5 | 3.19 | 70.95   |
| 14 | 150 | 0.15 | 1.5 | 6.97 | 64.1    |
| 15 | 120 | 0.1  | 1   | 3.02 | 68.9    |
| 16 | 120 | 0.1  | 1.5 | 3.97 | 67.8667 |
| 17 | 150 | 0.1  | 1   | 4.75 | 67.1    |
| 18 | 90  | 0.15 | 1.5 | 3.14 | 77      |
| 19 | 90  | 0.15 | 0.5 | 3.21 | 76.4    |
| 20 | 120 | 0.1  | 0.5 | 3.82 | 68.4667 |
| 21 | 120 | 0.1  | 1.5 | 3.96 | 75      |
| 22 | 150 | 0.15 | 0.5 | 6.48 | 56.9    |
| 23 | 90  | 0.1  | 1   | 2.86 | 75.8667 |
| 24 | 120 | 0.05 | 1   | 2.05 | 66.5667 |
| 25 | 150 | 0.05 | 0.5 | 3.66 | 57.5    |
| 26 | 90  | 0.1  | 1   | 2.88 | 75.5    |
| 27 | 150 | 0.15 | 1.5 | 6.94 | 64.9    |
| 28 | 120 | 0.05 | 1   | 2.05 | 61.79   |
| 29 | 90  | 0.05 | 0.5 | 3.67 | 69.4    |
| 30 | 150 | 0.15 | 0.5 | 6.48 | 54      |

The Figure 4.1 shows the data tabulated in the Table 4.1 uploaded to the Design Expert software for investigation of individual parameters on the surface roughness and temperature.

| File Edit View Display Options Design Tools Help |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
|--------------------------------------------------|-----|----------------------------------------|-------------------------------------|------------------------------------|------------------------------------------------------|-----------------------------------------------------------|--|--|
| Navigation Pane                                  |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Information                                      |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Notes                                            |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Summary                                          |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Graph Columns                                    |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Evaluation                                       |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Constraints                                      |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Analysis [ + ]                                   |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Surface roughness                                |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Cutting temperatur                               |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Material                                         |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Design Properties                                |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Run 2                                            |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Comment                                          |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Row Statu Normal                                 |     |                                        |                                     |                                    |                                                      |                                                           |  |  |
| Std                                              | Run | Factor 1<br>A:Cutting speed<br>(m/min) | Factor 2<br>B:Feed rate<br>(mm/rev) | Factor 3<br>C:Depth of cut<br>(mm) | Response 1<br>Surface roughn...<br>( $\mu\text{m}$ ) | Response 2<br>Cutting temper...<br>( $^{\circ}\text{C}$ ) |  |  |
| 2                                                | 2   | 90                                     | 0.05                                | 1.5                                | 3.54                                                 | 69.2                                                      |  |  |
| 29                                               | 3   | 90                                     | 0.15                                | 1.5                                | 3.17                                                 | 76.3                                                      |  |  |
| 23                                               | 4   | 90                                     | 0.05                                | 0.5                                | 3.61                                                 | 65.2                                                      |  |  |
| 18                                               | 5   | 120                                    | 0.15                                | 1                                  | 3.3                                                  | 65.41                                                     |  |  |
| 25                                               | 6   | 120                                    | 0.1                                 | 0.5                                | 3.87                                                 | 66.2                                                      |  |  |
| 24                                               | 7   | 120                                    | 0.15                                | 1                                  | 3.2                                                  | 67.9                                                      |  |  |
| 22                                               | 8   | 150                                    | 0.1                                 | 1                                  | 4.7                                                  | 66                                                        |  |  |
| 28                                               | 9   | 90                                     | 0.05                                | 1.5                                | 3.47                                                 | 69.4                                                      |  |  |
| 4                                                | 10  | 150                                    | 0.05                                | 1.5                                | 3.98                                                 | 67.5                                                      |  |  |
| 8                                                | 11  | 150                                    | 0.05                                | 0.5                                | 3.7                                                  | 62.98                                                     |  |  |
| 17                                               | 12  | 150                                    | 0.05                                | 1.5                                | 4.1                                                  | 68.01                                                     |  |  |
| 14                                               | 13  | 90                                     | 0.15                                | 0.5                                | 3.19                                                 | 70.95                                                     |  |  |
| 3                                                | 14  | 150                                    | 0.15                                | 1.5                                | 6.97                                                 | 64.1                                                      |  |  |
| 30                                               | 15  | 120                                    | 0.1                                 | 1                                  | 3.02                                                 | 68.9                                                      |  |  |
| 12                                               | 16  | 120                                    | 0.1                                 | 1.5                                | 3.97                                                 | 67.8667                                                   |  |  |
| 9                                                | 17  | 150                                    | 0.1                                 | 1                                  | 4.75                                                 | 67.1                                                      |  |  |
| 26                                               | 18  | 90                                     | 0.15                                | 1.5                                | 3.14                                                 | 77                                                        |  |  |
| 20                                               | 19  | 90                                     | 0.15                                | 0.5                                | 3.21                                                 | 76.4                                                      |  |  |
| 5                                                | 20  | 120                                    | 0.1                                 | 0.5                                | 3.82                                                 | 68.4667                                                   |  |  |
| 27                                               | 21  | 120                                    | 0.1                                 | 1.5                                | 3.96                                                 | 75                                                        |  |  |
| 1                                                | 22  | 150                                    | 0.15                                | 0.5                                | 6.48                                                 | 56.9                                                      |  |  |
| 11                                               | 23  | 90                                     | 0.1                                 | 1                                  | 2.86                                                 | 75.8667                                                   |  |  |
| 21                                               | 24  | 120                                    | 0.05                                | 1                                  | 2.05                                                 | 66.5667                                                   |  |  |
| 13                                               | 25  | 150                                    | 0.05                                | 0.5                                | 3.66                                                 | 57.5                                                      |  |  |
| 7                                                | 26  | 90                                     | 0.1                                 | 1                                  | 2.88                                                 | 75.5                                                      |  |  |
| 15                                               | 27  | 150                                    | 0.15                                | 1.5                                | 6.94                                                 | 64.9                                                      |  |  |
| 10                                               | 28  | 120                                    | 0.05                                | 1                                  | 2.05                                                 | 61.79                                                     |  |  |
| 16                                               | 29  | 90                                     | 0.05                                | 0.5                                | 3.67                                                 | 69.4                                                      |  |  |
| 19                                               | 30  | 150                                    | 0.15                                | 0.5                                | 6.48                                                 | 54                                                        |  |  |

Figure 4. 1: The data uploaded for analysis to design expert software.

#### 4.2. Analysis of Surface Roughness

Once the data was uploaded to the design expert software, the analysis was carried out separately for each response to be examined. Accordingly, the Fit summary including the lack of fit p-value, sequential p-values, adjusted and predicted R-square, ANOVA table and 3D surface graphs were generated to investigate the effectiveness of the model to predict the surface roughness and the significance level of the individual factors for the respective response.

#### 4.2.1. ANOVA for Surface Roughness

The fit summary for the quadratic model used for the surface roughness is shown in Table 4.2. Based on the provided data, the quadratic model is successful in predicting the surface roughness, as evidenced by the sequential P-value of less than 0.0001. The Lack of Fit F-value of 0.81 indicates that, in comparison to the pure error, the Lack of Fit is not significant. There is a 55.78% chance that a lack of fit F-value this large could occur due to noise. The adjusted and predicted model R-squares for the selected quadratic model are 0.9992 and 0.9987, respectively, indicating the maximum adjusted and predicted R-squares with a difference of less than 0.2.

Table 4. 2: Fit summary for surface roughness

| Source           | Sequential p-value | Lack of Fit p-value | Adjusted R <sup>2</sup> | Predicted R <sup>2</sup> |                  |
|------------------|--------------------|---------------------|-------------------------|--------------------------|------------------|
| Linear           | 0.0001             | < 0.0001            | 0.4900                  | 0.3685                   |                  |
| 2FI              | 0.0010             | < 0.0001            | 0.7121                  | 0.6446                   |                  |
| <b>Quadratic</b> | <b>&lt; 0.0001</b> | <b>0.5578</b>       | <b>0.9992</b>           | <b>0.9987</b>            | <b>Suggested</b> |
| Cubic            | 0.4572             | 0.5426              | 0.9992                  | 0.9982                   | <b>Aliased</b>   |
|                  |                    |                     |                         |                          |                  |

The surface roughness ANOVA table, which displays the input factors' significant levels, is displayed in Table 4.3. The significance of the model is indicated by its F-value of 3885.11. There is only 0.01% possibility of F-value to this level to happen. The P-value higher than 0.05 signifies that, the factors are not influencing the entire model. Accordingly, A, B, C, AB, AC, BC, A<sup>2</sup>, B<sup>2</sup>, and C<sup>2</sup> are influencing the responses.

Table 4. 3: ANOVA table for the surface roughness

| Source          | Sum of Squares | df | Mean Square | F-value  | p-value  |             |
|-----------------|----------------|----|-------------|----------|----------|-------------|
| <b>Model</b>    | 47.35          | 9  | 5.26        | 3885.11  | < 0.0001 | significant |
| A-Cutting speed | 18.09          | 1  | 18.09       | 13358.33 | < 0.0001 |             |
| B-Feed rate     | 7.50           | 1  | 7.50        | 5541.20  | < 0.0001 |             |
| C-Depth of cut  | 0.1201         | 1  | 0.1201      | 88.71    | < 0.0001 |             |
| AB              | 10.58          | 1  | 10.58       | 7812.61  | < 0.0001 |             |

|                  |        |    |        |         |          |                 |
|------------------|--------|----|--------|---------|----------|-----------------|
| AC               | 0.2576 | 1  | 0.2576 | 190.21  | < 0.0001 |                 |
| BC               | 0.0105 | 1  | 0.0105 | 7.76    | 0.0114   |                 |
| A <sup>2</sup>   | 3.17   | 1  | 3.17   | 2340.48 | < 0.0001 |                 |
| B <sup>2</sup>   | 0.6758 | 1  | 0.6758 | 499.09  | < 0.0001 |                 |
| C <sup>2</sup>   | 4.10   | 1  | 4.10   | 3025.40 | < 0.0001 |                 |
| <b>Residual</b>  | 0.0271 | 20 | 0.0014 |         |          |                 |
| Lack of Fit      | 0.0058 | 5  | 0.0012 | 0.8143  | 0.5578   | not significant |
| Pure Error       | 0.0213 | 15 | 0.0014 |         |          |                 |
| <b>Cor Total</b> | 47.37  | 29 |        |         |          |                 |

The percentage contributions of factors for a specific outcome can be computed using the following formula:

$$\text{Percentage contribution} = \frac{\text{Sum of squares for single factors}}{\text{Total sum of squares of all factors}} \times 100\%$$

The significance level of the parameters was evaluated using the percentage contribution value of the parameters.

The ANOVA suggested cutting speed as major influencing factor for quality of surface with the highest value of 40.6. Combined impact of speed and rate of feed came in second and third, with number of effects of 23.77 and 16.85, respectively.

Table 4.4 indicates the coefficients in terms of coded factor and variance inflation factor. The variance inflation factor (VIF) is the ratio that indicates the collinearity of the factors among each other, which may have a negative effect on the model.

Table 4. 4: The Coefficient Estimate and the variance inflation factors of the factors

| <b>Factor</b>   | <b>Coefficient Estimate</b> | <b>df</b> | <b>Standard Error</b> | <b>95% CI Low</b> | <b>95% CI High</b> | <b>VIF</b> |
|-----------------|-----------------------------|-----------|-----------------------|-------------------|--------------------|------------|
| Intercept       | 3.02                        | 1         | 0.0140                | 2.99              | 3.05               |            |
| A-Cutting speed | 0.9510                      | 1         | 0.0082                | 0.9338            | 0.9682             | 1          |
| B-Feed rate     | 0.6125                      | 1         | 0.0082                | 0.5953            | 0.6297             | 1          |
| C-Depth of cut  | 0.0775                      | 1         | 0.0082                | 0.0603            | 0.0947             | 1          |
| AB              | 0.8131                      | 1         | 0.0092                | 0.7939            | 0.8323             | 1          |

|                |         |   |        |         |         |     |
|----------------|---------|---|--------|---------|---------|-----|
| AC             | 0.1269  | 1 | 0.0092 | 0.1077  | 0.1461  | 1   |
| BC             | 0.0256  | 1 | 0.0092 | 0.0064  | 0.0448  | 1   |
| A <sup>2</sup> | 0.7850  | 1 | 0.0162 | 0.7512  | 0.8188  | 1.3 |
| B <sup>2</sup> | -0.3625 | 1 | 0.0162 | -0.3963 | -0.3287 | 1.3 |
| C <sup>2</sup> | 0.8925  | 1 | 0.0162 | 0.8587  | 0.9263  | 1.3 |

While for the rest variables unchanged, the coefficient of variation determination indicate the anticipated shift in response level. Following the variables, the coefficient are renewed along the mean. The VIFs are 1 when the variables are not correlated crossover is illustrated with VIFs larger than 1. The severity of the factor connection increases with the VIF. The individual factors coded as A, B, and C and the interaction of the factors: AB, AC, and BC are orthogonal factors, demonstrating that there is no correlation between these factors that may influence the model. Mostly, VIF below 10 are acceptable. In this case the VIF for non-orthogonal factors is 1.3, which indicates that the multicollinearity between the factors doesn't have a significant impact on the model.

The coded equation and actual factor equation are given in equation 1 and 2 respectively.

$$\text{Surface roughness} = +3.02 + 0.951A + 0.6125B + 0.0775C + 0.8131AB + 0.1269AC + 0.0256BC + 0.7850A^2 - 0.3625B^2 + 0.8925C^2 \quad (4.1)$$

At specific value of variables, estimates on the response possibly conducted with the help of regression equation with coding shown above. By default, the factors' high and low levels are denoted by the codes +1 and -1, respectively. By comparing the variables coefficient, the regression equation with coding allows to evaluate the individual effect of parameters. Surface roughness = +20.13450 - 0.240300 Cutting speed - 24.82500 Feed rate - 8.10250 Depth of cut + 0.542083 Cutting speed \* Feed rate + 0.008458 Cutting speed \* Depth of cut + 1.02500 Feed rate \* Depth of cut + 0.000872 Cutting speed<sup>2</sup> - 145.00000 Feed rate<sup>2</sup> + 3.57000 Depth of cut<sup>2</sup> (4.2)

#### 4.2.2. Model Diagnostics Methods

The prediction capacity the model showed for quality of surface was evaluated using the diagnostic techniques such as normal plots and predicted versus actual plots. Figure 4.2 shows the normal possibility distribution of the data. As shown in Figure 4.2, all data points are distributed along linear line, indicating that the model predicted all the data.

