Experimental Investigation of Turning AISI 1045 Steel for Surface Roughness in Double Cutting Tool Using Taguchi Method

By:

Abreham Dereje Abebe

A Thesis Submitted to

The Department of Mechanical Design and Manufacturing Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Manufacturing Engineering

Office of Graduate Studies

Adama Science and Technology University

August, 2021

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DECLARATION

I hereby declare that this Master Thesis entitled "Experimental Investigation on the Turning of AISI 1045 Steel for Surface Roughness in Double Cutting Tool Using Taguchi Method" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Abreham Dereje Abebe	__________	___________ .
Candidate	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Experimental Investigation on the Turning of AISI 1045 Steel for Surface Roughness in Double Cutting Tool Using Taguchi Method" prepared under my guidance by Abreham Dereje Abebe submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Manufacturing Engineering.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Moera Gutu Jiru	____________	___________
Advisor	Signature	Date

APPROVAL SHEET

I, the advisors of the thesis entitled "Experimental Investigation on the Turning of AISI 1045 Steel for Surface Roughness in Double Cutting Tool Using Taguchi Method" and developed by Abreham Dereje Abebe, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Moera Gutu Jiru	___________	__________
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Abreham Dereje Abebe have read and evaluated the thesis entitled "Experimental Investigation on the Turning of AISI 1045 Steel for Surface Roughness in Double Cutting Tool Using Taguchi Method" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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ACRONYMS

AISI	American Iron and Steel Institute
ABMI	Akaki Basic Metals Industry
ASTM	American Society for Testing and Materials
ANOVA	Analysis of Variance
BS	British Standard
CBN	Cubic Boron Nitride
CNC	Computer Numerical Control
CVD	Chemical Vapor Deposition
DOE	Design of Experiment
DOF	Degree of Freedom
EN	European Numerous
ISO	International Standard Organization
JIS	Japanese Industrial Standard
HSS	High Speed Steel
HV	Vickers Hardness
HRC	Rockwell Hardness C- scale
MQL	Minimum Quantity Lubrication
MSS	Mean Sum of Square
MRR	Material Removal Rate
MWFs	Metal Working Fluids
OA	Orthogonal Array
RSM	Response Surface Methodology
SD	Standard Deviation
S/N	Signal to Noise Ratio
SST	Total Sum of Squares
SSTR	Treatment Sum of Squares

ABBREVIATIONS

d_1	Primary depth of cut
d_2	Secondary depth of cut
et al.	And others
f	Feed
l	Chips length
R_a	Average surface roughness
R_t	Highest peak to the deepest valley
R_z	Average height profile
Rq	Root mean square roughness
t	Chips thickness
V_c	Cutting speed
Z_a	Highest peak of surface roughness
Z_p	Deepest valley of surface roughness

ABSTRACT

The surface finish quality in turning is an important requirement to produce mechanical parts. Failure of engineering materials starts at the surface. Optimizing cutting parameters is very important to get high surface finish that reduce mechanical failures caused by wear, corrosion and increasing productivity of mechanical parts. In this research double tool turning on AISI 1045 steel material was conducted. Ceramic inserted cutting tool was used and comparison of dry and wet machining were investigated showing wet machining was effective to reduce surface roughness. In both cases investigation on surface finish and material removal rate was analyzed in detail. Tooltip temperature also analyzed during dry machining. Taguchi L9 orthogonal array design of the experiments was used to optimize cutting parameter. For both machining condition Analysis of Variance (AVOVA) was applied. Among cutting parameters; cutting speed was the most significant factor for improving surface roughness in both cutting conditions. The minimum surface roughness attained for optimum cutting parameter was 1.02µm in dry turning conditions and 0.81µm for wet turning conditions. The results showed that in wet machining, a maximum of 38.1 %, and a minimum 3.9 % reductions were investigated in surface roughness when compared with dry machining. This reveals that wet machining improved the surface finish during double tool turning operations. Material removal rate was high due to double tool turning implemented. It was obtained maximum material removal rate of 93.75mm^3/sec.

Keywords: AISI 1045 Steel, *Material Removal Rate, Surface Roughness, Taguchi Method.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Machining is a material removal process where a cutting tool made of a harder material than the workpiece in conventional machining process. Machining is not only performed for the overall forming of parts into their ultimate shapes, but also it is used to convert castings, forgings or preformed blocks of metal into desired shapes, with size and finish specified to fulfil design requirements. Machining plays an important role in the manufacturing process. It is perhaps most versatile in the manufacturing industry, in which desired components/parts are achieved through the removal of material in the form of chips (Venkata Vishnu et al., 2018). In metal cutting and manufacturing industries, surface finish and strength of product are very crucial in determining the surface finish that assures the quality of the product. The effect and optimization of machining parameters on surface roughness in a turning operation are investigated by using the Taguchi method (Sahithi et al., 2019).

Most of the machining operation operated by lathe machine the principles of working of a lathe is the metal cutting is carried out by creating relative motion between the workpiece and the cutting tool in which the workpiece is rotated and the cutting tool is made to move parallel to the axis of rotation of the workpiece. A lathe provides a variety of rotating speeds and a means a manually and automatically move the cutting tool into the workpiece to remove the excess material. In dry machining, the required surface quality and cutting tool life cannot be achieved due to high heat generation at the cutting zone, which affects the hardness and sharpness of the cutting tool (Rajasekaran et al., 2013). Turning operations on a lathe machine require two basic simultaneous motions; one motion creates cutting speed, and the other is the feed motion (Patokar et al., 2016)

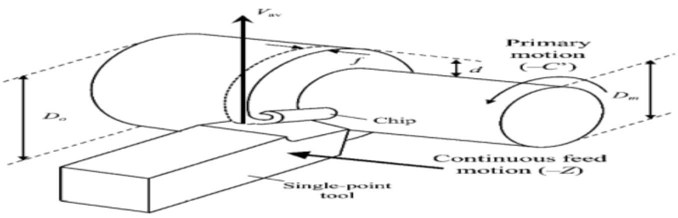


Figure 1.1 Turning operation (Patokar et al., 2016).

In general, turning refers to a class of processes carried out on a lathe. A brief outline of external straight turning processes are presented in the Figure 1.1. Different types of Turning Operations straight turning, Contour turning, Taper turning, form turning and boring (internal turning)

1.2. Concept of Double Cutting Tool Turning Operation

The concept of double cutting tool turning is to use two single point cutting tools rather than one for turning the same shaft. The second tool mounted on the additional tool post and the additional tool post is fitted on the same carriage and mounted on the same lead screw as the first one. Figure 1.2 below shows that the schematic representation of the two single cutting tools working simultaneously on a single workpiece. (Trikal et al., 2016).

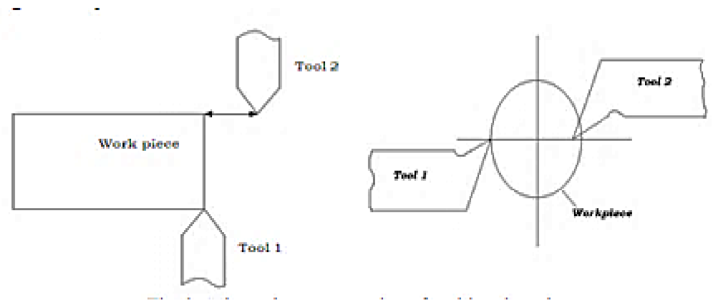


Figure 1.2 Schematic representation of double cutting tool

A double point cutting tool consists of two cutting tools that can simultaneously engage in cutting or shearing action at a time in a single pass. Contrary to this, a single point cutting tool contains only one main cutting edge and multi-point cutting tool contains more than one cutting edges for performing machining action in a single pass. The basic purpose of the secondary cutting tool is to perform a finish cut turning operation and shearing action at a time in a single pass.

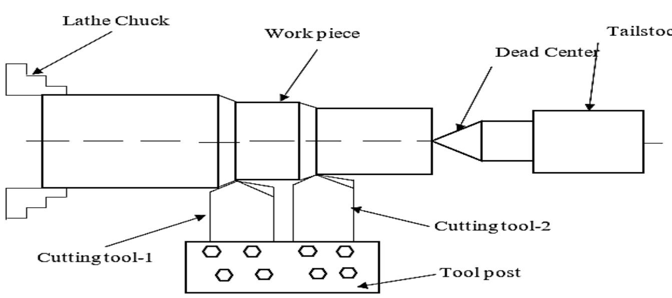


Figure 1.3 Double cutting tool on the same tool post

The double cutting tool process is advantageous compared to single-point cutting conventional turning in that it reduces the required number of passes, enhances the surface quality and, improves productivity, enhances the dynamic stability of the rotating work piece, and provides additional support to the work piece.

1.3. Overview of Surface Roughness

The principal form of surface roughness produced in a lathe is the cylindrical surface. In turning process, the workpiece is rotated while a cutting tool cuts the excess material when it is moved in a direction parallel to the axis of rotation. Surface roughness is the quantitative approach of determining the smoothness of a surface by measuring the height of peaks and depth of valleys over a fixed length and its important factor that determines the quality of a machined surface. The smoothness of a machined surface is determined by many factors such as cutting condition, machine tool vibration, cutting tool and work holding devices and cutting parameters. (Sarker et al., 2018).

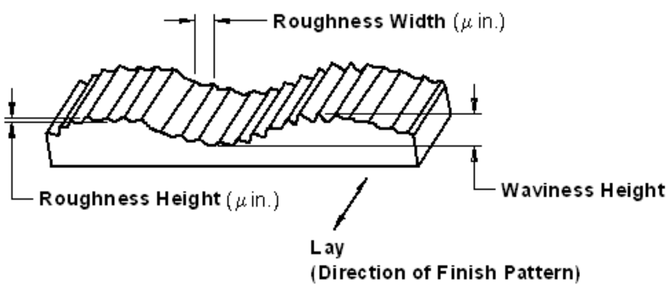


Figure 1.4 Surface roughness layout (Sarker et al., 2018).

Average surface roughness parameter (R_a) is calculated by measuring the average of surface heights and depths across the surface. This measurement is most commonly shown as "R_a" for "Roughness Average" and that value is used to determine compliance of equipment with various industry standards. (Sarker et al., 2018).

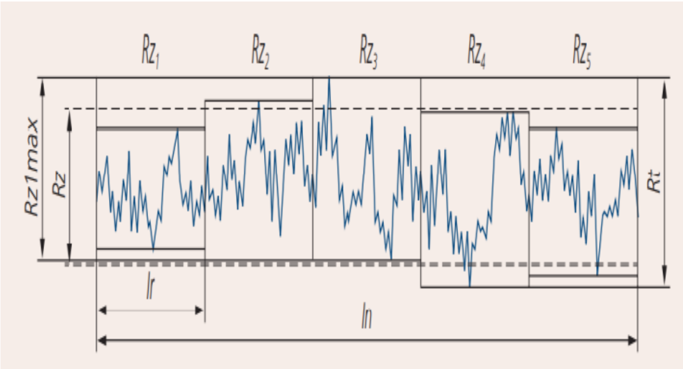


Figure 1.5 Surface roughness terminology (Sarker et al., 2018).

1.4. Research Motivation

The manufacturing of good quality of product in short lead time is the most important thing for customer satisfactions. It is difficult to discuss high production rate, long life of the product without defect, and mechanical properties of materials like (corrosion resistance, wear resistance) without surface quality. During machining operation, the machined surface quality is one of the most specified customer requirements and plays a vital role to increase the competitiveness among the manufacturers. In this aspect, a lot of research work has been done on the single tool turning process no more researches are done on multi-tool turning to reduce machining time during turning operations. Multi-tool turning process still needs to be further modifications. Using two cutting tools simultaneously improves the product quality and reduces lead time in turning operation. Surface roughness in multi- tool turning is an area that has received great attention despite its ability to produce a good surface finish in a short machining time. Therefore, the motivation for this work is mainly due to this reason.

1.5. Problem Statement

Machining is one method of producing parts that are applicable in many machinery components and industries. However, the problem of getting high surface finish, high production rate (material removal) and long tool life are a challenge for machining industries. Researchers are focusing on the techniques to improve surface finish and productivity. Since poor surface finish causes dimensional inaccuracy, less precision of surface finish, quick wear of parts, crack formation and propagation which causes final failure of the part. Controlling cutting parameters are a frequent problem since different work material, machining methods like double tool turning which is new research area are very important. Increasing depth of cut in the turning operation can improve productivity but there are problems in short tool life. Many attempts have been made in several different ways like optimizing the cutting parameters for minimize cost of production and maximize the production rate using single cutting tool turning. Researchers are focusing to solve such complexities on the multi cutting tool turning process to enhance the production rate by minimizing the machining time and maximize material removal rate at good surface finish. Therefore, taking cutting factors into consideration, AISI 1045 steel was used due to its application area that affected by tribological property like surface wear during the operations. Investigate effect of cutting parameters on surface finish, material removal rate and effect of cutting temperature generated during machining for both dry and with cutting fluid.

1.6. Research Question

Having all the above-mentioned facts about the machining process in the introductory part and statement of the problem, the following research questions are raised.

a. What is the optimum cutting parameters in the turning of AISI 1045 steel and what are the most significant cutting parameters during double cutting tool turning?
b. At what conditions the best surface quality achieved?
c. At what cutting parameters the optimum material removal rate has occurred during the double cutting tool turning of AISI 1045 steel that bridges the gap between productivity and quality is achieved?
d. What is the effect of cutting parameters on cutting temperature at the tooltip during dry machining conditions?
e. What does the chip morphology of AISI 1045 steel look like?