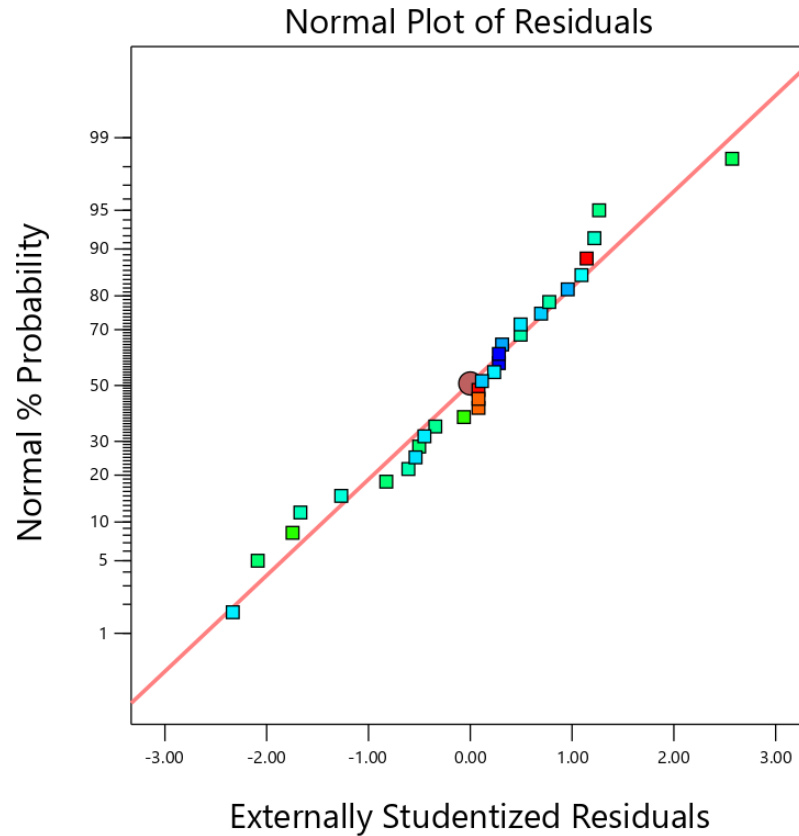


Figure 4. 2: The Normal Probability of surface roughness data

Figure 4.3 indicates the variation between the actual values of the surface roughness from the laboratory and the predicted values of the surface roughness by the quadratic model selected for the surface roughness. As shown in the figure, there is no significant variation between the actual values of the surface roughness and the predicted values, indicating that the model adequately predicted the surface roughness data.

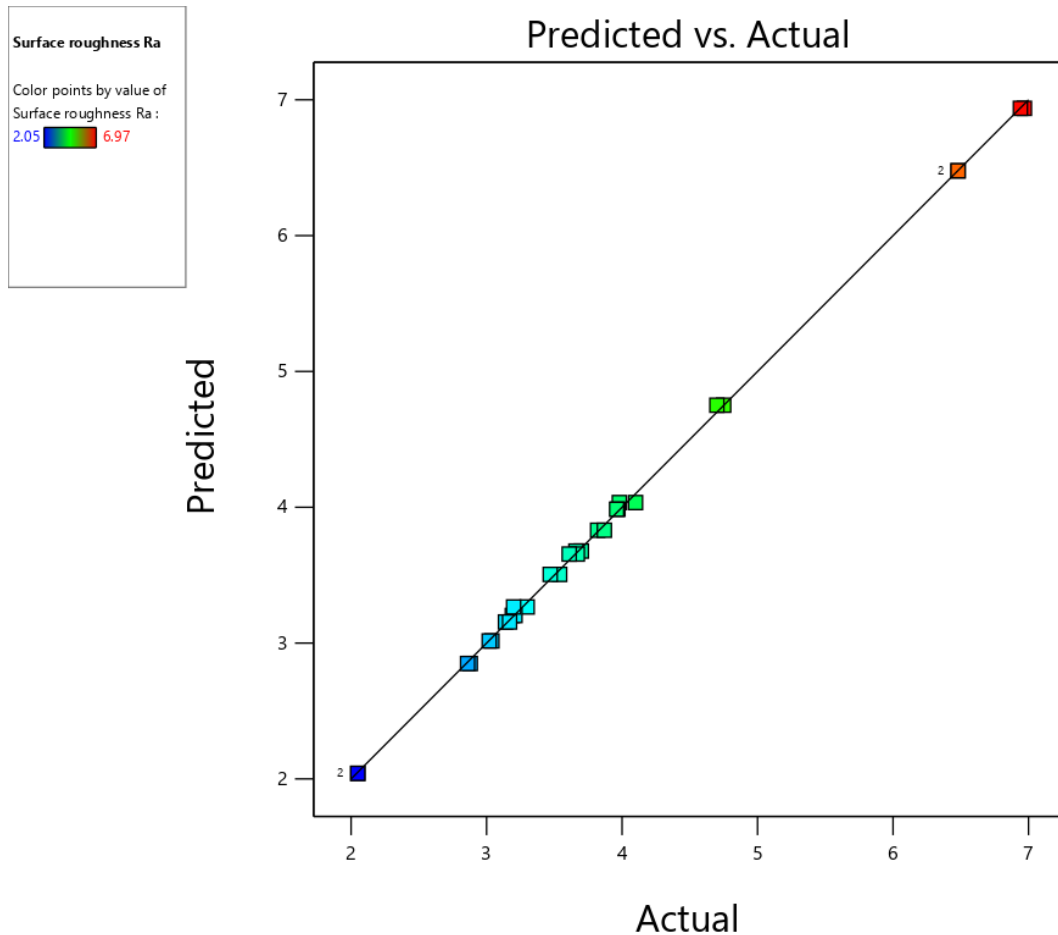


Figure 4. 3: The actual and Pridicted values of surface roughness

#### 4.2.3. The Effects of the Single Factors on the Surface Roughness

Figure 4.4 shows the effects of the individual settings in surface quality. Figure 4.4a indicates how the surface roughness is influenced while the cutting speed changes. As presented in the figure surface roughness tends to decrease for the lowest cutting speed up to the middle values of the cutting speed, in this case 120 m/min, and starts to increase as the cutting speed passes the middle values and increases to its highest values, in this case 150 m/min. This can be seen as grounded with as the speed of cut raise, the heat at engagement, can be increased, leading to the establishment of BUE, which spoils the surface quality of the machined sample. The impact of the rate of feed on the quality fo surface displayed in Figure 4.4b. As indicated in the figure, quality raises as the rate of feed become higher and begins to decline at the peak level of rate of feed, in this case 0.15 mm/rev.

Figure 4.4c presents the manipulation of cutting depth alone on the quality of generated surface. As illustrated by the figure, the quality was high at the smallest cutting depth and declined as the depth of cut went to its middle values, i.e., 1 mm in this case. As the depth of cut passes its middle values and starts increasing, the surface roughness gets worse. This confirms the fact that machining at the highest depth of cut favors the generation of BUE on the cutting tool and generates the rough surface.

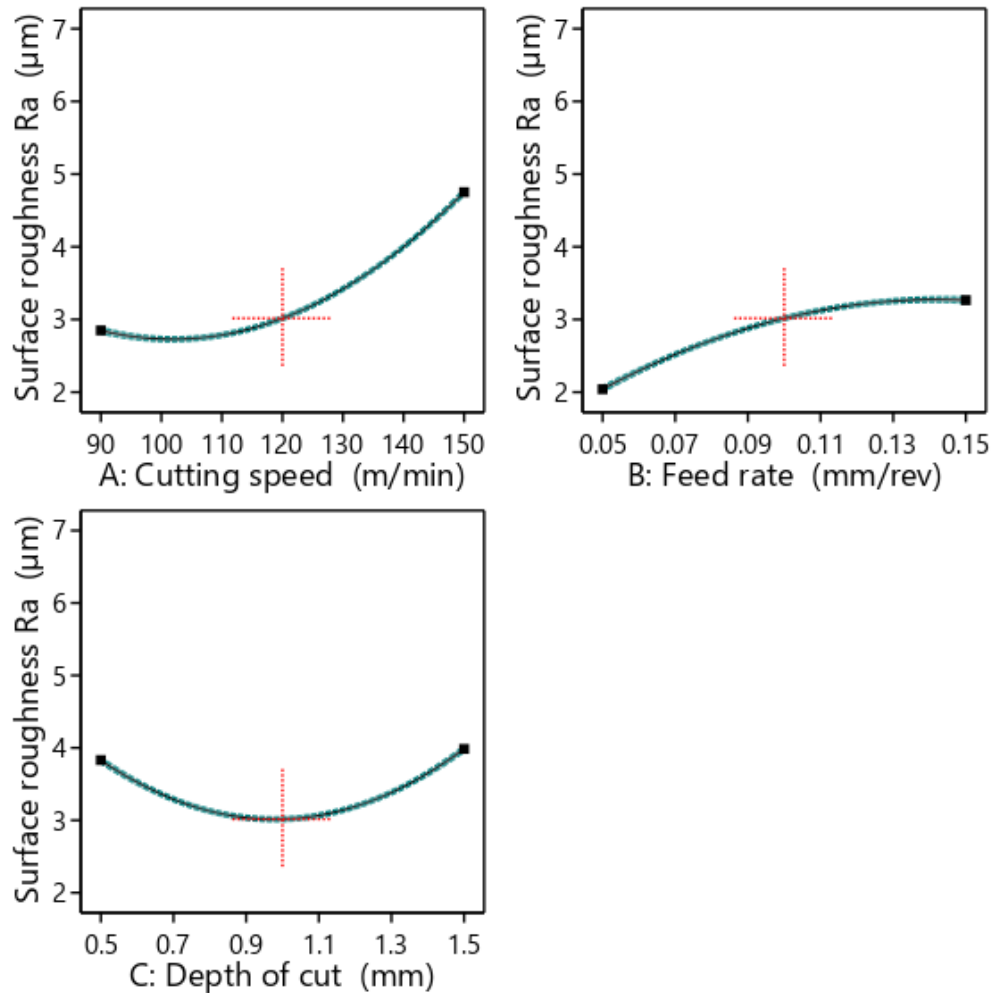


Figure 4. 4: The 2D graph shows the effects of individual factors on surface roughness

#### 4.2.4. The Combined Influence of Cutting Speed and Feed Rate on Quality of Surface

The 3D surface graph displayed in Figure 4.5 illustrates the combined influence of the speed of cut and rate of feed on the quality of surface. From Figure 4.5, the quality was minimum at the collaboration of smallest rate of feed and speed of cut. Even at the combination of the lowest values of feed rate, i.e., 0.05 mm/rev up to 0.1 mm/rev in this case, and all values of cutting

speed, including the highest value of cutting speed, the surface roughness was low. However, as the feed rate kept increasing for entire value of speed of cut, quality of surface increased. This phenomenon confirms the reality that machining with a higher feed rate reduces the time to evacuate chips from the cutting zone, creating unnecessary heat at the cutting zone, which produces a rough surface of the machined sample. The peak surface roughness was observed when the peak values of speed of cut and rate of feed employed..

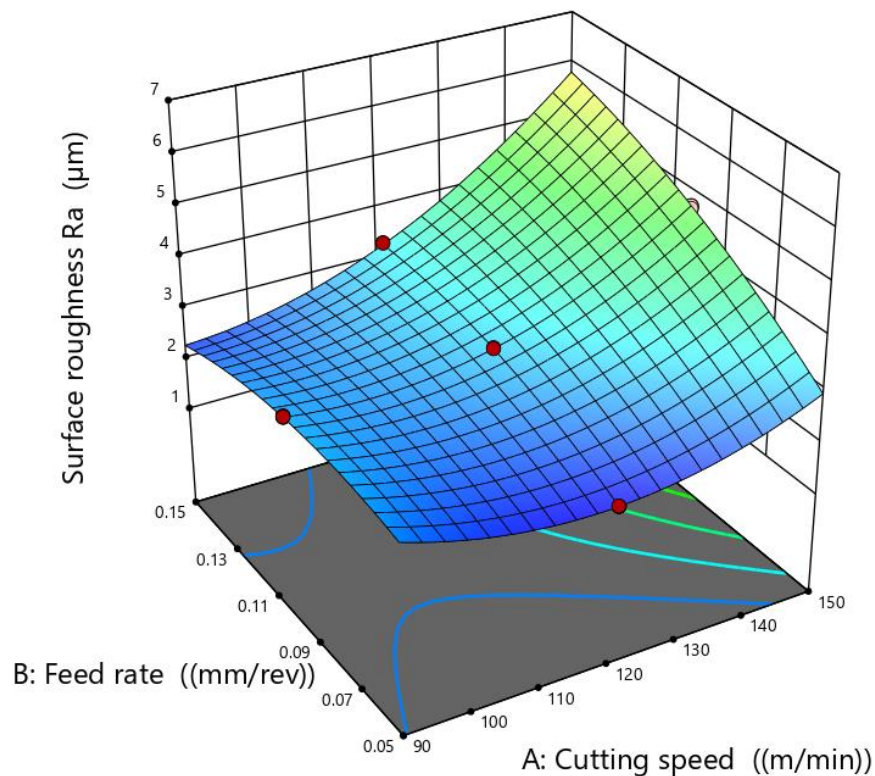


Figure 4. 5: The 3D model graph indicate connection effects of the cutting speed and feed rate on the surface roughness

#### 4.2.5. The Interaction Effects of Cutting Speed and Depth of Cut on Surface Roughness

The impact of both cutting speed and depth of cut are illustrated using the 3D surface graph indicated in Figure 4.6. Accordingly, the middle level of the depth of cut, i.e., 1 mm in this case, produces a smooth surface sample for all levels of speed of cut. The lowest level and highest level of cutting depth at all levels of cutting speed produce the worst surface roughness samples, according to the 3D surface graph shown in Figure 4.6. Moreover, the peak quality of surface in

this combination effect, i.e., 4 micrometers, was seen when the highest level of depth of cut was used for all values of the cutting speed. However, the combination of the middle level of depth of cut with cutting speed is the best condition for the quality of surface. The highest depth of cut generates higher heat at the cutting zone due to the plastic deformation of the surface being cut, and this in turn produces a BUE, which affects the surface quality. Furthermore, when the combination of the highest values of cutting depth and rate of feed is used, both favor the generation of a huge amount of heat at the engagement.

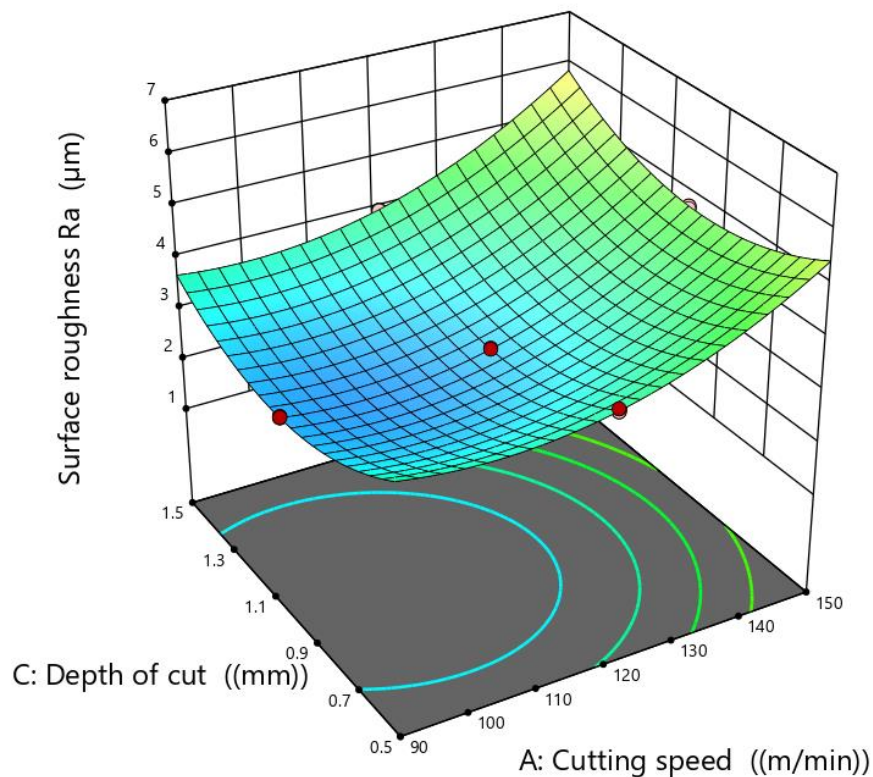


Figure 4. 6: The 3D surface graph indicating the interaction effects of the cutting speed and depth of cut on the surface roughness

#### 4.2.6. The Interaction Effects of Feed Rate and Depth of Cut on Surface Roughness

The 3D surface graph demonstrating the combination effect of the depth of cut and feed is shown in Figure 4.7. Unlike the combination effect of depth of cut and cutting speed, in which the middle level of depth of cut generates the best surface roughness for all levels of cutting speed, the middle level of depth of cut generates good surface quality at the smallest rate of feed. The

combination of the middle value of the depth of cut and the highest value of rate of feed resulted in increased surface roughness. Thus, the combination of the middle level of depth of cut and the lowest level of feed rate, i.e., 1 mm and 0.1 mm/rev, respectively, is the best condition for surface roughness in this case. Furthermore, the peak value of surface roughness, more than 4 micrometers, was observed when the highest level of the depth of cut and feed rate were the cutting arrangement.

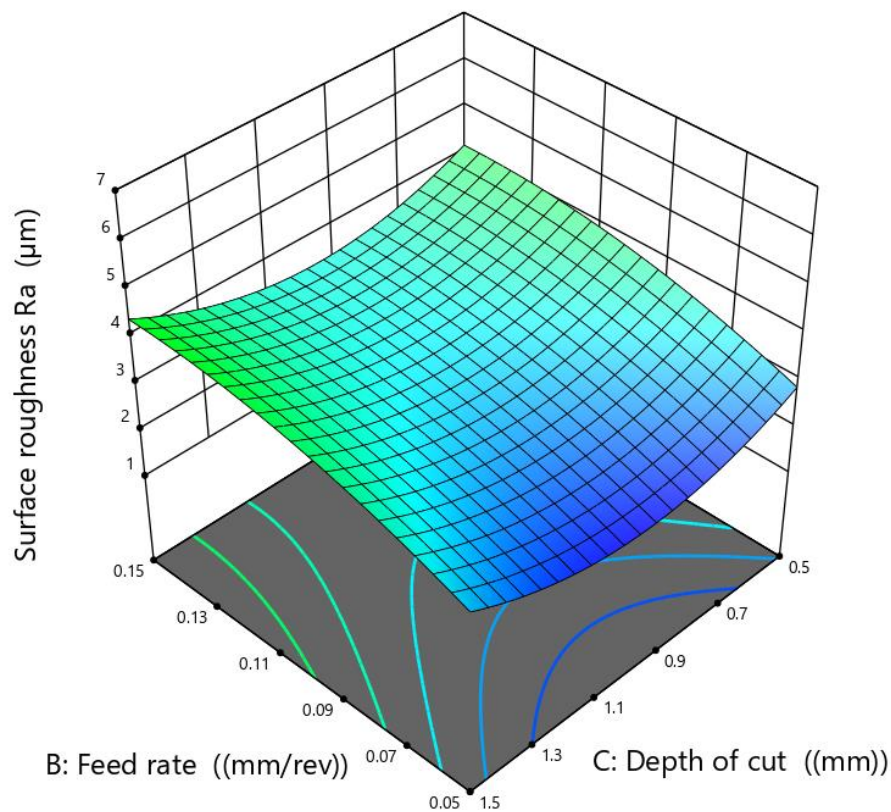


Figure 4. 7: The 3D surface graph indicating the combination impact of depth of cut and feed rate on surface roughness

#### 4.3. Analysis of the Effects of Input Parameters on Cutting Zone Temperature

The turning process parameters selected in this study have a significant impact on the temperature at the contact zone of the cutting tool and the specimen. One of the objectives of this study is to examine the influences of these parameters on the temperature at the contact area. The ANOVA table indicates the significance level of each process parameter on the response and indicates the appropriate regression model to forecast heat at engagement data. The Fit summary,

including the lack of Fit p-value, sequential p-values, adjusted and predicted R-squared, ANOVA table, and 3D surface graphs, was obtained from the Design Expert software and used to detect influence of variables and the model fitness.

#### 4.3.1. ANOVA of Cutting Zone Temperature

Examining the relevance level of each input parameter on the response is made easier by the region of cutting heat analysis of variance table, which is shown in Table 4.5. The model F-value of 20.74 indicates that the model is significant, according to the ANOVA table in Table 4.5. The p-value, or probability value, is used to indicate whether the hypothesis is true or false. When the p-value is less than 0.05, it means that the factor has a substantial impact on the response and that the hypothesis of the observed data is correct. As a result, the table's P-values below 0.0500 suggest factors are influencing. Factors such as A, C, AB, AC, and B<sup>2</sup> are significant. A large lack of fit F-value has a 97.98% due to error.

Table 4. 5: The ANOVA Table for Cutting Zone Temperature

| Source          | Sum of Squares | df | Mean Square | F-value | p-value  |                 |
|-----------------|----------------|----|-------------|---------|----------|-----------------|
| <b>Model</b>    | 851.38         | 9  | 94.60       | 20.74   | < 0.0001 | significant     |
| A-Cutting speed | 462.98         | 1  | 462.98      | 101.51  | < 0.0001 |                 |
| B-Feed rate     | 13.31          | 1  | 13.31       | 2.92    | 0.1031   |                 |
| C-Depth of cut  | 131.48         | 1  | 131.48      | 28.83   | < 0.0001 |                 |
| AB              | 118.48         | 1  | 118.48      | 25.98   | < 0.0001 |                 |
| AC              | 33.58          | 1  | 33.58       | 7.36    | 0.0134   |                 |
| BC              | 1.58           | 1  | 1.58        | 0.3453  | 0.5633   |                 |
| A <sup>2</sup>  | 14.90          | 1  | 14.90       | 3.27    | 0.0858   |                 |
| B <sup>2</sup>  | 82.20          | 1  | 82.20       | 18.02   | 0.0004   |                 |
| C <sup>2</sup>  | 0.0050         | 1  | 0.0050      | 0.0011  | 0.9738   |                 |
| <b>Residual</b> | 91.22          | 20 | 4.56        |         |          |                 |
| Lack of Fit     | 4.10           | 5  | 0.8195      | 0.1411  | 0.9798   | not significant |

|                  |        |    |      |  |  |  |
|------------------|--------|----|------|--|--|--|
| Pure Error       | 87.12  | 15 | 5.81 |  |  |  |
| <b>Cor Total</b> | 942.59 | 29 |      |  |  |  |

The most influential factor for cutting zone temperature is cutting speed, with a percentage contribution value of 54.4, exceeded with cutting depth and the combination of speed of cut and rate of feed , with fraction of 15.4 and 13.9, orderly. Feed rate is the least influential factor for cutting zone temperature according to the percentage contribution computation.

The Fit summary table illustrated in Table 4.6 indicates that the quadratic model is the significant model for prediction of cutting zone temperature with the maximum adjusted and forcasted R-squares of 0.8597 and 0.7755, respectively. The model is significant, according to the sequential p-value and lack of fit p-value, which are 0.0028 and 0.9798, respectively, while the lack of fit p-value is not significant, suggesting the model as a candidate for cutting temperature data prediction.

Table 4. 6: The Fit Summary Table for Cutting Temperature

| Source    | Sequential p-value | Lack of Fit p-value | Adjusted R <sup>2</sup> | Predicted R <sup>2</sup> |           |
|-----------|--------------------|---------------------|-------------------------|--------------------------|-----------|
| Linear    | < 0.0001           | 0.0084              | 0.6038                  | 0.5090                   |           |
| 2FI       | 0.0024             | 0.1138              | 0.7576                  | 0.6935                   |           |
| Quadratic | 0.0028             | 0.9798              | 0.8597                  | 0.7755                   | Suggested |
| Cubic     | 0.9746             | 0.6180              | 0.8296                  | 0.6442                   | Aliased   |

The model's data of the cutting temperature data shown in Table 4.7 illustrate the sufficient accuracy, showing model's capacity. The signal-to-noise ratio is measured with adequate precision. Your signal strength of 16.886 is sufficient. Additionally, the arranged R<sup>2</sup> of 0.8597 and the projected R<sup>2</sup> of 0.7755 shows better agreement with small variation below 0.2.

Table 4. 7: The Fit statistics of the quadratic model

|           |       |                          |        |
|-----------|-------|--------------------------|--------|
| Std. Dev. | 2.14  | R <sup>2</sup>           | 0.9032 |
| Mean      | 67.68 | Adjusted R <sup>2</sup>  | 0.8597 |
| C.V. %    | 3.16  | Predicted R <sup>2</sup> | 0.7755 |

|  |  |                |         |
|--|--|----------------|---------|
|  |  | Adeq Precision | 16.8863 |
|--|--|----------------|---------|

Forecasted variation in cutting temperature for small deviation of a specific factor when other factors kept same is shown in Table 4.8. The factors with negative coefficient estimates show that the change in that factor reduces the cutting temperature by the factor of the coefficient, and the factor with a positive coefficient estimate increases the response by the factor of the coefficient. Thus, based on Table 4.8, factors like cutting speed, depth of cut, combination of cutting speed and feed rate, and self-interaction of depth of cut and feed rate are the factors whose change reduces the heat produced at engagement region. The change of any other factors other than the above-listed factors increases the cutting zone temperature while other factors are held constant. VIF is the indicator of collinearity among the factors. The factors with VIF value of 1 are called orthogonal factors, which means there is no collinearity between these factors, and factors with VIF values above 1 indicate multicollinearity; high value of VIF show severity to factors co-relationship.

Table 4. 8: The Coefficients Estimate in terms of Coded Factors and the Variance Inflation

Factor

| Factor          | Coefficient Estimate | df | Standard Error | 95% CI Low | 95% CI High | VIF    |
|-----------------|----------------------|----|----------------|------------|-------------|--------|
| Intercept       | 69.23                | 1  | 0.8117         | 67.54      | 70.92       |        |
| A-Cutting speed | -4.81                | 1  | 0.4775         | -5.81      | -3.82       | 1.0000 |
| B-Feed rate     | 0.8157               | 1  | 0.4775         | -0.1805    | 1.81        | 1.0000 |
| C-Depth of cut  | 2.56                 | 1  | 0.4775         | 1.57       | 3.56        | 1.0000 |
| AB              | -2.72                | 1  | 0.5339         | -3.83      | -1.61       | 1.0000 |
| AC              | 1.45                 | 1  | 0.5339         | 0.3351     | 2.56        | 1.0000 |
| BC              | 0.3137               | 1  | 0.5339         | -0.7999    | 1.43        | 1.0000 |
| A <sup>2</sup>  | 1.70                 | 1  | 0.9417         | -0.2623    | 3.67        | 1.30   |
| B <sup>2</sup>  | -4.00                | 1  | 0.9417         | -5.96      | -2.03       | 1.30   |
| C <sup>2</sup>  | -0.0313              | 1  | 0.9417         | -2.00      | 1.93        | 1.30   |

The regression equations developed for the prediction of cutting Zone temperature in terms of coded and Actual factors are given in equations 1 and 2, respectively.

$$\text{Cutting Temperature} = +69.23 - 4.81 A + 0.8157B + 2.56 C - 2.72 AB + 1.45 AC + 0.3137 BC + 1.70A^2 - 4.00B^2 - 0.0313C^2 \quad (4.3)$$

One can evaluate the output variables at specific values of variables using this coded regression equation. The factors' high and low levels are denoted by the codes +1 and -1, respectively.

$$\begin{aligned} \text{Cutting Temperature} = & +83.90816 - 0.529419 \text{ Cutting speed} + 541.30086 \text{ Feed rate} - 7.46664 \text{ Depth of cut} \\ & - 1.81417 \text{ Cutting speed} * \text{Feed rate} + 0.096583 \text{ Cutting speed} * \text{Depth of cut} + 12.55000 \\ & \text{Feed rate} * \text{Depth of cut} + 0.001891 \text{ Cutting speed}^2 + 1599.18778 \text{ Feed rate}^2 - 0.125178 \text{ Depth of cut}^2. \end{aligned}$$

The normal plot of residuals illustrated in Figure 4.8 shows the probability distribution of the actual data along the linear line. As shown in Figure 4.8, all data points are closely distributed along the linear line, indicating that the suggested quadratic model can adequately predict all data points. This shows that the model can predict all data in a linearly manner, with no one data point excluded from the prediction capacity of the model.

The forecasted and real data plot for the regression model of cutting temperature is indicated in Figure 4.9. As shown in Figure 4.9, the actual cutting temperature data and the predicted values of the cutting temperature by the model adequacy. The predicted and the actual values of the cutting temperature were scattered along a linear line with no single data point at a significant distance from the mean line, indicating that there is no significant variation between actual and estimated the temperature at the engagement.

Therefore, the normal plots of residuals and the predicted versus actual plot are used as the diagnostic techniques of the model's fitness.