1.7. Objective

1.7.1. General Objective

The main objective of this research work is to investigate the impact of cutting parameters on surface finish, analyze significant of double tool turning, comparison of dry and wet machining on AISI 1045 steel using conventional lathe machine.

1.7.2. Specific Objectives

To achieve the above general objective, the following specific objectives are formulated:

1. To evaluate the influence of cutting parameters and determine the quality of surface finish during dry and wet double tool turning process.
2. Investigation of material removal rate at different cutting conditions.
3. Investigate effect of cutting temperature for different machining parameters.
4. To study chip morphology during turning of AISI 1045 Steel.

1.8. Significance of the Study

Double cutting tool turning is using two single cutting tools on the same tool post for the single workpiece and it is important to obtain better surface finish by optimizing the cutting parameters such as cutting speed, feed and depth of cut for both cutting tool, and also analysis material removal rate, cutting tool tip temperature, and chip morphology. The machining process of different workpiece materials largely depends on the performance of a cutting tool and cutting parameters. Therefore, studying the machinability of AISI 1045 materials and optimizing cutting parameters that affecting the surface quality is very important to manufacture products with high quality. Besides that, it is important in cost reduction, to reduce production time, for achieving good surface finish, increases the service life time of the product, enables customer satisfaction, increases the precision of the product, improves wear and corrosion-resistance of parts and increases market share. Furthermore, the study benefits the manufacturing industry (especially local industries like Akaki Basic Metals Industry and others machine shop industries).

1.9. Scope and Limitation of Studies

This study is limited to:

- ✓ The scope of this study highly focused on experimental analysis of cutting parameter for surface roughness during dry and wet turning of AISI 1045 steel by using a double cutting tool on the conventional lathe machine model of CM160
- ✓ Optimize and identifying the most significant cutting parameters at which better surface finish is achieved during double tool turning of AISI 1045 steel without considering cutting tool geometry were studied, because considering the simultaneous effect of cutting parameters and tool geometry is very complex.
- ✓ The effect of cutting force and machine vibration on the surface roughness was not included because of difficulties to measure cutting forces without dynamometer and difficulties to measure vibration frequencies.

1.10. Structure of the Thesis

The thesis consists of five chapters:

Chapter One:	Begins with an introduction and provides the background of the study, concept of double cutting tool turning, overview of surface roughness, research motivation, objectives, the problem of the statement, the significance of the study, scopes of the study and relevant literature are also enlightened.
Chapter Two	Is concerned with the literature review that is comprised of different researcher's work are revised that are related with machining operations. Finally, the summary of the literature and the research gap is described

Chapter Three	This chapter discusses the experimental details such as the materials used for the experiment, the experimental procedures, equipment used, and the methodology that achieved the objectives of this study are briefly explained.
Chapter Four	This chapter deal with the result and discussion of the experimental values. It analysis the effect of process parameters during double cutting tool turning on surface finish during dry and with cutting fluid machining conditions.
Chapter Five	Final chapter summarize and analyzed the experimental investigations during the study, proposed the recommendation and future work for further studies.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

This chapter discuses about the turning operation, turning parameter and the previous study that involved the optimization techniques. Here, the optimization technique, Taguchi method is reviewed to get a full understanding before applied to the study. The most emerging needs of the modern metal cutting operations are to increase the material removal rate with better surface finish and high machining accuracy. In metal cutting process, its effects are generally reduced by proper selection of process parameters. The selection of optimal cutting parameters is a very important issue for every machining process in order to enhance the quality of machined products, to reduce the machining costs and to increase the production rate. To overcome these problems, the researchers propose models that try to simulate the conditions during machining and establish cause and effect relationships between various factors and desired product characteristics. The presentation of each approach along with its advantages and disadvantages should help both the researchers and practitioners by providing compact yet adequate information so as to select the one that best suits their needs and specific requirements. In the following section, different papers focus on the turning operation and reveal different results which enhance to observed closeness in the results between experimental and predicted values in turning operation

2.2. Turning Operation

Competitive market demands efficient manufacturing with high quality, optimum manufacturing cost and environmental sustainability consideration. This is achieved by advanced engineering materials and automated machining. Machining processes, both conventional and advanced, are influenced by several factors including the cutting speed, depth of cut, feed rate, cutting fluid type, method of cooling the work piece, tool geometry, types of cutting tool and many more each of these factors influences the material removal rate and surface quality of the product, determined by certain surface characterization parameters such as average surface roughness and texture. With the challenges presented on processing hard-to-machine materials, it is necessary to determine the best machining parameters to optimize production (Angwenyi et al., 2021). In this study, a focused overview of some of the reported literature on conventional machining operations has been presented.

A conventional center lathe has been slightly modified to mount the second cutting tool on the tool holder. The multi-tool turning method plays a significant role to improve the production rate of turning operation without reducing the surface finish of the component. The multi-tool turning method can give an approximately double production rate than Conventional turning of the single cutting tool as several passes required for the multi tool turning method is exactly half than the conventional turning single cutting tool method. In another case of Multi-tool turning, a better surface finish is obtained than the conventional turning job as Ra value (Average Distance between the highest peak and lowest valley in its sampling plane) is higher for the conventionally turned job (Trikal et al., 2016). In manufacturing sector turning is the most common process used to remove material from cylindrical workpiece & produce a smooth surface finish on the workpiece. In the turning process, material removal rate & surface roughness are the important performance characteristics to be considered which is affected by several factors such as spindle speed, cutting tool material, feed rate, depth of cut, nose radius cutting tool, coolant and work material characteristics. Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helical tool path by moving more or less linearly while the work piece rotates. The cutting of faces on the work piece (that is, surfaces perpendicular to its rotating axis), whether with a turning or boring tool, is called “facing”, and may be lumped into either category as a subset (Bhushan et al., 2010).

2.3. Surface Roughness

Surface roughness is a vital measure of the quality of machined part it may influence the failure of surface or life of machined components. As far as turned components are concerned, a better surface finish (low surface roughness value) is important as it can reduce or even eliminate the need of further machining. Surface roughness has bearing on heat transmission, ability to hold lubricant, surface friction, wearing. Even though surface roughness plays a very important role in the utility and life of a machined component due to its dependence on several process parameters and numerous uncontrollable factors, the machining process has no complete control over surface finish (Dhar et al., 2007). The venture of controlling process parameters to produce the best surface finish is an ongoing process varying from various materials to tool combinations and the machining conditions. The surface finish of any given part is measured in terms of average heights and depths of peaks and valleys on the surface of the work piece. The surface roughness of EN31 steel increases with the increase in feed for all the different values of cutting speed and depth of cut. Therefore, feed is the most influencing and dominant parameter for the improvement of surface roughness (Karthik et al., 2020). It depicts that speed is the major dominating turning parameter for the roughness of the surface machined and the second influenced parameter is the depth of cut. Feed rate is found to be the least influencing parameter with only a small contribution towards surface roughness during turning of heat treated steel. So surface finish degrades with increasing the level of turning parameters by increasing the cutting speed, the surface roughness increases and the surface finish starts to degrade. A very rough surface is generated as increase the cutting speed to higher levels. In the case of feed rate, it also affects the surface roughness similarly (Shahid, 2020).

Surface integrity encompasses all of the elements that describe all conditions of the existing solid surface which is produced by different machining processes. It describes not only the topological (geometric) features of surfaces and their physical and chemical properties, but also their mechanical and metallurgical properties and characteristics. Every surface generation or modification process is associated with the alteration of various properties including roughness, plastic deformation, micro-cracking, phase transformations, micro-hardness, and residual stress. Several surface defects produced and caused by different factors during turning operation can be responsible for inadequate surface integrity. These defects usually are caused by one or a combination of the following factors as defects in the original material, the method by which the surface is produced, and improper control of the process parameters (Ahmed Al-Dolaimy, 2016). Smoothness of a surface is determined by the surface finish. It indirectly indicates the height and depth of asperities of the solid surface. No surface is perfectly smooth; even if it is perfectly smooth, it cannot be determined as every measuring instrument has a range of its capability. High surface finish is required in the following fields; optics and electronics (lenses, mirrors), medical instruments, micro fluid (nozzle, channel, mixture), and material properties with high fatigue life, wear resistance (Rajasekaran et al., 2013).

High surface roughness value result in poor surface finish, the low fatigue life of a machined component (Sharma et al., 2008). Finally, the developed equation for modelling surface roughness as: -

$$\text{Ra} = \frac{f^2}{32re} \quad (2.1)$$

where Ra = Surface roughness (µm).

f = feed rate (mm/rev$\frac{f^2}{32re}$), and

Re = tool nose radius (mm).

The surface roughness is significantly affected by workpiece hardness, cutting edge geometry, feed rate and cutting speed (Ozel et al., 2004).

2.4. Surface Integrity

Surface integrity is an enhanced condition of a surface produced in a machining or other surface generating condition that describes a geometric feature of surface, physical properties, chemical properties, mechanical properties (residual stress, hardness etc.), metallurgical properties (microstructure, phase transformation etc.) and topological properties (surface roughness). The processes of enhancing surface integrity are such as strain hardening of surface, the introduction of compressive residual stress can increase fatigue life. Every surface generation or modification process is associated with the alteration of various properties including roughness, plastic deformation, micro-cracking, phase transformations, micro-hardness, and residual stress (Rech and Moisan, 2003).

2.5. Cutting Fluid

Metal cutting fluid or lubricant is used in finishing operations of the high-speed machining process to reduce the rate of tool wear, which in turn will improve surface quality. The reduction in the friction at the cutting zone by cryogenic coolant resulted in the formation of a smooth chip underside surface (Chan & Xu, 2015). Machining under flooded conditions is found to be better than dry and MQL(Minimum Quantity of Lubricant) condition, but the very small difference in the results are observed between MQL and flooded condition, hence it can be stated that MQL is advantageous compared to Flooded as we are reducing the flow of lubricant in terms of milliliter(ml) to liters on the other hand, the use of MQL and cryogenic cooling condition resulted in a very smooth surface free from surface irregularities (Chetan et al.,2019). Analysis of Variance (ANOVA) suggests that the selected factors are found to be significant and the corresponding interactions between type of lubrication conditions with cutting speed (rpm), feed rate (mm/rev), depth of cut (mm) and type of tool coated are also found to be significant. It is also concluded that the effect of lubrication condition is more followed by the depth of cut, feed rate, type of tool and cutting speed for cutting temperature (Vishnu et al., 2018). Due to high cutting speed and high contact pressure between the tool and the workpiece, the coolant cannot penetrate the cutting zone.

Hard turning is dependent on the induced heat softening of the material in the chip shear zone and hence efficient cooling can make the cutting less efficient. Cutting conditions are important parameters to achieve the desired productivity, accuracy of the work pieces, and surface quality of the workpiece (Karthik et al., 2020).

2.6. Studies on Material Removal Rate

From the cutting parameters feed rate is the most crucial factor for material removal rate with a high contribution while the depth of cut is the second most dominating parameter. It is also observed that cutting speed is the least influencing parameter for MRR (Material Removal Rare) and its contributes is very small. While considering feed rate and depth of cut, steep lines are observed. The MRR is majorly influenced by these two turning parameters as analyzed by ANOVA. As the cutting parameters increase, the material is removed at a faster rate and hence MRR increases (Shahid, 2020).

2.7. Studies on Tooltip Temperature

The investigation of cutting temperature during machining is extremely valuable to address metal cutting issues such as dimensional accuracy, surface finish and tool life (Chinchanikar & Choudhury, 2014). During metal cutting operations generated heat at the cutting zone has a strong influence on the tool wear, affects workpiece surface quality, produces hot chips that cause safety hazards to the machine operator, and can cause inaccuracies in work part dimensions due to thermal expansion of the work material. There are three main zones in the cutting region. They are primary, secondary, and tertiary shear deformation zones. The heat generated in the primary shear deformation zone is due to the plastic deformation of the work material (El-Wardany et al., 1996). The friction between the rake face of the cutting tool and chip causes heat generation in the secondary shear deformation zone whereas the friction between the tool flank and the machined surface causes heat generation in the tertiary shear deformation zone. Higher cutting temperature adversely affects the tool life, decreases the wear resistance and hardness of the cutting tool, which causes poor surface finish and dimensional inaccuracy of the machined surface. Therefore, it is important to maintain a lower cutting temperature during the machining process. The cutting temperatures are measured by thermocouples, radiation pyrometers, and thermal paints. Thermocouple measures the average temperature of the contact area between the cutting tool and work material. On the other hand, the embedded thermocouple measures the temperature of a particular point in the cutting zone. The radiation pyrometers technique uses radiation to measure the cutting zone temperature. The advantages of radiation pyrometers are faster response time and no physical contact with the heat source. One main disadvantage of this method is that it is limited to accessible surfaces only (Kalidasan et al., 2016).

The effect of temperature on machining of steel and major heat source in turning was investigated. According to conducted studies during machining of materials the following heat was generated (Sharma et al., 2008).

- ✓ Heat due to internal friction of metal in deformation (Q_{def})
- ✓ Heat due to external friction of the chip at the cutters front surface ($Q_{f \cdot fr}$)
- ✓ Heat due to external friction of the cutting surface and the machined surface ($Q_{r.fr}$,)
- ✓ Heat liberated as a result of chip breakaway and dispersion (Q_{disp})

The total heat formed while cutting of hard materials is mathematically expressed as

$$Q = Q_{def} + Q_{r.fr} + Q_{f \cdot fr} + Q_{disp} \quad (2.2)$$

When the mechanical work is completely converted into heat, resulting heat may be written as

$$Q = (R/E) = P_{zv}\,(1/E) \quad (2.3)$$

where Pz R= work of cutting

Pz= component of cutting force along the axis

V = cutting speed, and

E= mechanical equivalent of heat =427 $\frac{kgfm}{kca}$

In real situation all work of cutting will not convert to heat, meaning only some partial of work goes to heat and expressed as

$$Q = P_z v \alpha_o /427 \qquad \text{where } \alpha_0 \text{= is takes account of loss.} \quad (2.4)$$

2.8. Studies on Chip Formation

Chip formation and effective chip removal are important in those cutting techniques in which the cutting zone is spatially limited, such as drilling, reaming, milling and all turning operations on automatic lathes. During the machining process, the cutting tool penetrates the work material, which deforms first elastically and then plastically. Generally, four main types of chips can be formed: continuous chips, continuous segmented chips, semi-continuous segmented chips, and discontinuous chips. Continuous chips form when the material being cut flows away continuously from the machining point. The regions of deformed material undergo lamellar sliding but without exceeding the shear strength of the material. If the work material being machined is of sufficient ductility, the chip formed will usually be continuous in form, provided that the cutting process is not impaired by the influence of external vibrations. If the workpiece material is of lower ductility, if it has an inhomogeneous microstructure or if it is subjected to external vibrations, machining will result in the formation of continuous segmented (or serrated) chips. Continuous segmented (or serrated) chips can form at high feed rates and high cutting speeds. Semi-continuous segmented (or serrated) chips, on the other hand, consist of chip sections that were completely separated in the shear zone. Discontinuous chips typically form when brittle materials with an inhomogeneous microstructure are machined (Mia et al., 2018). Fig. 2.1. below illustrate the different types of chips produced during hard turning experiments

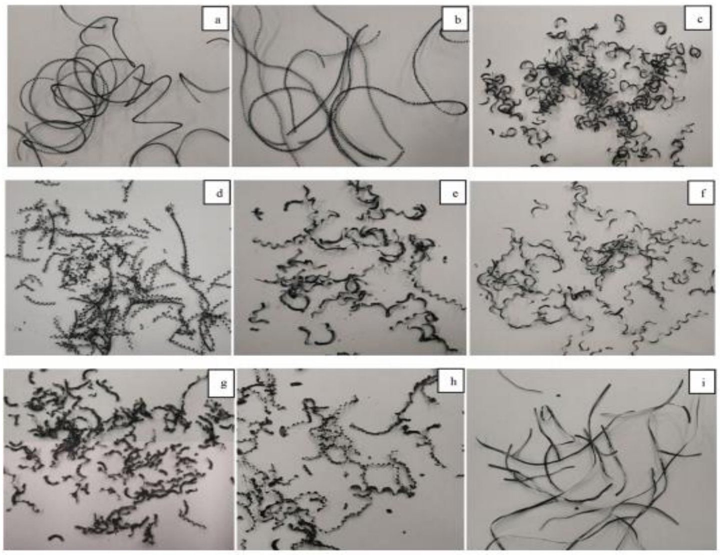


Figure 2.1 Chip morphology during turning operations (Mia et al., 2018).

The hardness-based flow stress and fracture models for numerical simulation of hard machining based on the stress model for the AISI 52100 bearing steel and fracture criteria was predicted.

The finding predicted that the change in chip morphology from continuous to segmented chip takes place as the hardness value change. During the machining of hard materials sticking friction occurs at cutting edge contacting with chip and the frictional shearing stress τ equal to average shear flow stress limit τ_{crit}. while sliding friction occurs far away from the area cutting edge contacting with a chip, the frictional stress calculated by friction coefficient μ (Zhang et al., 2011). They expressed mathematically as: -

$$\tau = \mu\sigma \text{ when } \mu\sigma < \tau_{crit} \text{ (in sliding area).} \quad (2.5)$$

$$\tau = \tau_{crit} \text{ when } \mu\sigma \geq \tau_{crit} \text{ (in sticking area).} \quad (2.6)$$

The shear stress limit (τ_{crit}) is estimated as (δy/3), δy yield stress of materials.

2.9. Design of Experiment

Taguchi method is one of the important tools used in the industry to shortage product design, develop time and produce lower product costs. Taguchi's method also takes into consideration the effect of uncontrollable factors on the response. This method is also highly flexible and can allocate different levels of factors, even when the numbers of the levels of factors are not the same. In the Taguchi approach, optimization, data analysis and the prediction of the optimum results are provided by the objective function, which is called signal to noise ratio (S/N). Signal factors represent system control inputs. Noise factors represent variables, which are expensive or difficult to control. The S/N ratios generally used are: the nominal the better, the-lower-the-better and the-larger-the-better. Different parameters affect the response to a different degree. Using analysis of variance (ANOVA) the relative effect of the different parameters is determined. S/N ratio and ANOVA provide determining of the optimum cutting parameters for the response. Finally, confirmation tests are recommended in the Taguchi method to verify the effectiveness and efficiency of the Taguchi method in optimizing the parameters (Krishnaiah & Shahabudeen, 2012). The Taguchi method involves reducing the variation in a process through the robust design of experiments and developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. Taguchi-based orthogonal array has the property of reducing the number of experiments without affecting the outcome significantly (Mia et al., 2018).

2.10. Machining Operation Under Different Conditions.

Sutter et al. (2003) In this study an experimental technique for the measurement of temperature fields for the orthogonal cutting in high-speed machining cutting temperature and heat generated at the tool-chip interface during high-speed machining operations have been recognized as major factors that influence tool performance and workpiece geometry or properties The technique of temperature measurement was developed on the principle of pyrometer in the visible spectral range by using an intensified CCD (Charge Coupled Device) camera with very short exposure time and interference filter at 0.8 μm. Temperature gradients were obtained in an area close to the cutting edge of the tool, along the secondary shear zone. Effects of the cutting speed and the chip thickness on the temperature profile in the chip were determined. Maximum chip temperature of about 82.5 °C was found, for cutting speed close to 20 m/s, located at a distance of 300 μm of the tool tip.

Dhar et al. (2007) investigated experimentally the effect of minimum quantity lubrication in machining AISI 1040 steel. This study compares the mechanical performance of MQL to completely dry lubrication for the turning of AISI 1040 steel based on experimental measurement of cutting temperature, chip reduction coefficient, cutting forces, tool wears surface finish and dimensional deviation. Results indicated that the use of near dry lubrication leads to lower cutting temperature and cutting force, favorable chip–tool interaction, reduced tool wears surface roughness and dimensional deviation. Minimum quantity lubrication enabled a sizeable reduction in the cutting zone temperature and favorable change in the chip tool and work tool interactions, which helped in reducing friction, built-up edge formation, thermal distortion of the work, and wear of the cutting tool. MQL reduced the cutting forces by about 5–15%.

Cakir et al. (2007) In this work presented the effects of cutting parameters (cutting speed, feed rate, and depth of cut) onto the surface roughness through the mathematical model developed by using the data gathered from a series of turning experiments performed. Two types of inserts Insert -1 (CVD coated (TiCN + Al2O3 + TiN)) and Insert -2 (PVD coated (TiAlN)) having the same geometry and substrate but different coating layers were used in the experiments and the effects of two coating layers as well as the cutting parameters onto the surface roughness were investigated. Total average errors of 4.2% and 5.2%, respectively, for Insert 1 and Insert 2, indicate the reliability of the surface roughness model generated. And among the cutting parameters, feed rate has the greatest influence, followed by cutting speed. Higher feed rates lead to higher surface roughness values, whereas cutting speed has a contrary effect and cutting depth has no significant effect. Considering the dissimilar behaviors of the two insert types against cutting speed, another study can be carried out concerning the tool life.

Bhushan et al. (2010) In this study, investigate the influence of cutting speed, depth of cut, and feed rate on surface roughness during machining of 7075 Al alloy and 10 wt.% SiC particulate metal matrix composites. The experiments were conducted on a (Computer Numerical Control) CNC turning machine using tungsten carbide and polycrystalline diamond (PCD) inserts. Surface roughness of 7075Al alloy with 10 wt.% SiC composite during machining by tungsten carbide tool was found to be lower in the feed range of 0.1 to

0.3 mm/rev and depth of cut (DOC) range of 0.5 to 1.5 mm as compared to surface roughness at other process parameters considered. Above cutting speed of 220 m/min surface roughness of SiC composite during machining by PCD tool was less as compared to surface roughness at other values of cutting speed considered. Wear of tungsten carbide and PCD inserts was analyzed using a metallurgical microscope and scanning electron microscope. Flanks wear of carbide tool increased by a factor of 2.4 with the increase of cutting speed from 180 to 240 m/min at a feed of 0.1 mm/rev and a DOC of 0.5 mm. On the other hand, flanks wear of PCD insert increased by only a factor of 1.3 with the increase of cutting speed from 180 to 240 m/min at a feed of 0.1 mm/rev and Depth of Cut (DOC) 0.5 mm.

Karthik et al. (2020) optimize cutting parameters for surface roughness during dry hard turning of EN 31 bearing steel using (Cubic Boron Nitride) CBN insert The hard-turning experiments were done for EN31steel bearing bush using CBN inserts. The effect of the cutting parameters on the surface roughness was studied and optimum cutting conditions were obtained. The conclusions are based on the Taguchi design of experiments and ANOVA. The surface roughness of EN31 steel increases with the increase in feed for all the different values of cutting speed and depth of cut. Therefore, feed is the most influencing and dominant parameter for the improvement of surface roughness. Optimum cutting parameters for achieving the minimum surface roughness were obtained from the Taguchi L9 Orthogonal array and main effect plots and they are cutting speed(v) = 100 m/min, Feed(f) = 0.04 mm/rev and Depth of cut(d) = 0.2 mm.

Sahijpaul (2013) Determining the Influence of various cutting parameters on surface roughness during wet CNC turning of AISI 1040 medium carbon steel. The purpose of this experimental investigation was to analyze the effect of controlled cutting parameters namely cutting speed, feed rate, depth of cut, cutting fluid concentration and two cutting fluids with different base oils on surface roughness (Ra) of EN8 or AISI 1040 steel during turning operation by applying design of experiments, custom design method, analysis of variance, leverage plots and desirability profiling using JMP software to optimize surface roughness during wet CNC turning operation. The analysis reveals that feed rate has the most significant effect on surface roughness (Ra) and the value of surface roughness does not significantly differ for two different cutting fluids used.

Singh et al. (2013) In this work experimental study investigates the effects of cutting parameters like spindle speed, feed and depth of cut on the hardness of EN-9. The relationship between cutting parameters (cutting speed, depth of cut, feed) and the performance measures (work-piece surface temperature) are expressed by the performance level for any parameter levels. The significant parameters for work-piece surface temperature were cutting speed, depth of cut and feed in which feed having the highest rank so find out that feed having the most effective parameter. Surface temperature is maximum i.e. 38.20^{o}C, when we have taken rpm (388), depth of cut (0.50 mm) and feed (0.9 mm), which is worthless. The significant parameters for optimum work-piece surface temperature are rpm (239), depth of cut (0.25 mm) and feed (1mm)

Deiab et al. (2014) In this analysis of lubrication strategies for sustainable machining during turning of Titanium Ti-6Al-4V alloy. Techniques like dry and cryogenic machining, minimum quantity lubrication (MQL) and minimum quantity cooled lubrication (MQCL) have also been proposed. The current study investigates the effect of six different strategies on the flank tool wear, surface roughness, and energy consumption during turning of titanium Ti-6Al-4V using uncoated carbide tool at a certain speed and feed. The use of rapeseed vegetable oil in MQL configuration turns out to be an overall sustainable alternative.

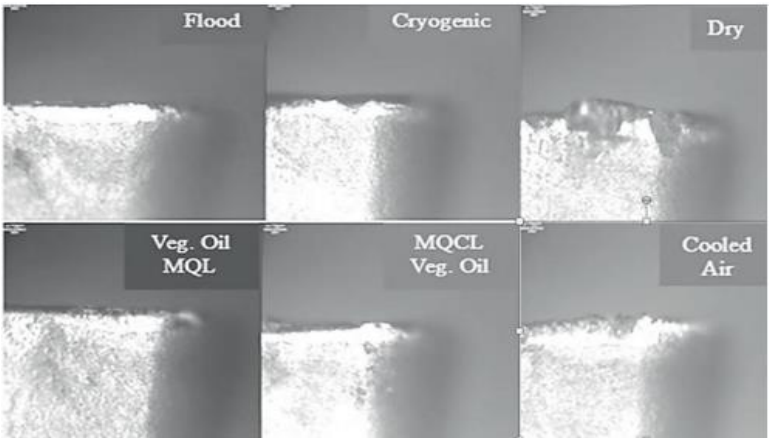


Figure 2.2 Flank tool wear at feed=0.1 mm/rev and speed = 90 m/min

Revankar et al. (2014) in this study investigate the difficulty of machining under different machining conditions. Taguchi technique has been employed and the optimization results indicated that MQL lubricating mode with cutting speed of 150 m/min, feed rate of 0.15 mm/rev, nose radius of 0.6 mm and 0.25 mm depth of cut is necessary to minimize surface roughness and dry mode with cutting speed of 150 m/min, feed rate of 0.15 mm/rev, nose radius of 0.6 mm and 0.75 mm depth of cut is necessary to maximize surface hardness. The results indicate the substantial benefit of the minimum quantity of lubrication (MQL) and justify PCD inserts to be the most functionally satisfactory commercially available cutting tool material for machining titanium alloys for better surface finish and hardness.