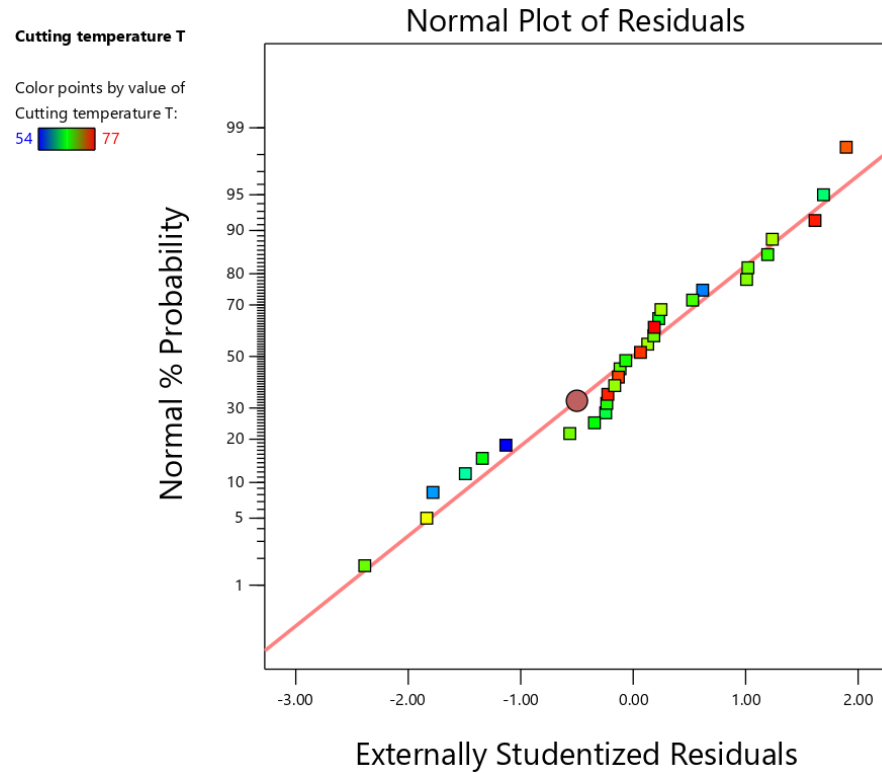


Figure 4. 8: The normal plots of Residuals

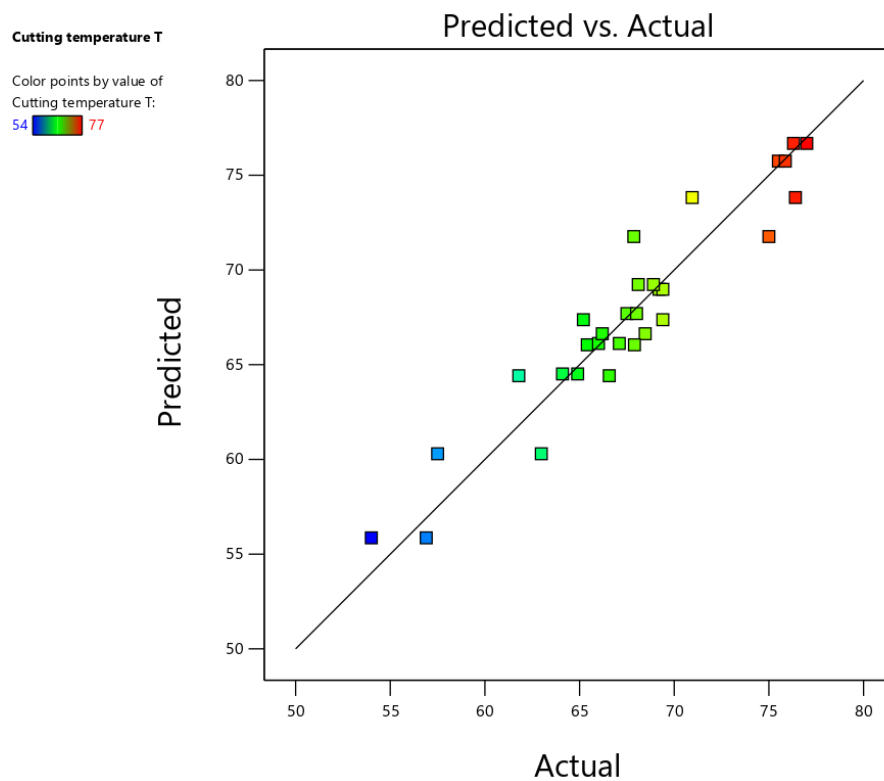


Figure 4. 9: The Predicted versus Actual plot of the Cutting Temperature data

#### 4.3.2. The Effects of the Individual Factors on the Cutting Zone Temperature

Figure 4.10 shows how each individual factor affects the cutting zone temperature. The role of speed of cutting on temperature at contact region is depicted in Figure 4.10a. The figure shows that the temperature at the cutting zone was high at the lowest cutting speed of 90 m/min. The cutting temperature drops as the cutting speed value rises from its minimum, or 90 m/min, to its maximum, or 150 m/min. Figure 4.10b illustrates the impact of feed rate, and it shows that the cutting temperature rises for the setup up to the middle cutting speed level.

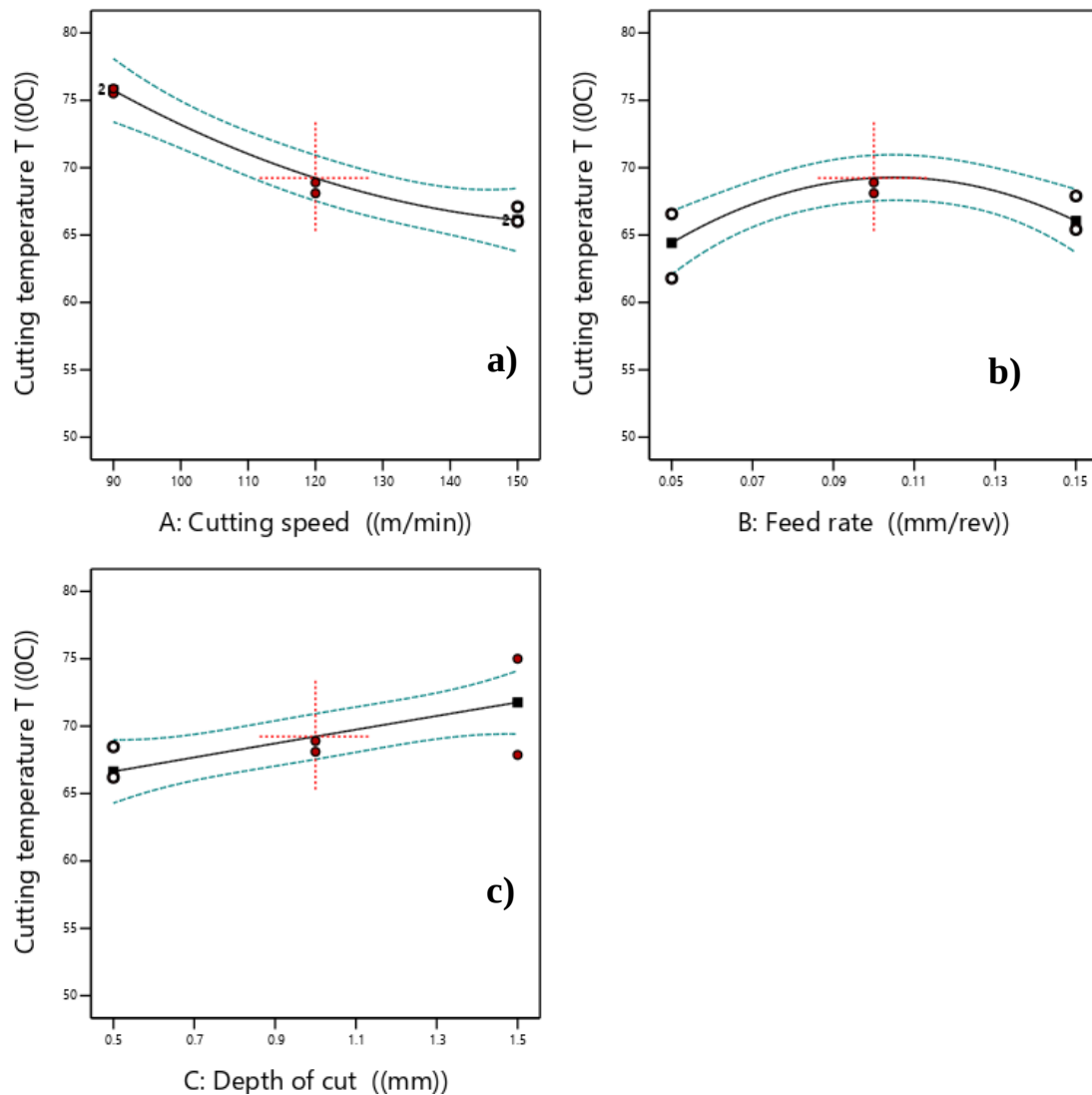


Figure 4. 10: The Effects of the Single Factors on the Cutting Zone Temperature

As the cutting speed passes its middle level, the cutting zone temperature tends to decline. This is due to the fact that at the high feed rate, the chip evacuation time is minimized, and the chip accumulated at the cutting zone creates extra heat at the contact area, increasing the temperature at the point. The effect of the depth of cut on the cutting zone temperature is shown in Figure 4.10c. As can be seen from the figure, the cutting zone temperature increases with the depth of cut. This effect confirms the fact that the high depth of cut needs high cutting force and cutting energy, which generates additional heat at the contact point, raising the cutting zone temperature.

#### **4.3.3. The Combined Effects of Cutting Speed and Feed Rate on Cutting Temperature**

Figure 4.11 displays the 3D surface graph that illustrates the combined effects of rate of feed and cutting speed on the temperature at contact region. The graph gives comprehensive details about how feed rate and cutting speed interact to affect cutting temperature. When the medium feed rate level (0.1 mm/rev) and the lowest cutting speed level (90 m/min) were combined as the cutting setting, the highest cutting zone temperature (76.46°C) was recorded. However, when the middle-level cutting speed (120 m/min) and the lowest level of feed rate (0.05 mm/rev) were chosen as the cutting process parameters, the lowest cutting zone temperature (65.25°C) was attained. Therefore, the combination of a low level of the feed rate and a middle level of the cutting speed was seen as the best condition for achieving a low temperature at the cutting area.

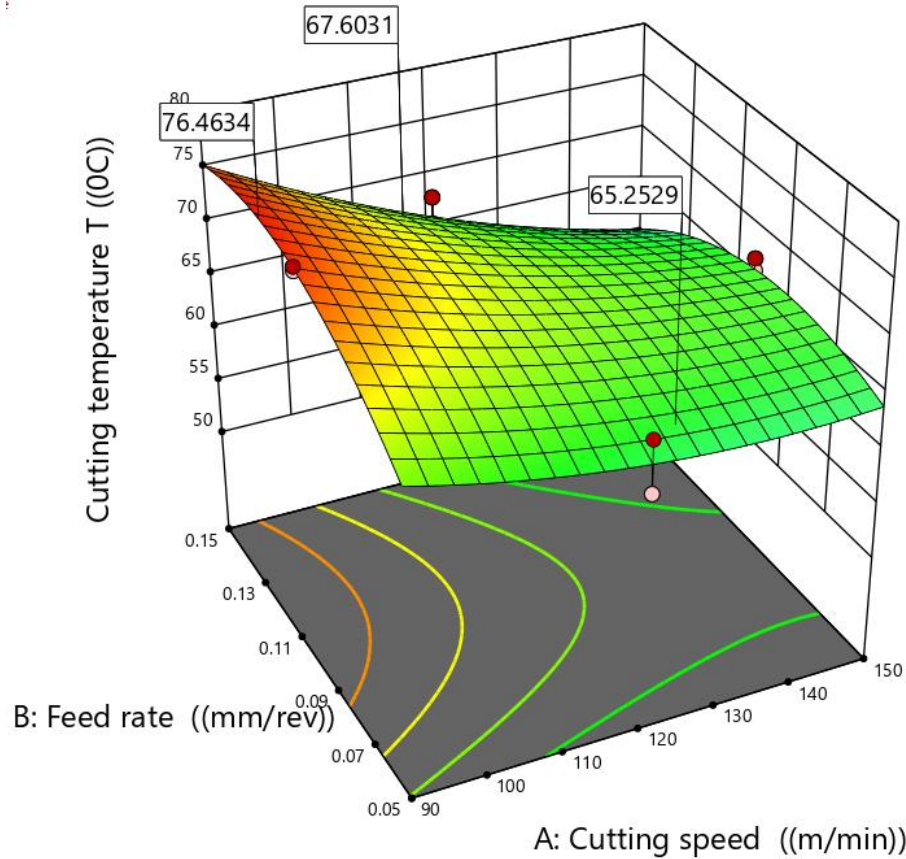


Figure 4. 11: The 3D surface graph show the Combined effect of the Cutting speed and Feed rate on the cutting temperature

#### 4.3.4. The Combined Effects of Cutting Speed and Depth of Cut on Cutting Temperature

The combined effects of cutting depth and speed on cutting zone temperature are shown in Figure 4.12. As a result, when the lowest cutting speed (90 m/min) and the highest cutting depth (1.5 mm) were selected as the cutting settings, the greatest temperature at the cutting area was recorded at 76.27°C. On the other hand, when the maximum cutting speed (150 m/min in this example) and the lowest depth of cut (0.5 mm) were selected as variables, the lowest cutting zone temperature (62.87°C) was reached. Thus, based on Figure 4.12, it can be inferred that the combination of the highest cutting speed and the lowest depth of cut was the best way to reduce the cutting zone temperature, whereas the combination of the lowest cutting speed and the highest depth of cut was the worst way to raise the cutting zone temperature.

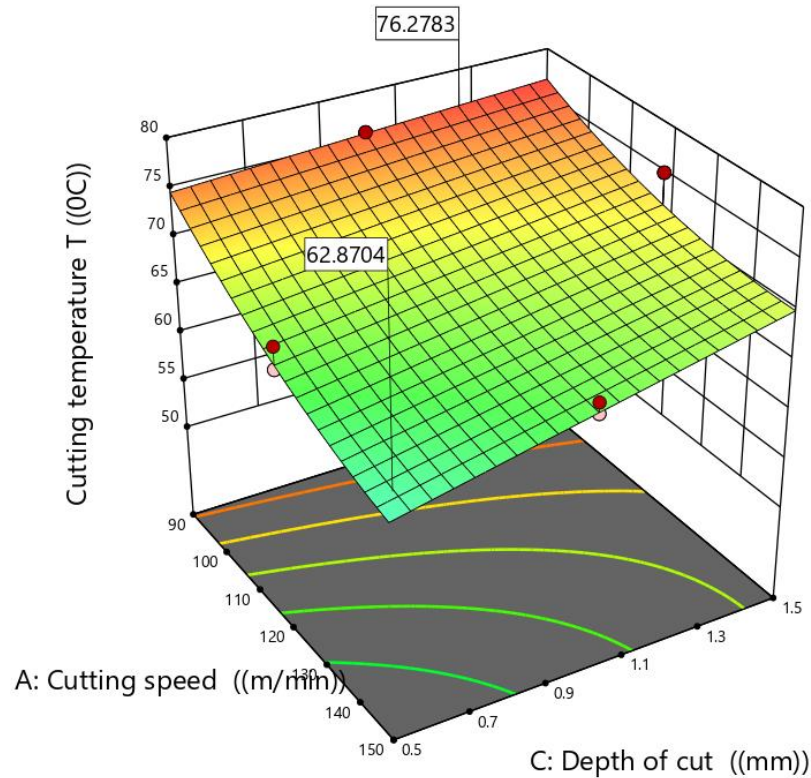


Figure 4. 12: The 3D surface graph illustrating the combination effect of cutting speed and depth of cut on the cutting temperature.

#### 4.3.5. The Combined Effects of Feed rate and Depth of Cut on Cutting Temperature

As can be observed from the 3D surface graph shown in Figure 4.13, the combination of the lowest value of depth of cut and feed rate was the combination that achieved the lowest cutting temperature, which is 62.6°C. This phenomenon agrees with the fact that machining at the lowest value of depth of cut and feed rate requires minimum cutting force and energy, which generates less heat in the machining area. It's known that the machining that uses a high depth of cut demands high cutting force and energy, which produces a huge amount of heat at the cutting point, and this in turn raises the temperature at the cutting zone. Similarly, the high temperature, i.e., 71.66°C, was observed when the combination of a high level of depth of cut, i.e., 1.5 mm, and a middle level of feed rate, i.e., 0.1 mm/rev, was chosen as the cutting variables. This confirms the reality that a high depth of cut requires a high amount of force, resulting in a rise of cutting temperature, and in addition to that, as the moderate level of feed rate, i.e., 0.1 mm/rev,

was employed as the cutting variable, there is not sufficient time for chip evacuation, and this raises the cutting zone temperature.