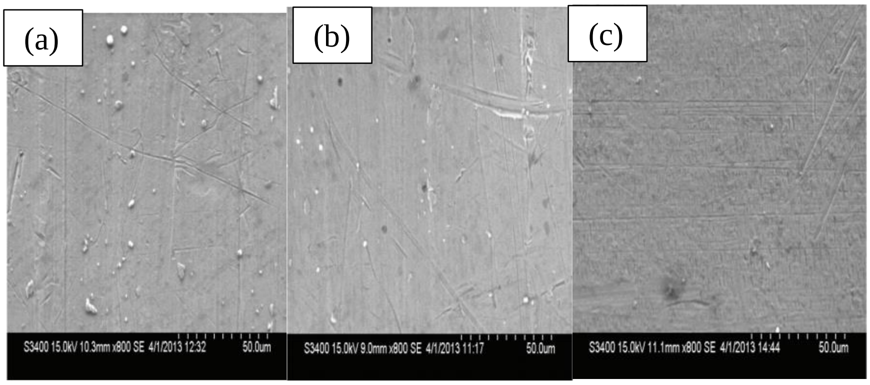


Figure 2.3 Surface generated under different machining conditions

Figure 2.3 (a) Surface generated during machining of titanium alloy (Ti-6Al-4V) with PCD insert under dry mode (cutting speed: 50 m/min, feed: 0.35 mm/rev, nose radius: 0.4 mm and depth of cut 0.25 mm). Figure 2.3 (b) Surface generated during machining of titanium alloy (Ti-6Al-4V) with PCD insert under flood lubrication (cutting speed: 150 m/min, feed: 0.35 mm/rev, nose radius: 0.6 mm, and depth of cut: 0.25 mm). Figure 2.3 (c) Surface generated during machining of titanium alloy (Ti-6Al-4V) with PCD insert under MQL condition (cutting speed: 150 m/min, feed: 0.15 mm/rev, nose radius: 0.4 mm, and depth of cut: 0.5 mm).

Bhushan et al. (2010) experimental investigation on influence of varying nozzle stand-off distance and pressure on surface roughness and cutting temperature in turning of EN31 steel (hardened) using minimum quantity lubrication. this paper presents a review on the influence of varying nozzle stand-off distance and cutting fluid pressure on surface roughness and cutting temperature in turning of EN 31 steel (hardened) using the minimum fluid application using regression analysis and mathematical modeling approach. In addition, ANOVA will be performed to find out the significant parameters using the statistical design of experiments. MQL provided better performance in turning hardened EN 31 steel at different nozzle distances, cutting speed and coolant pressure for responses like surface roughness and cutting temperature. It is observed that nozzle stand-off distance is found to be the most significant parameter of two, the cutting speed was found next significant parameter compared to coolant pressure. It is observed that the minimum surface finish obtained in hard turning of hardened EN31is 0.467 μm. optimum parameters for surface roughness are 20 mm nozzle distance, 2400rpm and 4.5 bar pressure.

Trikal el at. (2016) evaluation of surface roughness of mild steel component turned using multi-tool turning method. After the study has been made the authors reach the following conclusion - multi-tool turning method play a significant role to improve the production rate of turning operation without reducing the surface finish of the component and better surface finish is obtained than single point conventional turning job as surface roughness (Ra) value.

Siva Surya et al. (2017) multi-response optimization on EN19 steel using grey relational analysis through dry & wet machining. the paper aims to optimize the multi-response objectives (material removal rate and surface roughness) while machining EN19 steel using grey relational Analysis. Cutting speed, feed rate and depth of cut are the process parameters affecting material removal rate (MRR) and surface finish. The Minitab software is used to form the design of experiments with L9 orthogonal array. The influence of the cutting parameters on dry machining and wet machining is known through rankings. The ranks are obtained by following the analysis procedure. For dry machining the spindle speed has more influence as it is ranked one, the next most influential parameter resulted is feed rate and depth of cut is ranked third. For wet machining, it is found that the depth of cut has more influence as it is ranked one; the next most influential parameter resulted is spindle speed and further, feed rate which has ranked third.

Venkata Vishnu et al. (2018) Comparison among dry, flooded and MQL conditions in machining of EN353 steel alloys-an experimental investigation. This paper deals with the turning of EN 353 steel alloy under different lubrication conditions i.e. Dry Machining, Flooded and MQL conditions. From the experimental results, it is concluded that the optimal and best combination for minimizing cutting temperature from the present investigations are cutting speed at 1100 rpm, feed rate at 0.2 mm/rev, depth of cut at 0.5 mm and PVD coated tool. Machining under flooded conditions is found to be better than dry and MQL conditions, but very small differences in the results are observed between MQL and Flooded conditions, hence it can be stated that MQL is advantageous compared to Flooded as reducing the flow of lubricant in terms of milliliter(ml) to liters.

Singh et al. (2018) Optimization of machining process parameters in conventional turning operation of Al5083/B4C composite under dry condition. Experiments are performed on Al5083 metal matrix composite reinforcement of 7%B4C. The turning process is carried out by using High Speed Steel (HSS) single-point cutting tool under dry conditions. In the present experiment the turning parameters such as cutting speed, feed rate and depth of cut are being optimized by considering the constant length of material being machined. The experiments conducted as per L25 orthogonal array (OA) and their result are used to develop a linear regression model. The investigation shows that material removal rate (MRR) increases with increases in speed and depth of cut and shows the intermittent effect with an increase in feed rate. Surface roughness increases with an increase in depth of cut and feed rate and shows the intermittent effect with speed. Change in temperature increases with increase in speed and depth of cut and shows the intermittent effect with feed rate.

Chetan et al. (2019) Comparison between sustainable cryogenic techniques and nano-MQL cooling mode in turning of nickel-based alloy. In the present work, techniques such as cryogenic cooling and cryogenic treatment have been compared with Al_2O_3 nanoparticles-based MQL cooling method (nMQL) in turning of the nickel-based Nimonic 90 alloy. The machining of nickel-based alloy has been carried out using the AlTiN coated tungsten carbide inserts of different nose radii. The effects of these cutting environments have been studied by comparing the tool wear, cutting forces, work surface defects, surface finish, and chip underside surfaces. The application of liquid nitrogen as a cooling medium significantly reduced the tool flank wear of the 0.2 mm nose radius insert by 38% as compared to MQL technique.

Gupta et al. (2019) Assessment of machining parameters on EN 24 steel under dry, wet and MQL conditions using multi-coated inserts. In this experiment, a minimum quantity lubrication setup on a turning machine was designed and developed for comparison between dry and wet conditions and their effects are considered under different parameters. The design of the experiment was enacted on Taguchi's orthogonal array L9 to optimize the selected process parameters during turning of EN-24 under different conditions. The Grey relational method was also applied for optimizing purposes. The optimum conditions include a cut 0.6 mm deep, a nose radius of 0.8mm and a cutting speed of 575 rpm and the depth of cut was found out to be a most dominant parameter. MQL shows better results in terms of surface roughness as compared to dry and wet conditions.

Syed Irfan et al. (2019) Optimization of machining parameters in CNC turning of en45 by Taguchi's orthogonal array experiments. In this study, the Taguchi method and regression analysis has been used to optimize the machining parameters during the CNC turning of EN-45 spring steel by a plain carbide cutting tool. Experiments were designed and conducted by L18- orthogonal array. The surface roughness and material removal rate were optimized by considering cutting speed, feed rate and depth of cut as machining parameters. The ANOVA was obtained using Minitab 17 statistical software. A comparison between dry and wet machining is done after the ANOVA and regression analysis. For surface roughness, the speed and feed was directly proportional while DOC is inversely proportional. i.e.; with an increase in DOC, Ra decreases. In the case of MRR, all three parameters were found to be proportional, i.e.; with the increase in speed, feed and DOC the MRR increased.

Shahid (2020) Optimization of turning process parameters in machining heat treated steel. In the present work, an experimental approach on turning studies the process parameters that are affecting the machining performance and productivity of Plain Turning. The design of experiments is based on Taguchi's L9 orthogonal array. The machining parameters are Speed, Feed Rate and Depth of Cut, which is optimized for maximum material removal rate (MRR) and minimum Surface Roughness during turning of Heat Treated Steel (EN-9). It shows that feed is the most crucial factor for material removal rate with a contribution of 40.99% while the depth of cut is the second most dominating parameter with a contribution of 36.90%. It is also observed that cutting speed is the least influencing parameter for MRR and contributes only 11.40% towards it. It depicts that speed is the major dominating turning parameter for the roughness of the surface machined and contributes 54.87%. It is followed by depth of cut with a contribution of 35.80%. Feed rate is found to be the least influencing parameter with only 5.38% contribution towards surface roughness.

2.11. Research Gap

After reviewing recent published works on double tool turning, there found gaps which addresses the significant of double tool turning. As observed from literature, limited work has been carried out on the effect of machining parameters on surface roughness using double tool turning process. Some research works were carried out on a single cutting tool machining. The effects of cutting parameters, tool geometry, tool materials, cutting fluid on the surface quality of the machined part, machinability aspects, and improving productivity using single cutting tool were conducted by few researchers. There is a research gap on double tool turning and its parameters which this work is tried to fill the gap. Limited research work experimentally conducted to obtain optimum machining conditions for AISI 1045 steel during double cutting tool turning process. Studying the combined effect of cutting parameters under dry and wet machining condition was the main focus of this research work. The literature survey on the single tool turning process helps in setting the research direction for the multi-tool turning process. Identifying the optimum cutting parameters at which surface finish is good and material removal rate is high to bridge the gap between quality and productivity in turning of AISI 1045 steel by using double cutting tool turning process under dry and wet machining condition.

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

3.1. Introduction

Literature survey was helped in the proper selection of workpiece material, process parameters, research methodology, cutting conditions, and machine tool. In this study, the experiments are carried out using a proper selection of orthogonal array considering the cutting parameters i.e. cutting speed, feed and depth of cut. under dry and wet machining conditions for AISI 1045 steel double tool turning operations by using a conventional lathe machine tool model of CM 260.

3.2. Experimental Procedure

The figure 3.1 shows a general stage for studies of an experimental investigation of dry and wet machining conditions in the double cutting tool turning process.

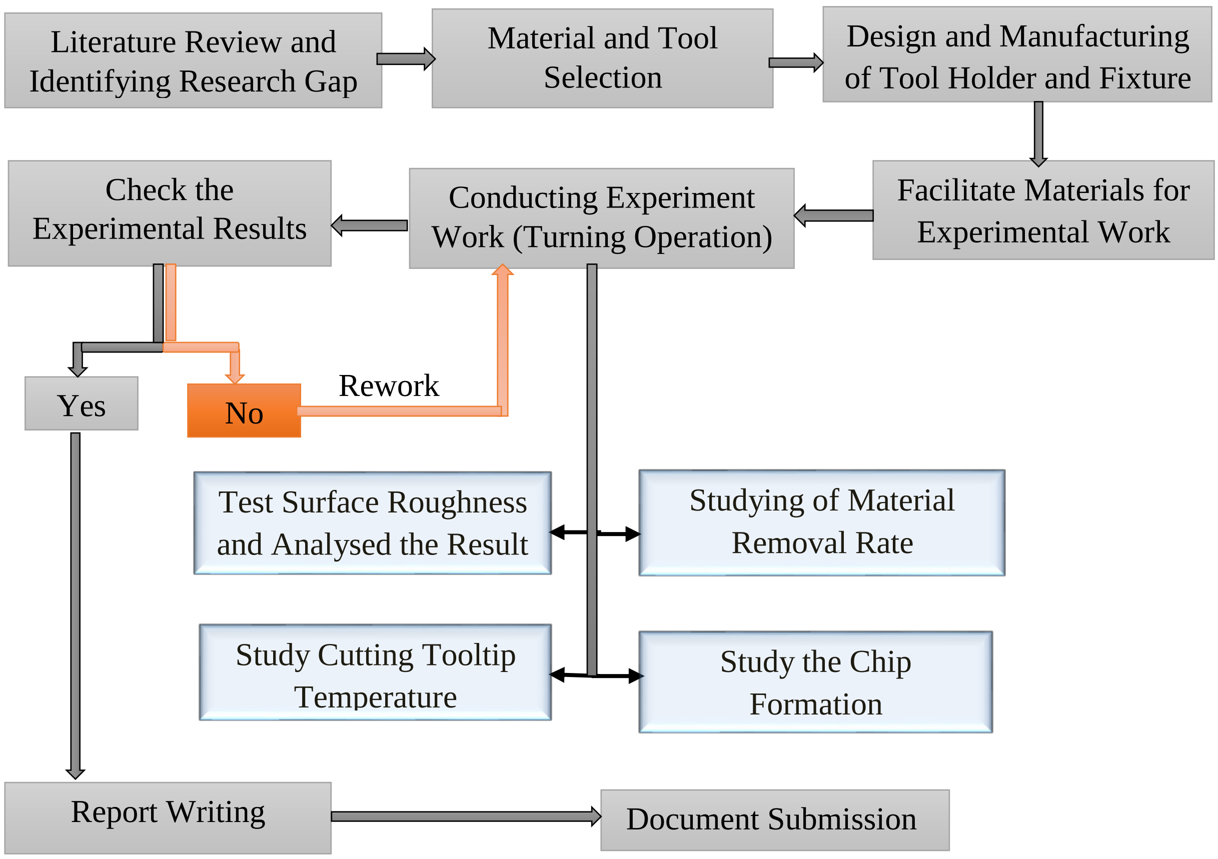


Figure 3.1 Flow chart for experimental work

3.3. Tool Fixture Designing and Manufacturing

The tooling fixture used in this experiment was manufactured from (66cm*83.5cm*117cm) stock size high carbon steel by using vertical milling machine model of WM 50 used to mount the lathe's tool post firmly. The tooling fixture features are grooved section with a 32cm*60cm dimension and M10 hole on the top side plate with an equal distance between them for mounting the cutting tool.

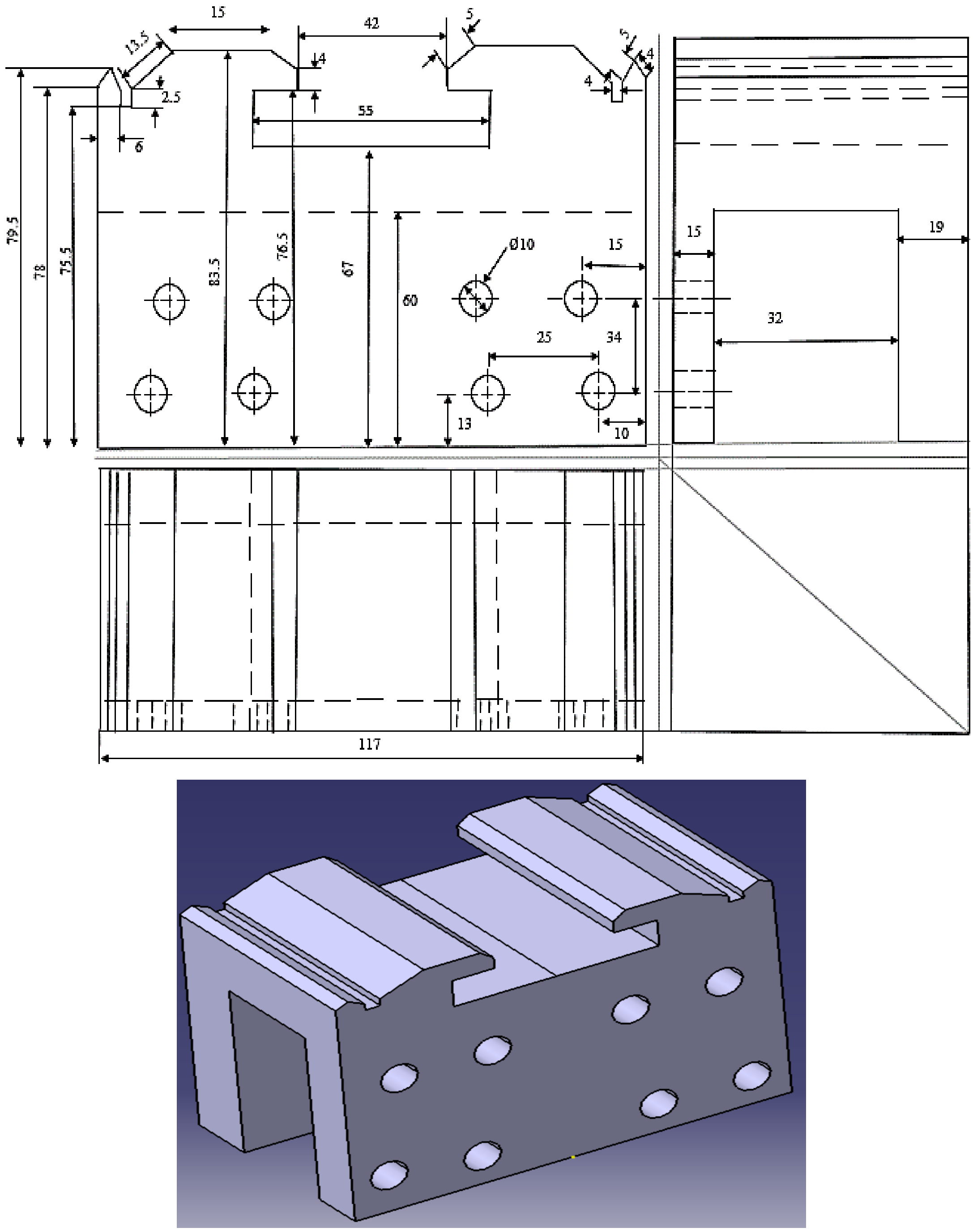


Figure 3.2 Detailed multiview drawing and isometric view of the tool holder

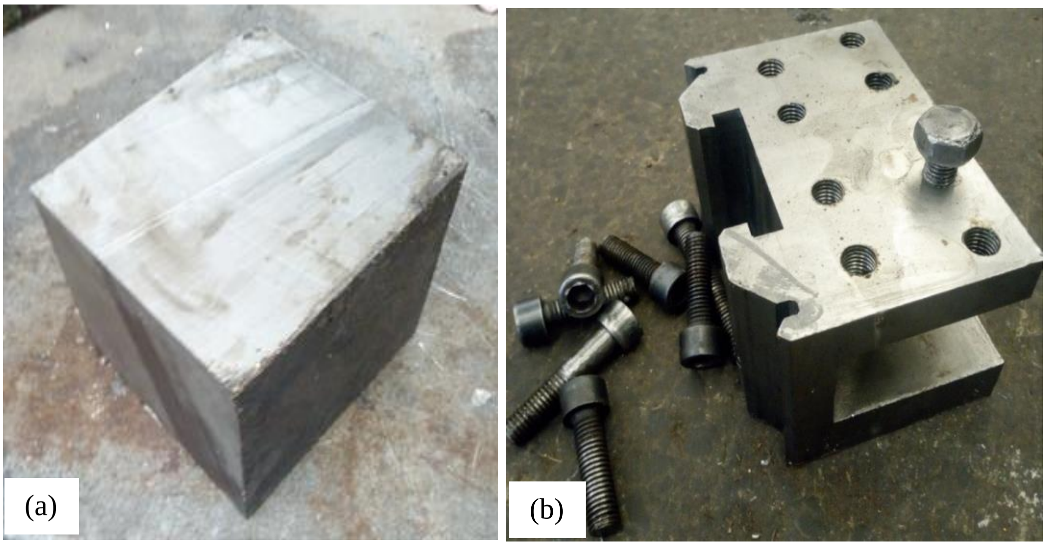


Figure 3.3 Photo of the cutting tool holder (a) stock part and (b) machined part

3.4. Materials and Machine Tools

This sub-topic describes the materials and machine tools used for the experimental investigation on the double turning of AISI 1045 steel under dry and with cutting fluid cutting conditions.

3.4.1. Workpiece Material

The workpiece material employed in this experiment was AISI 1045 steel, used for double tool turning operations at different cutting parameters during dry and with cutting fluid machining conditions in the conventional lathe machine. AISI 1045 steel is in the form of a round bar with 40mm in diameter, 500mm long and hardness of 55HRC (Rockwell hardness) was chosen. AISI 1045 steel was used for experimental study due to its applications in automotive, crankshafts, spindles, connecting rods, pump, gear, shafts, bolts, axels, pulley, driving pinion and as well as many applications in general mechanical engineering. AISI 1045 material was high tensile strength, good abrasion resistance, mechanical strength and widely employed in the industry.

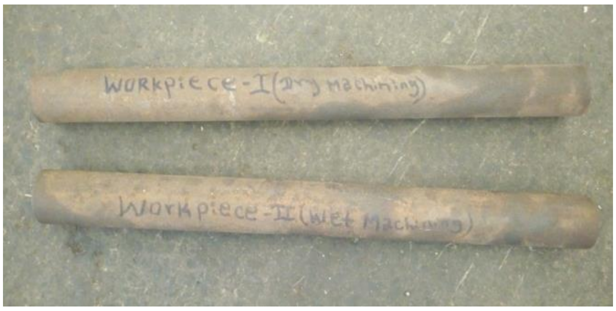


Figure 3.4 AISI 1045 steel used for experimental study

As observed from spectrometer testing in weight percentage. The specific chemical composition of AISI 1045 steel used for experimental study is shows in Table 3.1.

Table 3.1: Chemical composition of AISI 1045 steel.

Contents	C	Mn	S	P	Si	Ni	Cr
Weight percentage	0.45	0.60	0.009	0.011	0.30	0.08	0.07

3.4.2. Cutting Tool Materials

The cutting tool must be harder than the metal to be cut or workpiece material based on this ceramic insert cutting tool is used as an experimental tool for the machining of AISI 1045 steel at different cutting parameters. Therefore in this study, the ceramic tool is used for investigation because of their excellent properties such as producing good surface finish, economical nature, fracture strength, high hot hardness, high melting point, good chemical inertness, chemical stability at elevated temperature, thermal shock resistance, high stability against abrasive particle, high resistance to mechanical stress, ability to maintain its shape at elevated cutting temperature, wear resistance with a wide range of high-speed (Pradee et al., 2018). For the present study, the cutting tool used Al_2O_3–TiC ceramic insert containing 77% Al_2O_3, 21% TiC, and 2% other material was used with ISO (International Organization for Standardization). The specification of ceramics insert is TNGA160408 with tool holder of MTJNR2020M10. According to the orthogonal rake system of tool geometry definition, the used tool insert possessed -6°, -6°,6°,6°,30°,0°, and 0.8mm tool signature. These values are for inclination angle, orthogonal rake angle, orthogonal clearance of the principal flank, auxiliary orthogonal clearance, auxiliary cutting-edge angle, principal cutting-edge angle and nose radius of tool insert, respectively.

Figure 3.5 Ceramics cutting tool insert

3.4.3. Cutting Fluids

Metalworking fluids (MWFs) are part of a large family of lubricants. Until recently MWFs were among the least expensive components in metal cutting manufacture, because recycling processes for these fluids were not associated with high costs. However, this situation is changing rapidly. Modern MWFs for metal cutting are complex mixes of a number of different components, each of which fulfils specific functions (Astakhov & Joksch, 2012). Cutting fluids are chosen based on the type of machining process, the type of machined workpiece material, and the type of cutting tool material. In this experimental investigation used Aquatex 3180 cutting fluid. Aquatex 3180 is a general purpose water soluble oil, formulated for use in a wide variety of machining operations.

A 10% of Aquatex 3180 cutting fluid mixed with 90% of water and used for experimental work of double tool turning process.

Figure 3.6 Aquatex 3180 cutting fluid

3.4.4. Lathe Machine

The double tool turning operations was conducted mainly on conventional lathe machine, model of CM160 powered by a 7.5KW motor with spindle speed range of 36 up to 1600 rpm. The general view of the machine is given in Table 3.7

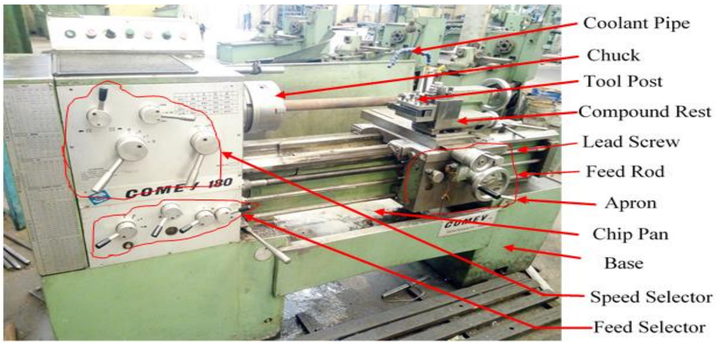


Figure 3.7 Conventional lathe machine used for experimental study

3.4.5. Thermocouple

In this study a contact-type thermocouple thermometer device consisting of sensor metals was used for the temperature sensing at the cutting tool insert end.

Figure 3.8 Thermocouple temperature tester

3.4.6. Profilometer

The equipment used to measure the surface roughness was a contact type Model 657111, reading distance range was 0.6mm and maximum measuring range was 10μm. surface roughness (R_a) data were taken at three different locations, 120^o from each other .

Figure 3.9 Surface roughness tester device

3.4.7. Spectrometers

Optical Emission Spectroscopy (OES) analysis, is a rapid method for determining the elemental composition of a variety of metals and alloys. For testing chemical composition of AISI 1045 steel material was used SPECTROTEST TXC02 model machine.

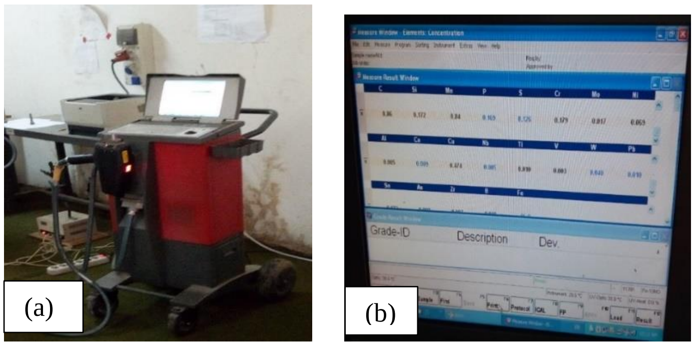


Figure 3.10 Spectrometer (a) machine tool, (b) result display window

3.4.8. Experimental Setup

The experiments study had performed in a conventional lathe machine COMEV CM 260 model was used and the cutting tool used was ceramics inserted double tool cutters, both cutting tools were secured in the cutting tool holder that modified for two cutting tools. According to the process parameter design conducted experimental work at Akaki Basic Metals Industry (ABMI)

Figure 3.11 is shows that the clamped AISI 1045 steel workpiece material diameter of 40mm and 500mm length used for experimental study and double cutting tool holder was mounted on double tool holder.