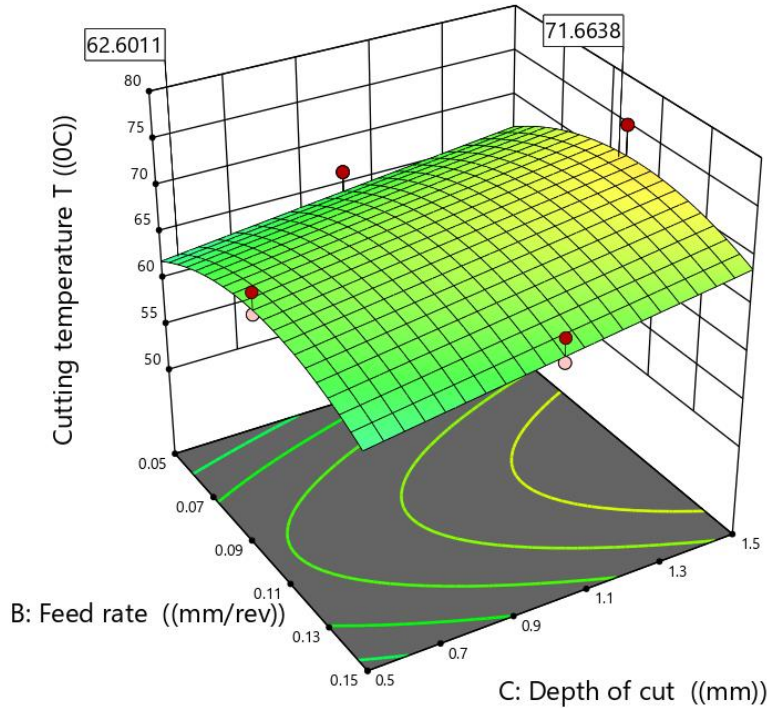


Figure 4. 13: The graph indicating the effect of the Feed rate and Depth of cut on temperature cutting area.

#### 4.4. The Effects of Input Variables on Material Removal Rate (MRR)

The material removal rate is the indicator of the production rate of the machining industry. Accordingly, researchers use the material removal rate to evaluate their productivity while engaged in machining operations. Most often researchers calculated the material removal rate using the analytical formula given under equation 5.(Du et al., 2020);

$$MRR = VC \times f \times dc \quad (4.4)$$

Where MRR is material removal rate in mm<sup>3</sup>/min, Vc is cutting speed in m/min, f is feed rate in mm/rev, and dc is depth of cut in mm. Therefore, the MRR is considered as the product of the three turning parameters, namely cutting speed, feed rate, and depth of cut, as given in equation 5. Thus, the MRR was calculated using the common formula provided in equation 5, and the effect of the parameters was examined. The highest MRR, i.e., 33750 mm<sup>3</sup>/min, was obtained when the highest levels of the parameters, 150 m/min of cutting speed, 0.15 mm/rev of feed rate, and 1.5 mm of depth of cut, were used as the cutting parameters. In the same manner, the lowest

MRR, i.e., 2250 mm<sup>3</sup>/min, was calculated when the lowest levels of the parameters, 90 m/min of cutting speed, 0.05 mm/rev of feed rate, and 0.5 mm of depth of cut, were selected as cutting parameters.

The Figure 4.14 shows the effect of the cutting parameters via 3D surface graph on the MRR. As illustrated in the Figure 4.14, the maximum MRR was obtained when the combination of the highest level of parameters was used.

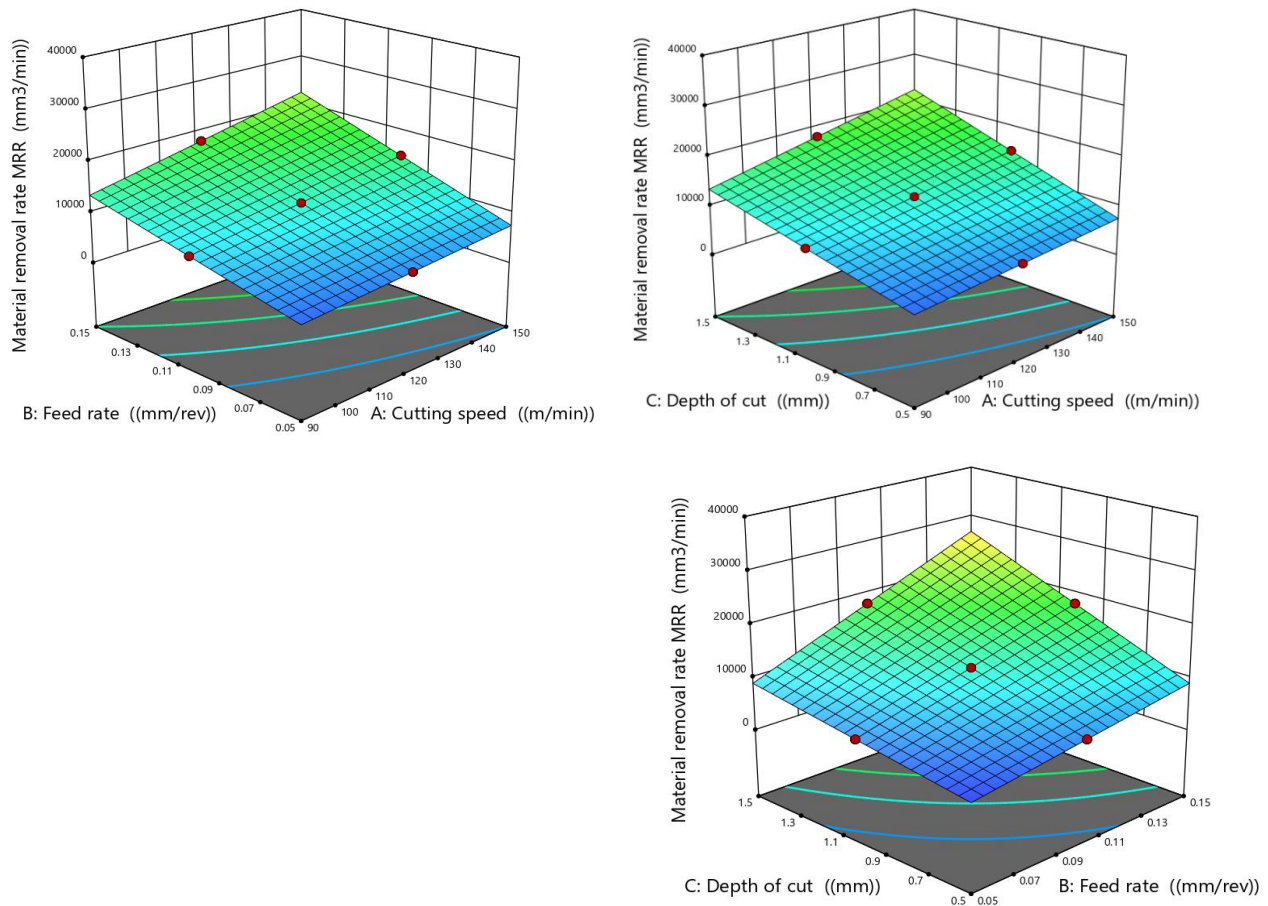


Figure 4. 14: The 3D surface graph illustrates the effects of the parameters on the MRR

#### 4.5. Multiobjective Optimization of The Output Variables

So far research has demonstrated that the cutting variables such as cutting speed, feed rate, depth of cut, and cutting tool geometry influence machining performance characteristics such as material removal rate, quality of surface, temperature at contact region, and tool wear (Abbas et al., 2023; Ahmed et al., 2023). Therefore, the selection of the factors [process variables for machine operation] for enhanced output variables like surface roughness, cutting temperature, tool wear, and MRR in dry conditions is yet a challenging task for

researchers and considered a contribution to environmental sustainability. Many researchers optimized the machining responses using single optimization techniques.

In this research, the surface roughness, MRR, and the cutting temperature were simultaneously optimized using multiobjective optimization (MO) using Design Expert software. The optimization techniques use the Desirability Function Analysis (DFA) algorithm.

#### 4.5.1. Desirability Function Analysis (DFA)

The concept DFA optimization was first developed by (Derringer & Suich, 1980) to reduce several optimization objectives into a single objective by considering the individual's desirability to optimize the multiple objectives simultaneously. The process in desirability optimization idea consists of two steps and first every objectives are transformed to a unique desirability function ( $d_i$ ), the value of which is between zero and 1. There are three common steps are to be followed to calculate the desirability function (Jumare et al., 2019).

The-smaller-the-better criteria: in current research since the aim is to reduce cutting zone temperature and surface roughness, the smaller-the-better criterion is applied for determining each response's specific desirability value. The function of desire for the smaller more favorable criterion is represented by the next formula.

$$d_i = \left\{ 0 \ 1 \left( \frac{y_n - y_{low}}{y_{low} - y_{max}} \right)^r, y \leq y_{min} \ y_{min} \leq y_n \leq y_{max}, r \geq 0 \quad y \geq y_{max} \right\}$$

Where  $y_n$  is expected to be the smaller the better and is the lower limit of  $y_n$ ,  $y_{max}$ , represents the higher tolerance limit of  $y_n$  and  $r$  is the weight.

The larger, the better criteria: this step is applied when the aim of the optimization is to maximize the objective function, which can be applied for optimizing material removal rate in this optimization procedure.

$$d_i = \left\{ 0 \ 1 \left( \frac{y_n - y_{low}}{y_{low} - y_{max}} \right)^r, y \leq y_{min} \ y_{min} \leq y_n \leq y_{max}, r \geq 0 \quad y \geq y_{min} \right\}$$

Where  $y_n$  is expected to be the larger the better.

The determination of overall desirability ( $D_c$ ) is the final step in desirability analysis optimization, where the overall desirability of all objectives to be optimized is computed by integrating the desirability of individual responses using the following formula:

$$D_c = \sqrt{(d_1^{w1} \times d_2^{w2} \times d_3^{w2} \dots \dots d_i^{wn})}$$

Where  $w_n$  is the weight criteria and is assumed to have equal importance for this analysis

$D_c$  And  $d_i$  are overall desirability and individual desirability.

Thus, the desirability function analysis optimization approach was used for optimization of selected responses in the current research.

Accordingly, the optimization criteria were set to be in range for all three parameters, and the optimization goal for surface roughness was to minimize, MRR was to maximize, and the cutting temperature was to minimize. The equal weight, i.e., 1 and 3 importance, was the optimization criterion.

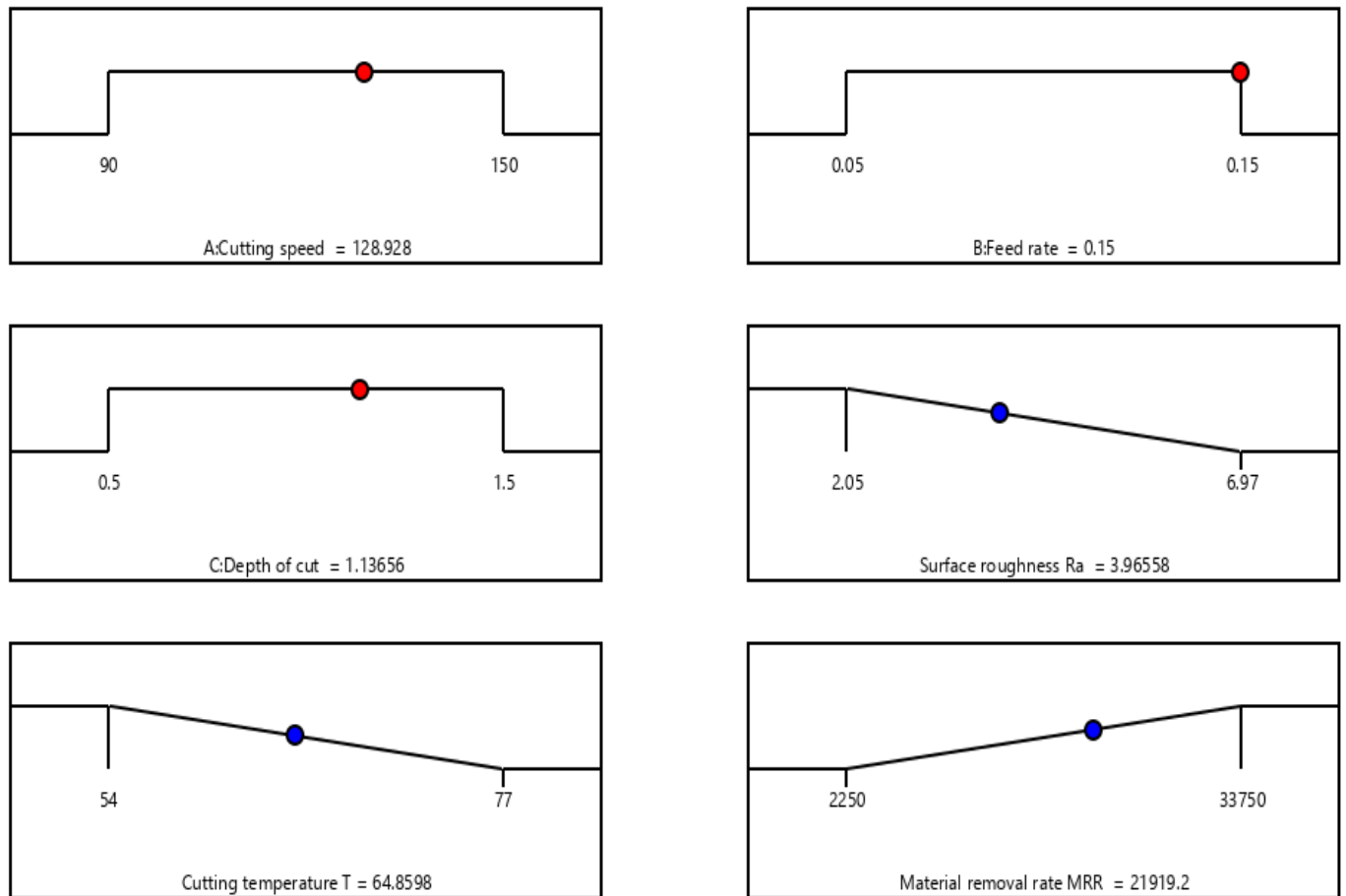


Figure 4. 15: The graphical Ramps shows the optimum values of the parameters and the responses

From the 38 solutions found, the first was taken as the optimal selection. The cutting speed of 128.928 m/min, feed rate of 0.150 mm/rev, and depth of cut of 1.137 mm were the optimal settings that provide a minimum surface roughness of 3.966  $\mu\text{m}$ , a cutting temperature of 64.9°C, and a maximum MRR of 21919.191  $\text{mm}^3/\text{min}$  with 0.586 desirability. Figure 4.16 shows the bar

graph showing the desirability value for each input parameter and the combined variability.