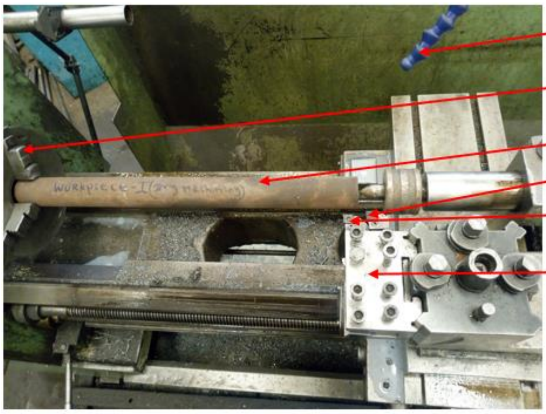


Figure 3.11 Machine tool setup for experimental study.

3.5. Research Methodology

In Research methodology, the materials mentioned above through the following method the experimental work had proceeded.

3.5.1. Specimen Preparation for Turning Operation

The workpiece material used for this study was AISI 1045 steel, which, is highly used in the applications of bolts, nuts, gears, pinions, high-speed screw machine parts. AISI 1045 steel of 500mm in length and 40mm in diameter was prepared for both dry and wet machining conditions under double tool turning process.

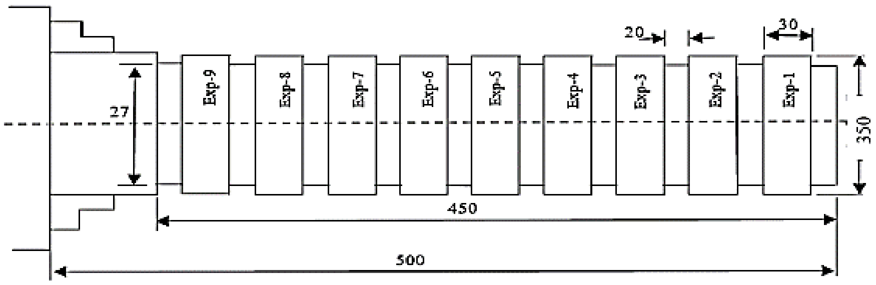
Figure 3.12 AISI 1045 steel material

3.5.2. Process Plan for Experimental Turning Operation

As shown Table 3.2 process route was prepared for experimental study of AISI 1045 steel on a conventional lathe machine. Factors such as the condition of the cutting tool bit, the rigidity of the machine, types of workpiece and cutting parameters (cutting speed, feed and depth of cut) are affect the type of surface finish produced. For both dry and wet cutting conditions using the same workpiece material and cutting parameters such as cutting speed, feed, first depth of cut and second depth of cut for both dry and wet experimental study. Table 3.2 shows that the route sheet of turning operation of the AISI 1045 steel in double cutting tool during dry and wet machining conditions in the experimental studies (All dimensions are in mm).

Table 3.2: Process route sheet for double tool turning of AISI 1045 steel

Process Route Sheet:-Akaki Basic Metals Industry Machine Shop



Material: AISA 1045 Steel**, Stock Size:** Ø40mm and 500mm long**, Note:** for both dry and wet machining operation are used the same process route with new ceramics inserted cutting tool for each experimental work.

No	Operation Description	Machine	Tooling
10	Cut off the blank Ø40, length 500mm	Hack Saw	Hack Saw
20	Face at the right side of the workpiece	Lathe machine model CM160	Carbide inserted cutting tool
30	Make a center at right end side.	Lathe machine model CM160	Center drill Ø5mm, with 60^o,

40	Clamp 500mm long, support with tailstock, center and turn from Ø40mm to Ø35mm, length 450mm from right-hand to left, then stop the lathe and measure the diameter with caliper 0.02mm accuracy.	Lathe machine model CM160	Carbide Inserted tool
50	Groove from Ø35mm to Ø32mm, from length of 0mm to 20mm, 50mm to 70mm, 100mm to 120mm, 150mm to170mm, 200mm to 220mm, 250 to 270mm, 300mm to 320, 350mm to 370mm, and 400mm to 420mm from right side to left and measure the diameter with caliper 0.02mm accuracy.	Lathe machine model CM160	Carbide tailstock center inserted tool
60	Set cutting parameters (Speed of cut, feed, first and second depth of cut) based on the given experimental design to operate nine turning operations under dry and wet machining conditions	Lathe machine model CM160	Two Ceramic Inserted tools, tailstock center
70	Finally check the machined surface diameter with caliper 0.02mm accuracy and stop the operation		

3.5.3. Design of Experiment

Taguchi's which is one of the Design of Experiment (DOE) applications are used to analyze the effect of multitudinous parameters and their comportment by performing a minimum number of experimentations and observing their effect on a specific behavior. It can conjointly determine the optimum condition for the experiment to give a better result. As stated by Taguchi it has three major phases and is planning, conducting and analysis. The optimized parameters are determined by the Signal to Noise ratio (Krishnaiah & Shahabudeen, 2012). In this process, four parameters such as cutting speed, feed, first and second depth of cut were considered. In the Taguchi DOE concept, the preference of orthogonal array depends on the total degrees of freedom of the process parameters. Degree of freedom is accounted or defined as the number of comparisons in between the parameters required to optimize each parameter (factor) with the selected levels. The experimental design of process parameters and numerical analysis is done by the Minitab 17 statistical software with four factors and three levels of the experiment.

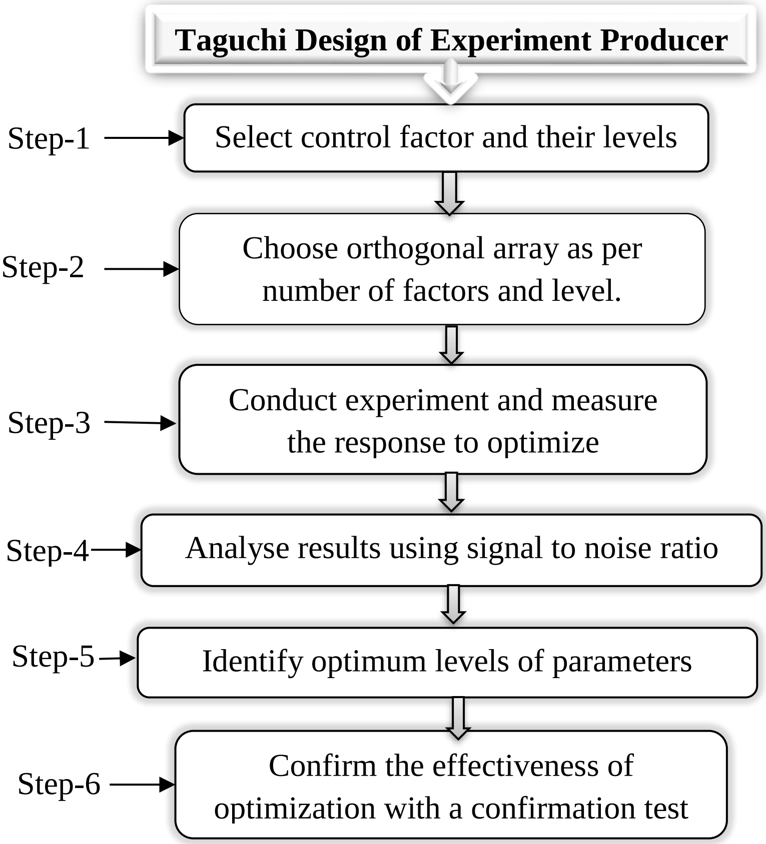


Figure 3.13 Design producer of Taguchi methods

One of the important task is to select the cutting parameters for the investigations of experimental study. This experimental investigation was evaluated the effect of the cutting parameters on surface roughness, cutting tool temperature and material removal rate at three levels of study during double tool turning of AISI 1045 steel. For experimentation purposes, selected cutting parameters such as cutting speed, feed, and depth of cut for both cutters. These cutting parameters were selected depending on knowledge found as mentioned previews based on the revised literature, according to the recommendations of tool manufacturer, current industrial practice specially at Akaki Basic Metals Industry

Table 3.3: List of process parameters and their levels

Cutting Parameters (Factors)	Level 1	Level 2	Level 3
A - Cutting speed (m/min)	90	120	150
B - Feed (mm/rev)	0.05	0.10	0.15
C – First depth of cut (mm)	0.15	0.20	0.25
D – Second depth of cut (mm)	0.05	0.10	0.15

3.5.4. Selection of the Orthogonal Array

Before selecting the orthogonal array, the minimum number of experiments to be conducted shall be fixed based on the total number of degrees of freedom. The minimum number of experiments that must be run to study the factors shall be more than the total degrees of freedom available (Krishnaiah & Shahabudeen, 2012). In this study, the selection of a particular orthogonal array was based on the number of levels of various factors. Here, to conduct the experiments four factors each at three levels were selected these parameters are given in Table 3.3.

$$DOF=P^{*} (L-1) \quad (3.1)$$

Where, DOF= degree of freedom,

P = number of factors and,

L = number of levels

$$DOF= 4(3 – 1) = 8 \approx L9.$$

The Degree of Freedom (DOF) was calculated then selected the number of experimental run from orthogonal array. Total number of the experiment of the orthogonal array (OA) should be greater than or equal to the calculated value, so due to this selected L9 orthogonal array for the design of the experiment. Thus L9 orthogonal array design by Minitab 17 statistical software was shown in Table 3.4 and this array specifies nine experiments.

Table 3.4: The experimental design of the cutting parameters

No	Cutting parameters			
	Cutting speed(mm/rev)	Feed (mm/rev)	First depth of cut(mm)	Second depth of cut(mm)
1	90	0.05	0.15	0.05
2	90	0.10	0.20	0.10
3	90	0.15	0.25	0.15
4	120	0.05	0.20	0.15
5	120	0.10	0.25	0.05
6	120	0.15	0.15	0.10
7	150	0.05	0.25	0.10
8	150	0.10	0.15	0.15
9	150	0.15	0.20	0.05

3.5.5. Data Analysis and Parameter Optimization

The results obtained from various experimentations was analyzed in detail. Optimization of parameters were done by utilizing minitab17 statistical software. The experimental investigation data of surface roughness were transformed into Signal-to-Noise (S/N) ratio. Signal to noise ratio is interpreted as the ratio of the mean value of the signal to the standard deviation of noise value. It is used to arbitrate the rank of input process factors or parameters. There are three types of quality indicative, namely larger is better, smaller is better, and nominal is best (Krishnaiah & Shahabudeen, 2012) For surface roughness is ‘smaller is better’ characteristic is used, shown in equation 3.2.

$$\frac{S}{N} = -10\, log(\frac{1}{n}\sum_{j=1}^{3} R_j^2) \tag{3.2}$$

Where R is the value of surface roughness rate and n is the number of observations. The process parameters and their three levels used for experimental investigation of AISI 1045 steel have been shown in Table 3.4. Experimental results of response parameters with their corresponding S/N ratio have been listed in a distinctive subtitle.

3.5.6. Analysis of Variance (ANOVA)

Analysis of variance for the investigation is calculated by minitab17 statistical software and analysis of a response parameter for several experimental responses. ANOVA is the statistical technique used to find the influence of all control parameters. In the analysis of variance, the percentage contributions of each control factor were used to measure the corresponding effects on the performance characteristics. The significance level of 5%, i.e. for a 95 % level of confidence was considered. From the analysis of variance Percentage contribution of each influential parameter was calculated by the following formula (Krishnaiah & Shahabudeen, 2012).

$$P(\%) = \frac{SSTR}{SST} * 100 \tag{3.3}$$

Where P is the percentage contribution of individual factors, SSTR is the sum of squares or treatment sum of squares, and SST total sum of squares.

3.5.7. Confirmation Experiment

Confirmation experiment is conducted using the optimal levels of the significant factors. Once the optimal combination of process parameters and their levels was obtained, the final step is to verify the predicted result against experimental results. if the optimal combination of parameters and their levels coincidently match with one of the experiments in the orthogonal array and then no confirmation test is required.

3.5.8. Minitab Statistical Software

Minitab is a powerful statistical software package used in the areas of mathematics, statistics, economics, sports, and engineering. It is highly interactive software that makes entering data, conducting regression analysis, ANOVA analysis, designing experiments using DOE, performing Taguchi analysis, drawing control charts for processes, performing reliability/ survival tests, plotting time series plots. very easy and time-saving. It is the best tool for data-driven quality improvement programs.

3.6. Surface Roughness Measurement

The quality of the surface made using conventional and non-conventional machining is important because a smooth surface reduces the chances of surface damage caused by wear and corrosion. Likewise, the quality of a part made by turning operation can affect the performance of the surface for wear and corrosion protection. In present study, the surface roughness parameters were measured by using the Model: 657111 surface contact profilometer roughness tester. During the surface roughness data collection, the three readings were taken at three different locations 120^0 from each other after each machining run, and the mean value was accepted for further analysis.

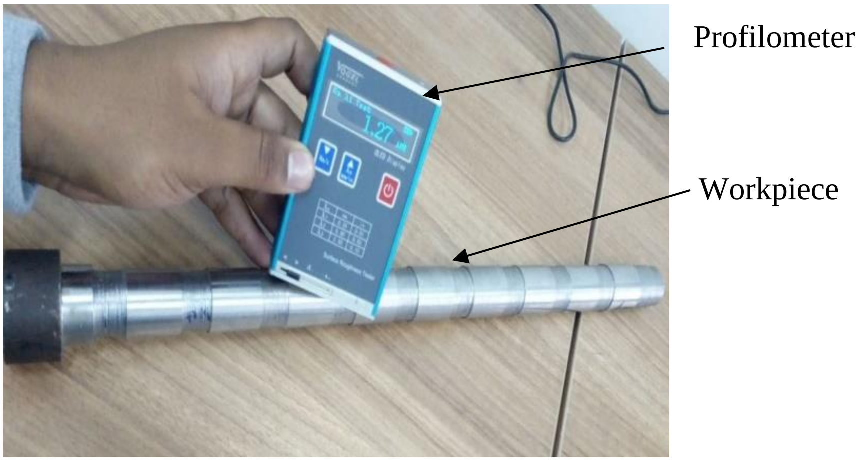


Figure 3.14 Surface roughness testing by using a surface contact profilometer

3.7. Measurement of Material Removal Rate (MRR)

The material removal rate is the amount of material removed per unit time and ultimately determines machining productivity in roughing operations and production of large batches, the material removal rate needs to be maximized (El-Hofy, 2013). In the present investigation, the following formula has been used to compute the material removal rate

$$MRR = Vc\ x\ f\ x\ ap \tag{3.4}$$

Where, MRR = Material removal rate,

f = feed (mm/rev), Vc = cutting speed (m/min), and

ap = total depth of cut (mm).

3.8. Measurement of Tooltip Temperature

The friction between the rake face of the cutting tool and chip causes heat generation in the secondary shear deformation zone whereas the friction between tool flank and the machined surface causes heat generation in the tertiary shear deformation zone. Higher cutting temperature adversely affects the tool life, decreases the wear resistance and hardness of the cutting tool, which causes poor surface finish and dimensional inaccuracy of the machined surface. Therefore, it is important to maintain a lower cutting temperature during hard machining process. Measures the temperature of the cutting tooltip during dry machining of AISI 1045 steel in a double cutting tool turning operation was used contact type temperature tester. During measuring the cutting tool tip temperature first contact the temperature sensor with the cutting tooltip at the measured dimensional range of workpiece was initial from 0mm up to 5mm, at medium part from 10mm up to 20mm and finally measure from 25mm up to 30mm length of machined workpiece for all nine experiment then finally accepted average values for each experimental runs. In this study, the temperature generated at the cutting tool tip was measured for each of nine experiments using a contact-type temperature tester shown in figure 3.15.

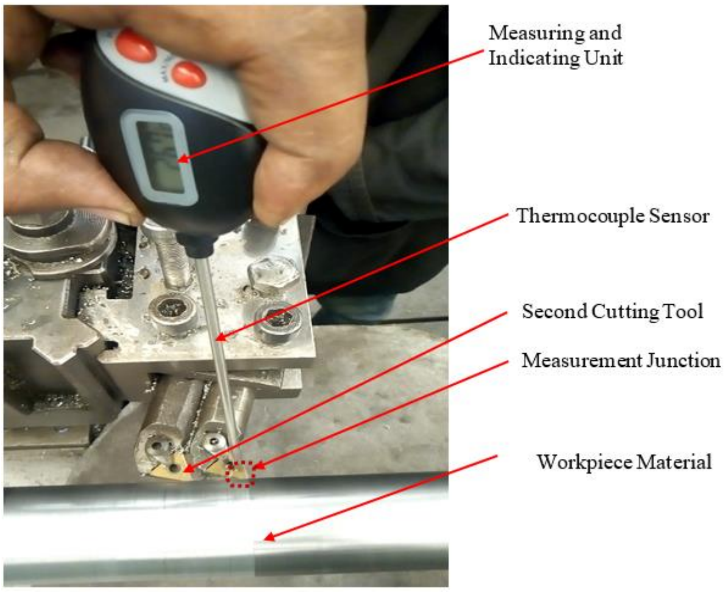


Figure 3.15 Tooltip temperature measurement set up

3.9. Studying Chip Morphology

The study of chip morphology is a major concern of turning processes. Both the chip tool interaction and favorable machining state can be easily determined with the help of chip morphology. In this present experimental investigation for each experimental run, chips were collected at the end of each experiment for the successive examinations. The type of chips was studied. Furthermore, the highest chip thickness, the lowest chip thickness, the average maximum and minimum length of the chips were identified using Vernier caliper 0.02 accuracy for each experimental run by taking three samples for each experiment results.

CHAPTER FOUR

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1. Introduction

This experimental work was conducted to evaluate the effect of main cutting parameters on the surface quality, material removal rate, tooltip temperature and chip morphology of AISI 1045 steel material during the double tool turning process under dry and with cutting fluid machining. After completing the machining operation, the response parameters were measured. The outcome results for each experiment were discussed in this chapter in detail. The response results from experimental investigation carried out by orthogonal array are analyzed using Taguchi methods were to identify the optimum cutting parameters and the most influential cutting parameters on surface finishing.

All nine experiments conducted with different cutting parameters but with constant length of cut 30mm and diameter of the workpiece prepared for experimental study is 40mm. This experimental investigation on double tool turning process of AISI 1045 steel during dry and with cutting fluid machining operations was performed at various spindle speeds (90m/min, 120m/min, 150m/min), at a feed of (0.05mm/rev, 0.10mm/rev, 0.15 mm/rev) and the first and second depth of cut was taken as (0.15mm, 0.20mm, 0.25mm) and (0.05mm, 0.10mm, 0.15mm) respectively. Optimize the cutting parameters for dry and with cutting fluid machining in double tool turning process has been performed separately on the conventional lathe machine model: COMEV CM160 for surface roughness. Sample after double tool turning process of AISI 1045 steel in both machining conditions are given in figure 4.1.

Figure 4.1 Samples after turning process for both operations

4.2. Optimization of Cutting Parameters in Dry Turning

The main focus of the work was on the investigation and optimization of cutting parameters for turning of AISI 1045 steel material using the Taguchi L9 orthogonal array method

Table 4.1: Machining parameters and their levels for dry machining

Cutting Parameters	Level 1	Level 2	Level 3
A - Cutting speed (m/min)	90	120	150
B – Feed (mm/rev)	0.05	0.10	0.15
C – First depth of cut (mm)	0.15	0.20	0.25
D – Second depth of cut (mm)	0.05	0.10	0.15

4.2.1. Experimental Values of Surface Roughness

Measurements of surface roughness (R_a) data were taken at three different locations, 120° from each other, on the machined surface using a surface roughness tester (profilometer), and the average values were recorded. The measured experimental results of mean values of surface roughness for each trial experiment are illustrated in Table 4.2. Optimization of the cutting parameters for both cutting conditions has been performed separately. For surface roughness analysis the smaller-the-better performance characteristics were used. Therefore, in this case, Average Surface Roughness (Ra) and Signal to Noise Ratio (S/N) is defined as:

$$\text{Avg. } R_a = \frac{R_1+R_2+R_1}{3} \tag{4.1}$$

Where R_a-Average surface roughness, R_1, R_2 and R_3 are the first, second and third trial test of surface roughness value

$$\eta = -10\log\left(\frac{1}{n}\sum_{j=1}^{3} R_j^2\right)$$

Where η is the S/N ratio, n is the number of trial test in each experiment, R_j is the observed data and j is the number of the trial test.

Using equation (4.1 and 3.2) to calculate average surface roughness(Ra) and S/N ratios for surface roughness. In ANOVA, the 95% confidence level was chosen to determine the effect of cutting parameters on the surface roughness of machined part.

Table 4.2: Experimental results during dry turning process

No	Cutting Parameters				Surface roughness(µm)	S/R
	Speed (m/min)	Feed (mm/rev)	First depth (mm)	Second depth (mm)		
1	90	0.05	0.15	0.05	1.52	-3.63687
2	90	0.10	0.20	0.1	1.33	-2.47703
3	90	0.15	0.25	0.15	1.67	-4.45433
4	120	0.05	0.20	0.15	1.64	-4.29688
5	120	0.10	0.25	0.05	1.42	-3.04577
6	120	0.15	0.15	0.1	1.61	-4.13652
7	150	0.05	0.25	0.1	1.31	-2.34543
8	150	0.10	0.15	0.15	1.02	-0.17200
9	150	0.15	0.20	0.05	1.27	-2.07607

From Table 4.2 data show that the maximum and minimum values of average surface roughness during the experimental investigations of double cutting tool turning operations under dry machining environment.

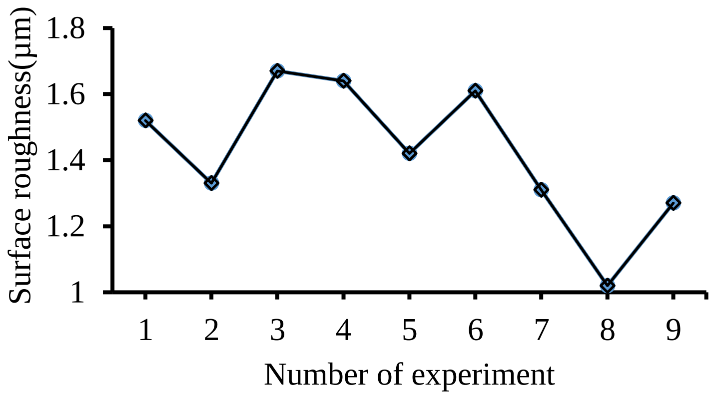


Figure 4.2 Number of experiments Vs Average surface roughness

Figure 4.2 shows that at experiment number seven, eight and nine, the maximum cutting speed (150m/min) was used, the result was indicated that the lowest value of surface roughness obtained this means cutting speed significantly determined the value of surface roughness.

4.2.2. Response Table for Mean

A response table for each response characteristic like mean and signal-to-noise ratio are calculated. Which factors have the largest impact on the response and which level of the factor is related to higher or lower response characteristic values can be indicated by the response table. Steps to generate response table.

1. Calculates the selected response characteristic for cutting speed, feed, first depth of cut, and second depth of cut at each level.
2. After this delta values are calculated, which is the difference between the highest average response characteristic value and the lowest average response characteristic values for levels of that factor.
3. By considering the delta values ranks are allotted from high to low. The factor with the highest delta value is ranked one.

Table 4.3: Response table for mean effects plot for smaller is better

Level	Speed(A)	Feed(B)	First depth (C)	Second depth (D)
1	1.507	1.49	**1.383**	**1.403**
2	1.557	**1.257**	1.413	1.417
3	**1.20**	1.517	1.467	1.443
Delta	0.357	0.260	0.083	0.040
Rank	1	2	3	4

The response for each factors is calculated as example shown for factor A.

For factor A, the mean

At level 1(A_1) = $\frac{(1.52+1.33+1.67)}{3}$ = 1.507.

At level 2(A_2) = $\frac{(1.64+1.42+1.61)}{3}$ = 1.557

At level 3(A_3) = $\frac{(1.31+1.02+1.27)}{3}$ = 1.20

In a similar manner calculated mean for factor B, C, and D in each levels. After calculating the average S/N ratios for each factor, the delta value is calculated. Delta value calculated by subtracting minimum value from maximum.

From Table 4.3 cutting speed (A) has the highest value so it is ranked first, feed (B) has the second highest value and ranked second, first depth of cut (C) is ranked third and second depth of cut (D) has the least value compared to other factors so it is ranked fourth. At these cutting parameters level ($A_3B_2C_1D_1$) selected for double cutting tool of AISI 1045 steel under dry machining environment. that means will be taken as a possible parameter combination for smaller is better values. Main effect plots for means helps adjust the mean on better value The control factors main effect plot for means of surface roughness value variations is as shown in figure 4.3.

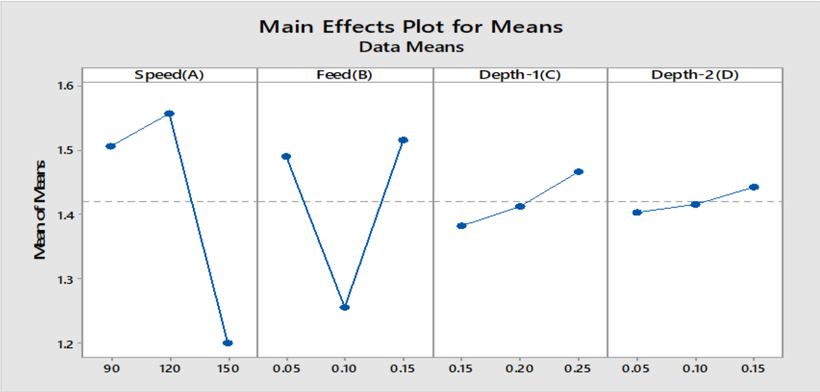


Figure 4.3 Main effect plot for means

The numerical value of the minimum point in each graph shows the best value of that particular parameter at that level. They also indicate the optimum conditions in the range of the experimental conditions. The most effective parameter to enhance the surface roughness is the cutting speed weight percentage when compared with other cutting factors and second depth of cut has the least effect on the surface roughness. That is cutting speed at level three (150 m/min), feed (0.1mm/rev) at level two, first depth of cut at level one (0.15mm) and second depth of cut at level one (0.05) was selected as optimum parameters ($A_3B_2C_1D_1$).

4.2.3. Interaction Effect

Interaction effects indicate that a third variable influences the relationship between an independent variable and dependent variable (surface roughness).

As shown from figure 4.4 at medium feed (0.1mm/rev) was obtained best surface roughness. As increasing feed from 0.05mm/rev to 0.1mm/rev, the surface roughness was decreased from 1.52μm to 1.33μm, at cutting speed of 90m/min, decreased from 1.64 μm to 1.42μm at cutting speed of 120m/min and decreased from 1.31μm to 1.02μm at cutting speed of 150m/min. Then as feed increased again from 0.1mm/rev to 0.15mm/rev surface roughness was increased to 1.67 μm at cutting speed of 120m/min, 1.61μm at cutting speed of 120m/min and 1.27μm at cutting speed of 150m/min.