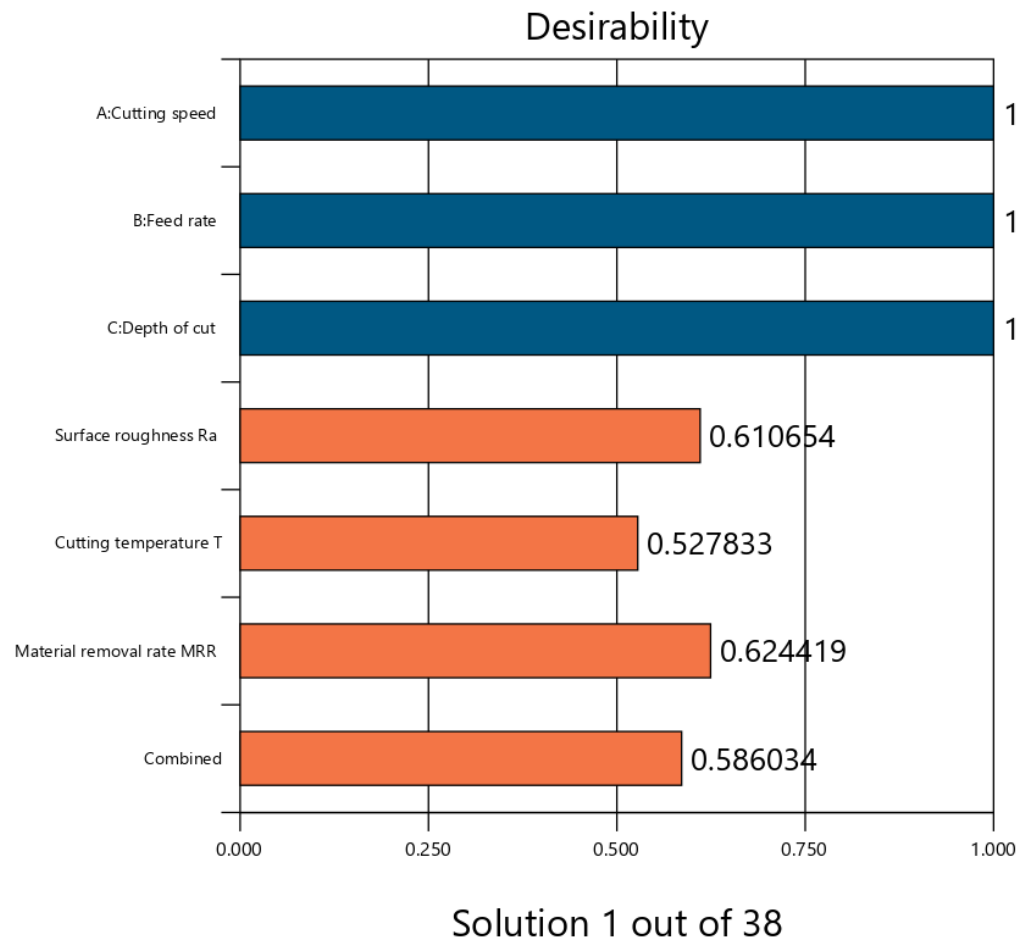


Figure 4. 16: The Bar plot for input parameters and responses indicating combined desirability

#### 4.5.2. Confirmatory Experiments

Whether or not the outcomes of study effort are valid, they still need to be verified. Confirmatory experiments are one method used in engineering research to verify the results gained. In confirmatory experiments, the optimum parameter values predicted by the model are verified by conducting experiments using those parameters to confirm the model's accuracy and predictive capability. Confirmatory experiments must be carried out when optimization is complete and the ideal turning parameters are determined in order to verify whether the produced model is legitimate and capable of correctly predicting the supplied answers. Therefore, in this research, the confirmatory experiments are conducted at the optimum set of turning parameters.

Accordingly the confirmation test done at optimum variable choice of the parameters shown in the Table 4.9.

Table 4. 9: Confirmation experiment result at optimum value

| S/N | Cutting speed (m/min) | Feed rate (mm/rev) | Depth of cut (mm) | Surface roughness ( $\mu\text{m}$ ) | Temperature ( $^{\circ}\text{C}$ ) | MRR ( $\text{mm}^3/\text{min}$ ) |
|-----|-----------------------|--------------------|-------------------|-------------------------------------|------------------------------------|----------------------------------|
| 1   | <b>128.928</b>        | <b>0.150</b>       | <b>1.137</b>      | 3.95                                | 65.76                              | 21987.3                          |
| 2   | <b>129.04</b>         | <b>0.15</b>        | <b>1.148</b>      | 3.989                               | 64.91                              | 22157.98                         |
| 3   | <b>127.046</b>        | <b>0.15</b>        | <b>1.126</b>      | 3.814                               | 65.186                             | 21422.213                        |

The confirmation runs were conducted, and the observed values were uploaded to the Design Expert software, and the post-analysis was performed for confirmation. The two-sided confirmation was performed at a 95% confidence interval, and the data mean for the responses falls between 95% PI high and 95% PI low, indicating the selected optimal parameters were valid.

Table 4. 10: A Two-sided confirmation at 95% Confidence level

| S / N | Analysis                  | Predicted Mean | Predicted Median | Std Dev | n | SE Pred | 95% PI low | Data Mean | 95% PI high | Std Dev |
|-------|---------------------------|----------------|------------------|---------|---|---------|------------|-----------|-------------|---------|
| 1     | Surface roughness Ra      | 3.96613        | 3.96613          | 0.0367  | 1 | 0.042   | 3.879      | 3.95      | 4.0523      | 0.03679 |
| 1     | Cutting temperature T     | 64.86          | 64.8627          | 2.1356  | 1 | 2.399   | 59.86      | 65.76     | 69.867      | 2.1356  |
| 1     | Material removal rate MRR | 2197           | 21927.5          | 625.54  | 1 | 656.7   | 20569      | 21987.3   | 23286       | 625.543 |
| 2     | Surface roughness Ra      | 3.988          | 3.98891          | 0.0367  | 1 | 0.041   | 3.907      | 3.989     | 4.0751      | 0.03679 |
| 2     | Cutting temperature       | 64.91          | 64.9124          | 2.1356  | 1 | 2.398   | 59.91      | 64.91     | 69.914      | 2.1356  |
| 2     | Material removal rate MRR | 2213           | 22153.8          | 625.54  | 1 | 657.2   | 20794.2    | 22158     | 23513       | 625.543 |
| 3     | Surface roughness Ra      | 3.813          | 3.81381          | 0.0367  | 1 | 0.041   | 3.72745    | 3.814     | 3.9001      | 0.03679 |
| 3     | Cutting temperature T     | 65.18          | 65.1831          | 2.1356  | 1 | 2.402   | 60.17      | 65.186    | 70.195      | 2.1356  |
| 3     | Material removal rate MRR | 2143           | 21413.7          | 625.54  | 1 | 655.1   | 20058      | 21422.2   | 22769       | 625.543 |

#### **4.6. Discussion**

The results and associated findings by the researchers are described in this section. Considering the findings of this research, factor like rate of feed, speed of cut, and cutting depth were regarded as input for both quality of surface roughness and temperature at joint area, as revealed by the ANOVA result. It was highlighted the influencing variable as the speed of cut for both responses, with the percentage contribution values of 40.6 and 54.4, respectively.

The peak value of surface roughness was achieved when the highest value of cutting speed, which is 150 m/min, and the highest level of feed rate, which is 1.5 mm/rev, were used as cutting conditions. However, the surface roughness value was low when both cutting speed and feed rate were at their minimum levels.

Because of this phenomenon, the maximum cutting speed permits the development BUE at the joint area, which deteriorates the surface quality since BUE adhere to the freshly created surface. Also, this ensures that the tool vibration increases at the higher cutting speed, and the tool vibration may influence the surface roughness. This finding also agrees with the finding of Zerti et al. (2017b) (Chowdhury, Debnath, Kamruzzaman, Nuruzzaman, & Shahin Mia, 2019).

Considering the effects of the parameters on the cutting zone temperature, the combination of the low cutting speed and high feed rate generated the highest cutting zone temperature.

The high tool vibration generated due to the low level of speed of cut raise the temperature at the cutting point. Also, when the cutting time was kept low, the contact time of the tool and workpiece increased, leading to increased friction, which produces higher cutting temperature. The increasing feed rate has a similar impact as cutting speed on cutting temperature. Again, the low value of the cutting speed and high level of depth of cut were the worst conditions for the cutting zone temperature, yielding the peak cutting zone temperature. This situation confirms the fact that at low cutting speed, there is not sufficient time for chip evacuation from the cutting zone, which adds additional heat to the area. When this situation is integrated with a high depth of cut, it further exacerbates the situation, resulting in increased temperature at the cutting zone. Analyzing the influence of the combined feed rate and depth of cut, the moderate value of the feed rate and the highest level of the depth of cut raise the temperature. This is due to the fact that the high depth of cut requires high cutting force and energy, which releases a huge amount of heat at the cutting zone.

## **CHAPTER FIVE**

### **CONCLUSION AND RECOMMENDATION**

#### **5.1. Conclusion**

This chapter outlines the findings of this work. In this research the AISI 1060 steel was used for the turning experiment. The thirty CNC turning experiments were conducted on the CKE 6150 and serial number HG01450 CNC lathe machine. Design Expert software version 13.0.5.0's CCD was used to create the randomized trials. Cutting speed, feed rate, and depth of cut were the input parameters; each of these variables had three levels. The performance characteristics that were measured and taken into consideration as the output variables were MRR, surface roughness, and cutting zone temperature. A mechanical stylus instrument that records and amplifies the vertical movement of the stylus pushed by the sample surface is selected to measure surface roughness. The cutting zone temperature was measured using a thermal camera, and the results were displayed in picture form. After the results of the responses were recorded, the value was taken to the design expert software for analysis, and the ANOVA was used to investigate the effects of the factors and the significance level of the factors. Finally, the multiobjective optimization was performed based on the Desirability function analysis (DFA) to search for the best combination of the conditions for the surface roughness, cutting zone temperature, and the MRR.

From this research, below points can be summarized:

- The ANOVA result indicated that the selected cutting parameters, such as cutting speed, feed rate, and depth of cut, are the significant factors for the surface roughness, cutting temperature, and the MRR.
- The speed of cut influence the quality of surface with a percentage contribution value of 40.6% and highlighted as the top influencing variable. The combination of cutting speed and feed rate had percentage contributions of 23.77 and 16.85, respectively.
- With a percentage contribution value of 54.4, cutting speed was the most significant element when taking the cutting zone temperature into account. The depth of cut and the combination of cutting speed and feed rate had the next highest percentage contributions, at 15.4 and 13.9.

- The peak surface roughness, i.e., 6.97  $\mu\text{m}$ , was observed when the combination of the highest level of cutting speed and feed rate was used, while the lowest surface roughness, i.e., 2.05  $\mu\text{m}$ , was seen when the low level of feed rate, i.e., 0.05 mm/rev, and the middle level of the depth of cut, i.e., 1 mm, were chosen as the cutting setting.
- The peak cutting zone temperature, 76.46°C, was observed when the combination of the middle level of feed rate, i.e., 0.1 mm/rev, and the lowest level of cutting speed, i.e., 90 m/min, was used as the cutting setting. The lowest temperature at cutting, i.e., 54°C, was achieved when the highest levels of the cutting speed and feed rate were selected as input variables.
- Based on the data recorded, the predictive regression models were developed for the accurate prediction of surface roughness and temperature where confirmed the prediction versus actual plot and normal probability distribution plots for the responses.
- The ideal set of parameters that produced the lowest surface roughness of 3.966  $\mu\text{m}$ , the highest MRR of 21919.191  $\text{mm}^3/\text{min}$  with a 0.586 desirability value were the cutting speed of 128.928 m/min, feed rate of 0.150 mm/rev, and depth of cut of 1.137 mm.

## 5.2. Recommendation

Based on the outcomes of the current work, the following recommendations are given by the author:

- The metal cutting industries, those engaged in the production of the components from the AISI 1060 steel through turning, should use the lowest feed rate and a moderate depth of cut, i.e., 1 mm, when the cutting speed is held at a moderate value, i.e., 120 m/min in this case.
- Following its adverse effects on the environment, dependency on the natural non-renewable resources, and disposal cost, the cutting fluids should be avoided in the machining industries, and sustainable machining practices such as dry turning should be encouraged. As observed from the outcome of the current work, the lowest surface roughness of 2.05  $\mu\text{m}$  and cutting zone temperature of 54°C can be attained during dry turning of the selected steel.
- Depending on the findings of the current work, the author recommends that the machining industry should use a cutting speed of 128.928 m/min, a feed rate of 0.150

mm/rev, and a depth of cut of 1.137 mm as the optimum cutting parameters for turning a specific AISI 1060 steel.

### **5.3. Future Work**

Although this study offers insightful information about how to optimize CNC dry turning parameters for AISI 1060 steel, there are still a number of uncharted areas that could improve machining sustainability and efficiency. The following topics could be the focus of future studies:

- Although the current study concentrated on dry turning, using different cooling techniques including water vapor-based cooling, cryogenic cooling, or Minimum Quantity Lubrication (MQL) may improve tool life, surface polish, and environmental effect. Prior research has demonstrated that, in contrast to dry machining, methods such as cryogenic chilling can enhance surface integrity and lessen tool wear.
- Examining the application of substitute cutting tool materials, like those coated with AlTiSiN, may enhance dry turning operations' performance. Research has shown that in hard turning applications, these coatings can improve surface quality and tool life.
- Dynamic machining parameter change may be possible with the use of sensors and adaptive control algorithms in real-time monitoring systems, which would enhance process stability and product quality.

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## APPENDIX TABLE

Table App 1: The model fitness and prdictivie capacity report for surface roughness

| Run Order | Actual Value | Predicted Value | Residual | Leverage | Internally Studentized Residuals | Externally Studentized Residuals | Cook's Distance | Influence on Fitted Value DFFITS | Standard Order |
|-----------|--------------|-----------------|----------|----------|----------------------------------|----------------------------------|-----------------|----------------------------------|----------------|
| 1         | 3.04         | 3.02            | 0.0240   | 0.144    | 0.705                            | 0.696                            | 0.008           | 0.286                            | 6              |
| 2         | 3.54         | 3.51            | 0.0344   | 0.399    | 1.205                            | 1.219                            | 0.096           | 0.993                            | 2              |
| 3         | 3.17         | 3.16            | 0.0144   | 0.399    | 0.504                            | 0.494                            | 0.017           | 0.402                            | 29             |
| 4         | 3.61         | 3.66            | -0.0456  | 0.399    | -1.599                           | -1.669                           | 0.169           | -1.359                           | 23             |
| 5         | 3.30         | 3.27            | 0.0340   | 0.278    | 1.087                            | 1.092                            | 0.045           | 0.678                            | 18             |
| 6         | 3.87         | 3.83            | 0.0390   | 0.278    | 1.247                            | 1.266                            | 0.060           | 0.785                            | 25             |
| 7         | 3.20         | 3.27            | -0.0660  | 0.278    | -2.111                           | -2.333                           | 0.171           | -1.447                           | 24             |
| 8         | 4.70         | 4.75            | -0.0520  | 0.278    | -1.663                           | -1.746                           | 0.106           | -1.083                           | 22             |
| 9         | 3.47         | 3.51            | -0.0356  | 0.399    | -1.248                           | -1.267                           | 0.103           | -1.032                           | 28             |
| 10        | 3.98         | 4.04            | -0.0551  | 0.399    | -1.932                           | -2.088                           | 0.247           | -1.700                           | 4              |
| 11        | 3.70         | 3.68            | 0.0224   | 0.399    | 0.784                            | 0.776                            | 0.041           | 0.632                            | 8              |
| 12        | 4.10         | 4.04            | 0.0649   | 0.399    | 2.273                            | 2.573                            | 0.343           | 2.095 <sup>(1)</sup>             | 17             |
| 13        | 3.19         | 3.20            | -0.0131  | 0.399    | -0.460                           | -0.451                           | 0.014           | -0.367                           | 14             |
| 14        | 6.97         | 6.94            | 0.0324   | 0.399    | 1.135                            | 1.143                            | 0.085           | 0.931                            | 3              |
| 15        | 3.02         | 3.02            | 0.0040   | 0.144    | 0.118                            | 0.115                            | 0.000           | 0.047                            | 30             |
| 16        | 3.97         | 3.99            | -0.0160  | 0.278    | -0.512                           | -0.502                           | 0.010           | -0.311                           | 12             |
| 17        | 4.75         | 4.75            | -0.0020  | 0.278    | -0.064                           | -0.062                           | 0.000           | -0.039                           | 9              |
| 18        | 3.14         | 3.16            | -0.0156  | 0.399    | -0.548                           | -0.538                           | 0.020           | -0.438                           | 26             |
| 19        | 3.21         | 3.20            | 0.0069   | 0.399    | 0.241                            | 0.235                            | 0.004           | 0.191                            | 20             |
| 20        | 3.82         | 3.83            | -0.0110  | 0.278    | -0.352                           | -0.344                           | 0.005           | -0.213                           | 5              |
| 21        | 3.96         | 3.99            | -0.0260  | 0.278    | -0.831                           | -0.825                           | 0.027           | -0.511                           | 27             |
| 22        | 6.48         | 6.48            | 0.0024   | 0.399    | 0.083                            | 0.081                            | 0.000           | 0.066                            | 1              |
| 23        | 2.86         | 2.85            | 0.0100   | 0.278    | 0.320                            | 0.312                            | 0.004           | 0.194                            | 11             |
| 24        | 2.05         | 2.04            | 0.0090   | 0.278    | 0.288                            | 0.281                            | 0.003           | 0.174                            | 21             |
| 25        | 3.66         | 3.68            | -0.0176  | 0.399    | -0.618                           | -0.608                           | 0.025           | -0.495                           | 13             |
| 26        | 2.88         | 2.85            | 0.0300   | 0.278    | 0.959                            | 0.957                            | 0.035           | 0.594                            | 7              |
| 27        | 6.94         | 6.94            | 0.0024   | 0.399    | 0.083                            | 0.081                            | 0.000           | 0.066                            | 15             |
| 28        | 2.05         | 2.04            | 0.0090   | 0.278    | 0.288                            | 0.281                            | 0.003           | 0.174                            | 10             |
| 29        | 3.67         | 3.66            | 0.0144   | 0.399    | 0.504                            | 0.494                            | 0.017           | 0.402                            | 16             |
| 30        | 6.48         | 6.48            | 0.0024   | 0.399    | 0.083                            | 0.081                            | 0.000           | 0.066                            | 19             |

Table App 2: The model fitness and pridictivie capacity report for cutting zone Temperature

| Run Order | Actual Value | Predicted Value | Residual | Leverage | Internally Studentized Residuals | Externally Studentized Residuals | Cook's Distance | Influence on Fitted Value DFFITS | Standard Order |
|-----------|--------------|-----------------|----------|----------|----------------------------------|----------------------------------|-----------------|----------------------------------|----------------|
| 1         | 68.10        | 69.23           | -1.13    | 0.144    | -0.573                           | -0.563                           | 0.006           | -0.231                           | 6              |
| 2         | 69.20        | 68.98           | 0.2196   | 0.399    | 0.133                            | 0.129                            | 0.001           | 0.105                            | 2              |
| 3         | 76.30        | 76.68           | -0.3817  | 0.399    | -0.230                           | -0.225                           | 0.004           | -0.183                           | 29             |
| 4         | 65.20        | 67.38           | -2.18    | 0.399    | -1.315                           | -1.341                           | 0.115           | -1.092                           | 23             |
| 5         | 65.41        | 66.05           | -0.6394  | 0.278    | -0.352                           | -0.344                           | 0.005           | -0.214                           | 18             |
| 6         | 66.20        | 66.64           | -0.4364  | 0.278    | -0.240                           | -0.235                           | 0.002           | -0.146                           | 25             |
| 7         | 67.90        | 66.05           | 1.85     | 0.278    | 1.020                            | 1.021                            | 0.040           | 0.633                            | 24             |
| 8         | 66.00        | 66.12           | -0.1224  | 0.278    | -0.067                           | -0.066                           | 0.000           | -0.041                           | 22             |
| 9         | 69.40        | 68.98           | 0.4196   | 0.399    | 0.253                            | 0.247                            | 0.004           | 0.201                            | 28             |
| 10        | 67.50        | 67.70           | -0.1977  | 0.399    | -0.119                           | -0.116                           | 0.001           | -0.095                           | 4              |
| 11        | 62.98        | 60.30           | 2.68     | 0.399    | 1.618                            | 1.692                            | 0.174           | 1.378                            | 8              |
| 12        | 68.01        | 67.70           | 0.3123   | 0.399    | 0.189                            | 0.184                            | 0.002           | 0.150                            | 17             |
| 13        | 70.95        | 73.82           | -2.87    | 0.399    | -1.735                           | -1.835                           | 0.200           | -1.494                           | 14             |
| 14        | 64.10        | 64.51           | -0.4141  | 0.399    | -0.250                           | -0.244                           | 0.004           | -0.199                           | 3              |
| 15        | 68.90        | 69.23           | -0.3317  | 0.144    | -0.168                           | -0.164                           | 0.000           | -0.067                           | 30             |
| 16        | 67.87        | 71.76           | -3.90    | 0.278    | -2.148                           | -2.386                           | 0.177           | -1.480                           | 12             |
| 17        | 67.10        | 66.12           | 0.9776   | 0.278    | 0.539                            | 0.529                            | 0.011           | 0.328                            | 9              |
| 18        | 77.00        | 76.68           | 0.3183   | 0.399    | 0.192                            | 0.187                            | 0.002           | 0.153                            | 26             |
| 19        | 76.40        | 73.82           | 2.58     | 0.399    | 1.556                            | 1.617                            | 0.160           | 1.317                            | 20             |
| 20        | 68.47        | 66.64           | 1.83     | 0.278    | 1.008                            | 1.009                            | 0.039           | 0.626                            | 5              |
| 21        | 75.00        | 71.76           | 3.24     | 0.278    | 1.783                            | 1.895                            | 0.122           | 1.175                            | 27             |
| 22        | 56.90        | 55.86           | 1.04     | 0.399    | 0.627                            | 0.618                            | 0.026           | 0.503                            | 1              |
| 23        | 75.87        | 75.75           | 0.1216   | 0.278    | 0.067                            | 0.065                            | 0.000           | 0.041                            | 11             |
| 24        | 66.57        | 64.42           | 2.15     | 0.278    | 1.184                            | 1.197                            | 0.054           | 0.742                            | 21             |
| 25        | 57.50        | 60.30           | -2.80    | 0.399    | -1.691                           | -1.780                           | 0.189           | -1.449                           | 13             |
| 26        | 75.50        | 75.75           | -0.2451  | 0.278    | -0.135                           | -0.132                           | 0.001           | -0.082                           | 7              |
| 27        | 64.90        | 64.51           | 0.3859   | 0.399    | 0.233                            | 0.227                            | 0.004           | 0.185                            | 15             |
| 28        | 61.79        | 64.42           | -2.63    | 0.278    | -1.448                           | -1.492                           | 0.081           | -0.925                           | 10             |
| 29        | 69.40        | 67.38           | 2.02     | 0.399    | 1.221                            | 1.237                            | 0.099           | 1.007                            | 16             |
| 30        | 54.00        | 55.86           | -1.86    | 0.399    | -1.124                           | -1.132                           | 0.084           | -0.921                           | 19             |

## APPENDIX FIGURE

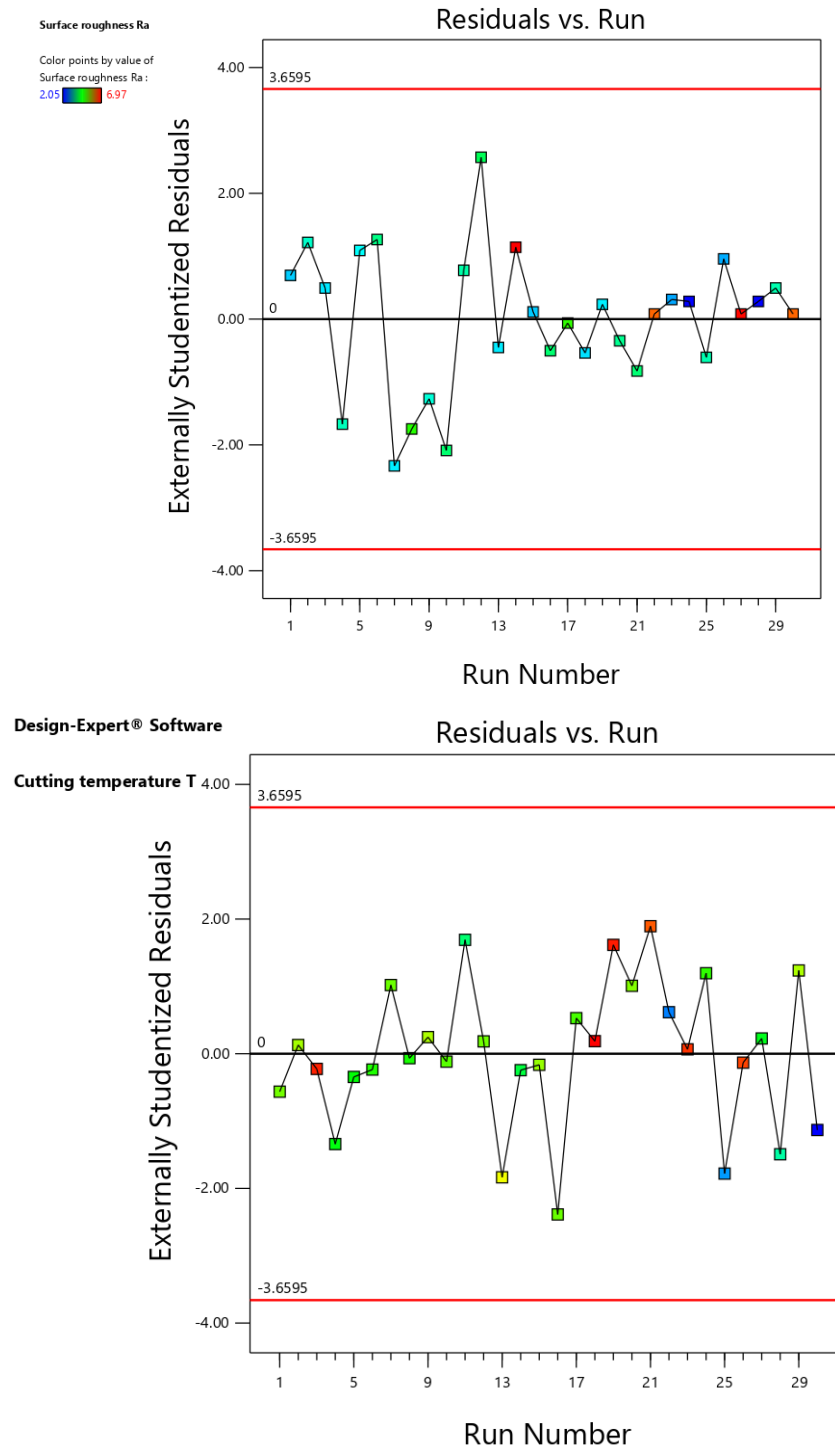


Figure App 1: The Residual versus Run plot for the surface roughness and cutting temperature

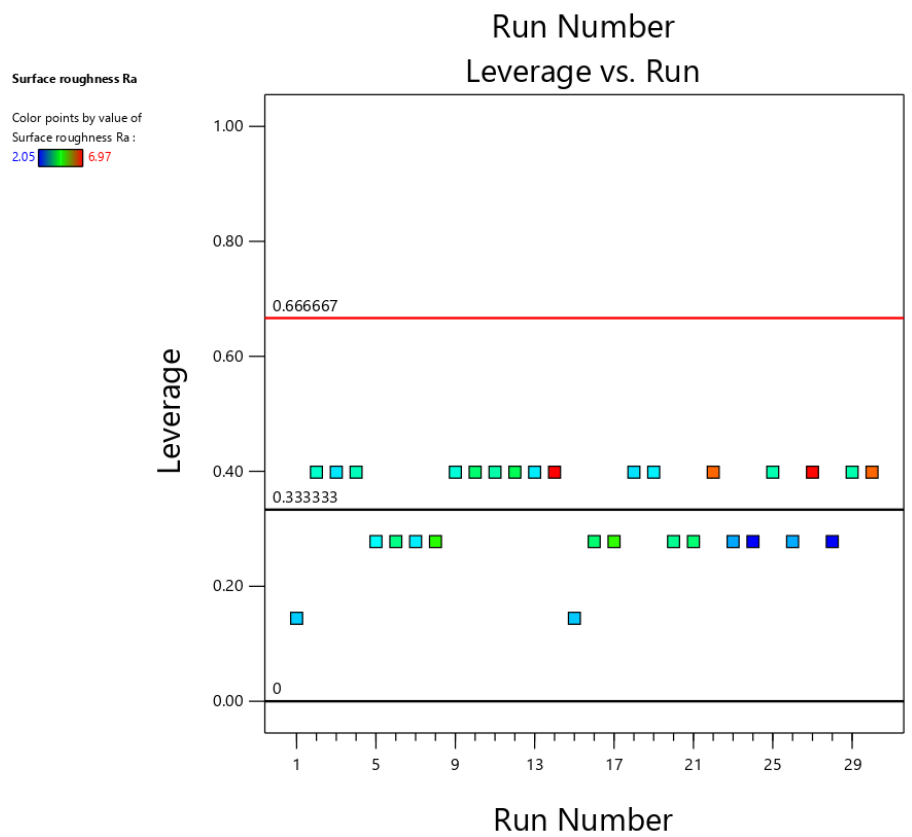
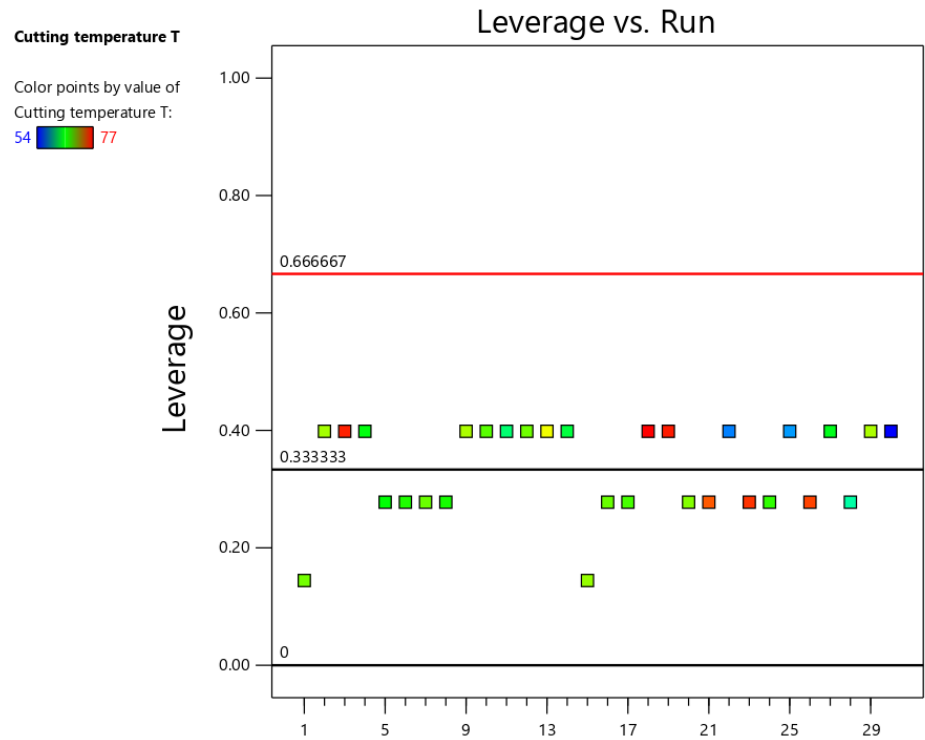


Figure App 2: The leverage versus run plot for the surface roughness and cutting temperature

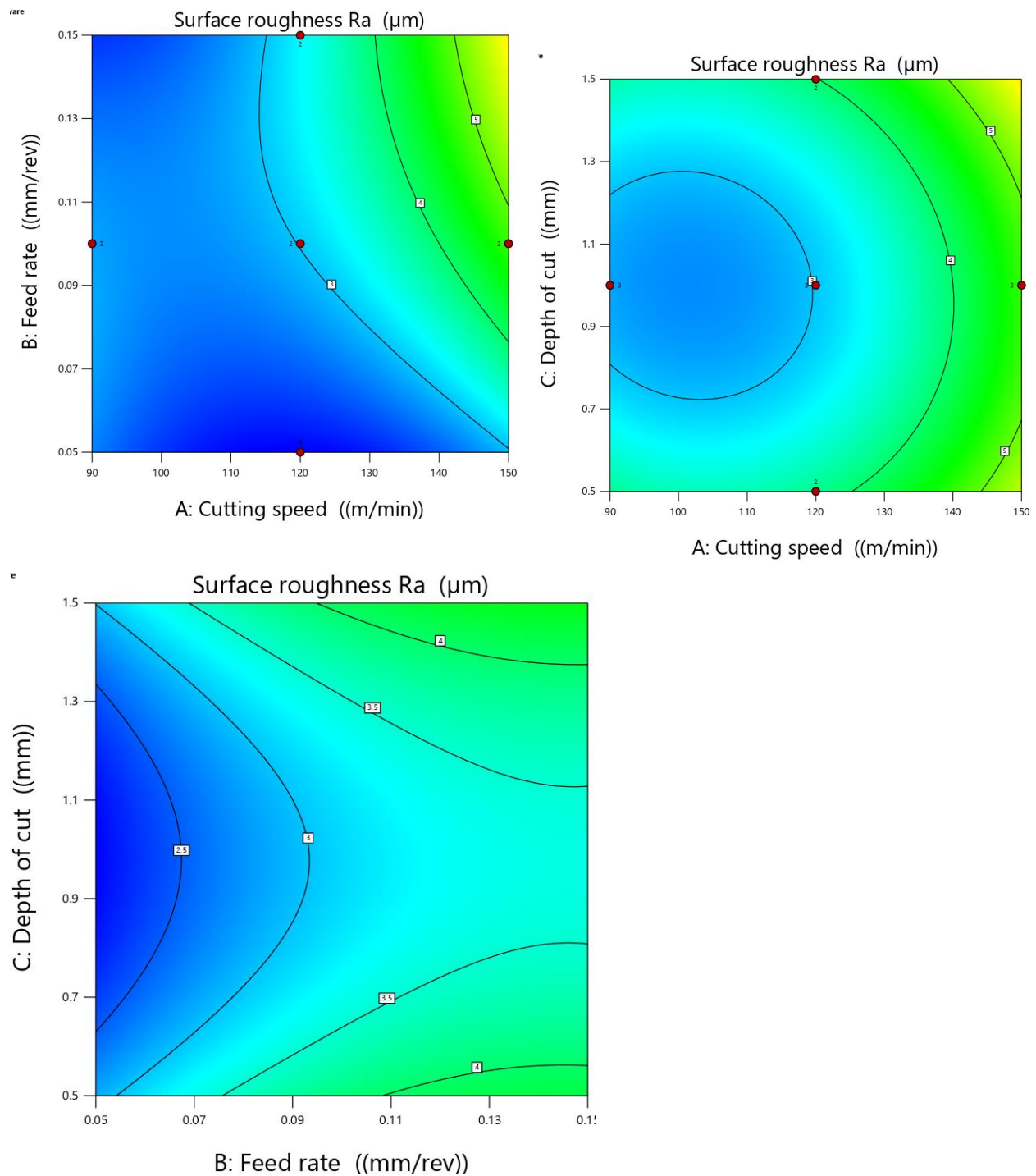


Figure App 3: The Contour plot for the interaction effect of the parameters on surface roughness

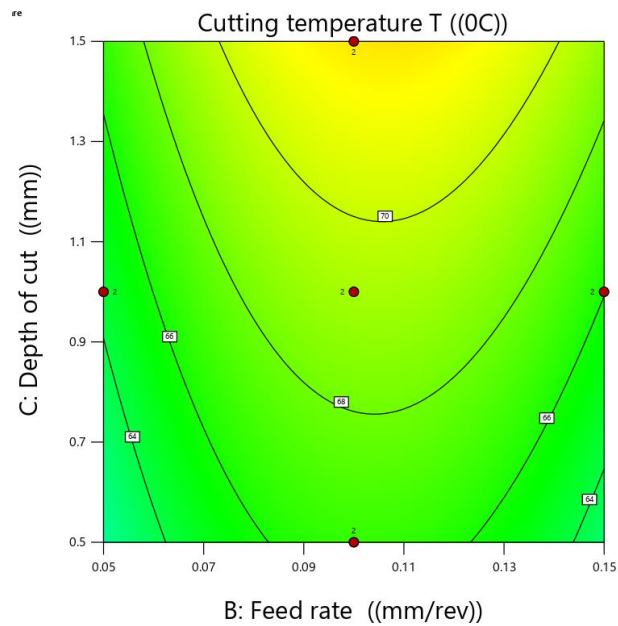
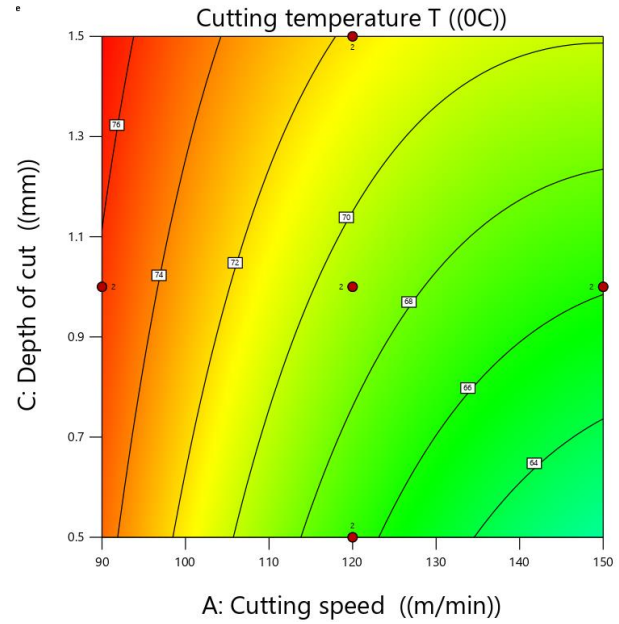
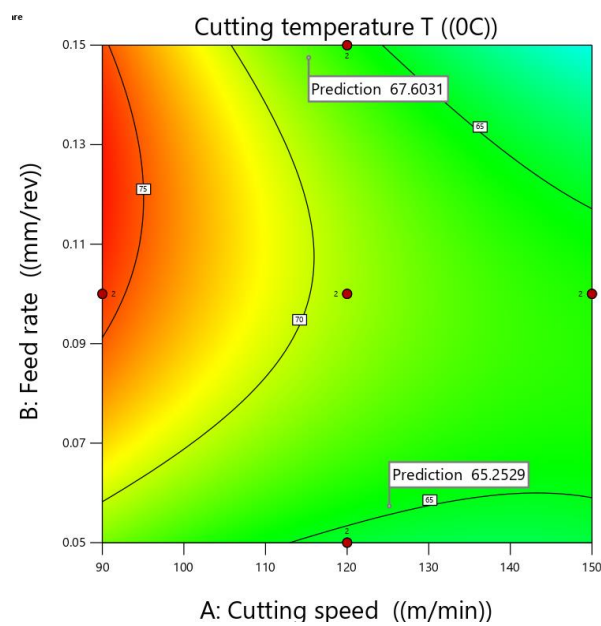


Figure App 4: The Contour plot of the effect of the cutting parameters on the cutting temperature

## Supplementary Files for assurance of materials purchased

|  |      | <b>COMPANY NAME</b><br>ADDIS MACHINE AND SPARE PART MANUFACTURING INDUSTRY |      |                      |              |                                      |            | <b>DOC.NO</b><br>.OF /AMSMI/OD/001 |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
|-----------------------------------------------------------------------------------|------|----------------------------------------------------------------------------|------|----------------------|--------------|--------------------------------------|------------|------------------------------------|---------------|-----------------------|-----------------|------------------------|--|---------------------------|--|-----------------------------------|--|------------|--|-------------|--|----------------|--|----------------------------|--|--|--|--|--|--|--|--|--|--|--|-------------------------|--|--|--|--|--|--|--|--|--|--|--|
| <b>TITLE</b><br>PART MANUFACTURING PROCESS DESCRIPTION FORM                       |      |                                                                            |      |                      |              |                                      |            |                                    |               |                       |                 | <b>ISSUE NO.</b><br>03 |  | <b>PAGE NO.</b><br>1 OF 2 |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
| <b>Part no.</b>                                                                   |      | <b>Order date 05/10/17</b>                                                 |      |                      |              | <b>Work dispatched date 05/10/17</b> |            |                                    |               | <b>CMF</b>            |                 | <b>PMF</b>             |  | <b>MTD</b>                |  | <b>MBF</b>                        |  | <b>BPF</b> |  | <b>MBSF</b> |  | <b>N&amp;B</b> |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
| v - Specify your factory in the above box                                         |      |                                                                            |      |                      |              |                                      |            |                                    |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
| <b>Job O. No.</b>                                                                 |      | <b>Ord. Qty.</b>                                                           |      | <b>DR.NO</b>         |              | <b>Production No.</b>                |            | <b>Cost Sheet No.</b>              |               | <b>Title of parts</b> |                 |                        |  |                           |  | <b>Customer</b><br>TESFAYE OLJIRA |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
|                                                                                   |      | 04                                                                         |      |                      |              | OPRN-1//17                           |            | OPRN-1//17                         |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
| <b>Material Code</b>                                                              |      |                                                                            |      | <b>Material type</b> |              |                                      |            | <b>Blank size</b>                  |               |                       |                 | <b>shaft</b>           |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
|                                                                                   |      |                                                                            |      | 12060                |              |                                      |            | Ø60x100mm                          |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
| S/N                                                                               | OPN. | Operation description                                                      | Feed | RPM                  | Planned time |                                      |            | Actual time                        | perform ed by | Tools used            | Measuring tools | Inspected by           |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
|                                                                                   |      |                                                                            |      |                      | Set up Time  | Mach. Time                           | Total Time |                                    |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
| 01                                                                                | PH   | -Cut the material to Ø60X100mm                                             |      |                      | 1hr          | 2.5hr                                | 3.5hr      |                                    |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
| 02                                                                                | L    | -Face the material to get datum surface.                                   | 0.5  | 500                  | 1hr          | 0.5hr                                | 0.5hr      |                                    |               | -F. cutter            | V. caliper      |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
|                                                                                   |      | ➤ Turn Ø51x90mm length.                                                    | 0.1  | 120                  |              | 0.5hr                                | 0.5hr      |                                    |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
|                                                                                   |      | ➤ Step turn Ø41x67.5mm length.                                             | 0.15 | 90                   |              | 0.5hr                                | 0.5hr      |                                    |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
|                                                                                   |      | ➤ Step turn Ø31x45mm length.                                               | 0.15 | 120                  |              | 0.5hr                                | 0.5hr      |                                    |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
|                                                                                   |      | ➤ Step turn Ø21x22.5mm length.                                             | 0.05 | 150                  |              | 0.5hr                                | 0.5hr      |                                    |               |                       |                 |                        |  |                           |  |                                   |  |            |  |             |  |                |  |                            |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
| Prepared by: - HABTAMU S.                                                         |      |                                                                            |      |                      |              |                                      |            |                                    |               |                       |                 | Checked by: - HABTAMU  |  |                           |  |                                   |  |            |  |             |  |                |  | Approve by: - SHEWATATK. T |  |  |  |  |  |  |  |  |  |  |  | Remark _____            |  |  |  |  |  |  |  |  |  |  |  |
| Signature                                                                         |      |                                                                            |      |                      |              |                                      |            |                                    |               |                       |                 | Signature              |  |                           |  |                                   |  |            |  |             |  |                |  | Signature                  |  |  |  |  |  |  |  |  |  |  |  |                         |  |  |  |  |  |  |  |  |  |  |  |
| Date: 05/10/2017                                                                  |      |                                                                            |      |                      |              |                                      |            |                                    |               |                       |                 | Date: 05/10/2017       |  |                           |  |                                   |  |            |  |             |  |                |  | Date: 05/10/2017           |  |  |  |  |  |  |  |  |  |  |  | Received by (PPC) _____ |  |  |  |  |  |  |  |  |  |  |  |





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Ethio-engineering Group  
Addis Machine and Spare Part Manufacturing Industry

ቁጥር ኢ.ግ/ኢ.ማ/መ/

ቀን 10/10/17

Date : 10/10/2017

Requested by: TESFA OLJIRA

Sample type: STEEL

Purpose: IDENTIFICATION

| S<br>/<br>N | Sample<br>Name         | Chemical Composition |      |      |       |      |      |        |       |      |       |      |        |
|-------------|------------------------|----------------------|------|------|-------|------|------|--------|-------|------|-------|------|--------|
|             |                        | C                    | Si   | Mn   | P     | S    | Cr   | Mo     | Ni    | Cu   | W     | Fe   | CSN    |
| 1           | Round bar<br>Ø60 small | 0.61                 | 0.15 | 0.65 | 0.058 | 0.12 | 0.12 | 0.003  | 0.051 | 0.10 | 0.040 | 98.1 | 1060   |
| 2           | Round bar<br>Ø60 big   | 0.58                 | 0.12 | 0.65 | 0.068 | 0.14 | 0.11 | 0.0030 | 0.047 | 0.10 | 0.040 | 98.2 | 12061* |

Prepared by: Aberu

Sign: [Signature]

Date: 10/10/17

Checked by: [Signature]

Sign: [Signature]

Date: 10/10/17

Approved by: [Signature]

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Date: 10/10/17



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