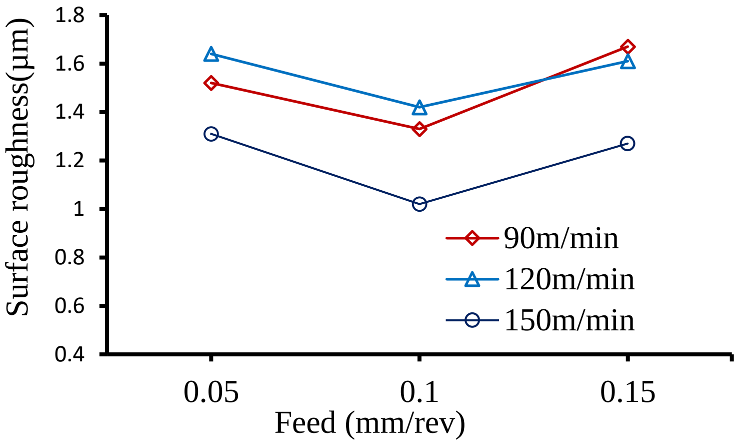


Figure 4.4 Shows the effect of feed on surface roughness

From figure 4.5 for first depth of cut, as the depth of cut is increased from 0.15 mm to 0.2mm the surface roughness was increased at 120m/min from 1.61μm to 1.64μm, also increase at 150m/min from 1.02μm to 1.27μm and decreased at 90m/min from 1.52μm to 1.33μm, but surface roughness increased when the depth of cut was increased to 0.25mm at cutting speed of 90 m/min increased to 1.67μm and also at cutting speed of 150m/min increased to 0.31μm but at cutting speed of 120m/min decreased to 1.42μm as shown from the figure.

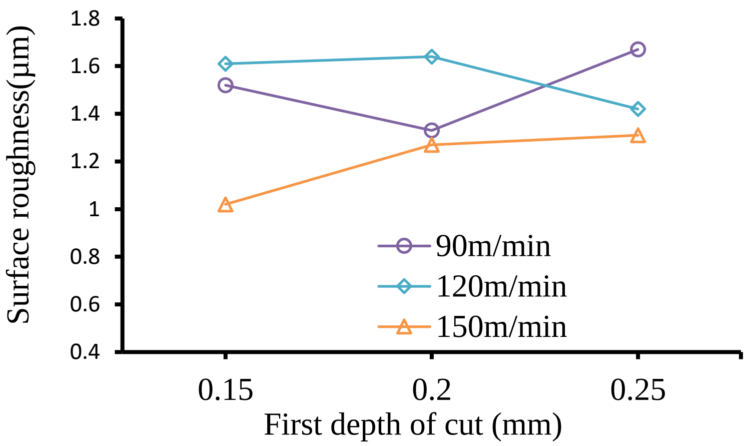


Figure 4.5 Shows the effect of first depth of cut on surface roughness

Figure 4.6 shows the effect of second depth of cut on surface roughness as the depth of second cutting tool is increased from 0.05mm to 0.1mm the surface roughness was decreased to 1.33µm at cutting speed of 90m/min, but surface roughness increased to 1.61µm at cutting speed of 120m/min and 1.33µm at cutting speed of 150m/min. when the second depth of cut was increased to 0.15mm surface roughness is decreased to 1.02µm at 150m/min and increased to 1.67µm, 1.64µm at cutting speed of 90 m/min, 120m/min respectively.

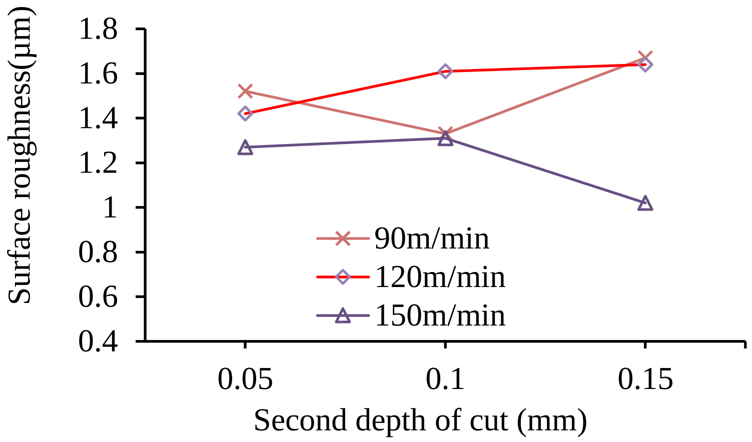


Figure 4.6 Shows the effect of second depth of cut on surface roughness

From figure 4.7 shows the effect of cutting speed on surface roughness at different feed of 0.05mm/rev, 0.1mm/rev and 0.15mm/rev. As increasing cutting speed from 90m/min to 120m/min the surface roughness also increases at 0.05mm/rev and 0.1mm/rev of feed and slowly decreases at 0.6mm/rev feed. As increasing cutting speed from 120m/min to 150m/min the surface roughness is decreased at 0.05mm/rev, 0.1mm/rev and 0.15mm/rev of feed. From this the increase in cutting speed results in decrease of surface roughness at maximum cutting speed and improves surface quality.

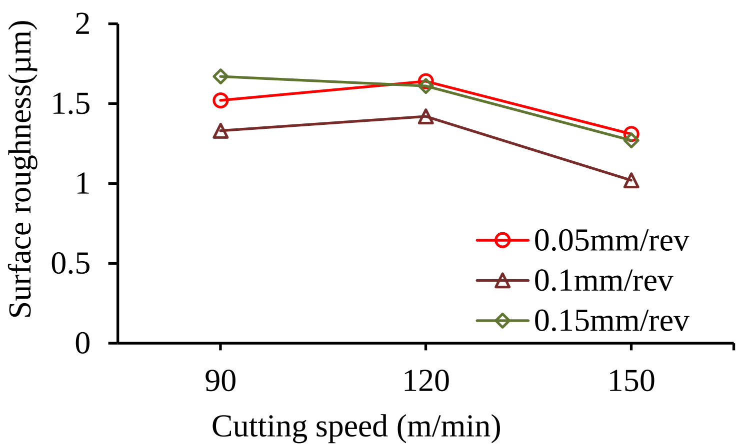


Figure 4.7 Shows the effect of cutting speed on surface roughness

4.2.4. Response Table for S/N Ratio

Table 4.4: Response table for Signal to Noise ratios smaller is better.

Level	Cutting Speed (A)	Feed (B)	First depth of (C)	Second depth of cut (D)
1	-3.523	-3.426	**-2.648**	**-2.920**
2	-3.826	**-1.898**	-2.950	-2.986
3	**-1.531**	-3.556	-3.282	-2.974
Delta	2.295	1.657	0.634	0.067
Rank	1	2	3	4

Looking at the surface roughness response Table 4.4 and main effect plot for the signal to noise (S/N) ratios the cutting speed weight percentage has the greatest effect (Delta = 2.295, Rank = 1). The factor with the least effect on the (S/N) ratio is second depth of cut (Delta = 0.067, Rank = 4). The optimal parameter combination on smaller is the better surface quality character is $A_3B_2C_1D_1$ are the possible parameter combinations for increasing the surface quality of AISI 1045 steel.

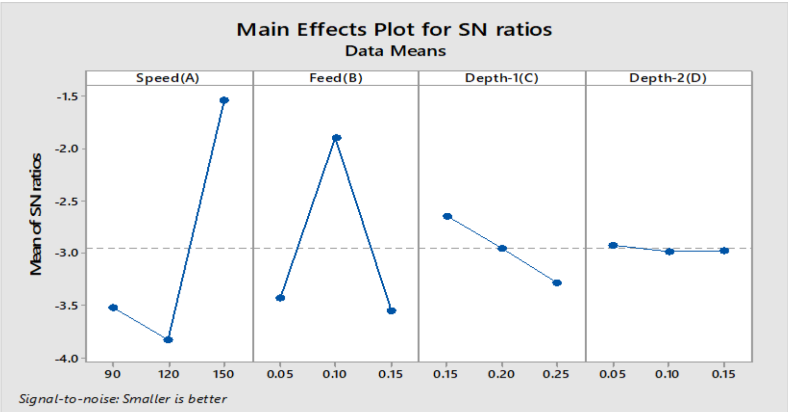


Figure 4.8 Main effects plot for S/N ratios

The numerical value of the maximum point in each graph shows the best value of that particular parameter at that level. The most effective parameter to enhance the surface roughness is the cutting speed when compared with other cutting factors and the second depth of cut has the least effect on the value of surface roughness. Since S/N ratio was selected cutting speed at level three(150m/min), feed at level two (0.1mm/rev), first depth of cut at level one (0.15mm) and second depth of cut at level one(0.1mm) was selected.

4.2.5. Predict the Performance of Optimum Level

For predicting the optimum response, four factors of parameters are selected by a small mean value, $A_3B_2C_1D_1$ is the optimum level of parameters mean value for surface roughness value. To find out the predicted value of the responses (surface roughness value) the following linear regression equation is used.

$$y_{opt} = \text{m} + (\text{m}A_3 - \text{m}) + (\text{m}B_2 - \text{m}) + (\text{m}C_1 - \text{m}) + (\text{m}D_1 - \text{m}) \quad (4.2)$$

Where, m is average performance mean value for surface roughness, mA_3 is optimum level value for parameter A, mB_2 is optimum level value for parameter B, mC_1 is optimum level value for parameter C, and mD_1 is optimum level value for parameter D.

Average value of surface roughness$(m = \frac{R_a}{9}) = 1.421$

mA_3 = 1.20 is optimum level value for factor A,

mB_2=1.257 is optimum level value for factor B,

mC_1= 1.383 is optimum level value for factor C.

mD_1= 1.403 is optimum level value for factor D

y_{opt} = 1.421 + (1.20 - 1.421) + (1.257 - 1.421) + (1.383 - 1.421) + (1.403 - 1.421)

y_{opt} = **0.98** (predict mean value for surface roughness value)

For predicting the optimum response approximately, four factors of parameters are selected at $A_3B_2C_1D_1$ is the optimum levels of parameters S/N ratio value for surface roughness value. To find out predicted values of the response linear regression equation 4.2 was used:

$$y_{opt} = \text{m} + (\text{m}A_3 - \text{m}) + (\text{m}B_2 - \text{m}) + (\text{m}C_1 - \text{m}) + (\text{m}D_1 - \text{m})$$

Where, m = Average performance S/N value for Ra, $(m = \frac{R_a}{9} = -2.96)$

y_{opt} = -2.96 + (-1.531 – (-2.96)) + (-1.898 - (-2.96)) + (-2.648 - (-2.96)) + (-2.920 - (-2.96)) = -0.117

y_{opt} = -0.117 (predict S/N value for surface roughness value)

4.2.6. Analysis of Variance (ANOVA) for Surface Roughness

Analysis of variance (ANOVA) is used to identify the most significant factors which affects the surface roughness of the machined part. It was calculated and reported in Table 4.5

Table 4.5: Analysis of Variance for surface roughness value.

Source	DOF	SS	MSS	F-value	P-value	%C	Significance (α=0.05)
A	2	1.103	0.55	26.54	0.36	72.57%	Highly Significant
B	2	0.35	0.175	7.69	0.106	23.02%	Significant
C	2	0.027	0.027	0.21	0.741	1.8%	Less Significant
D	2	0.0129	0.0064	0.24	0.764	0.85%	Less Significant
error	2	0.04	0.02			2.245%	
Total	10	1.52				100%	

Where DOF= degree of freedom, SST=Total sum of squares, SSTR = Treatment Sum of squares, MSS = Mean Sum Square, and F = F- Ratio generated from Minitab 17 statistical software.

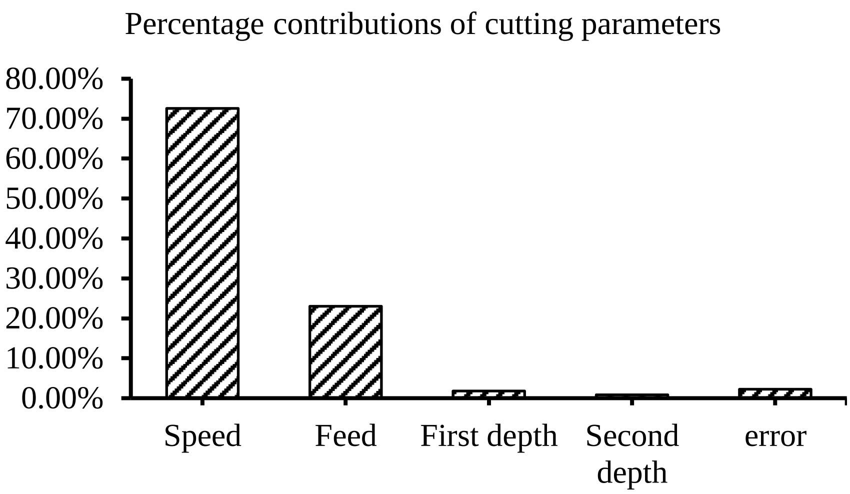


Figure 4.9 Shows the percentage contributions of each parameter

From figure 4.9 it was observed that the cutting speed weight percentage (72.57%), feed (23%), first depth of cut (1.8%) and second depth of cut (0.85%) have a significant influence on the surface roughness of AISI 1045 steel material. Therefore, cutting speed has a highly significant effect parameter on the surface roughness of AISI 1045 steel during double tool turning in dry machining condition.

4.2.7. Determining the Optimum Condition

The optimum level value of cutting speed is 150 m/min at level three, feed optimum level value 0.1 mm/rev at level two, first depth of cut optimum value is 0.15mm at level one and second depth of cut optimum level value is 0.05mm make the mean values small. Therefore, the optimum processing parameters was selected. Table 4.6 presents the optimum parameters setting selected for surface roughness obtained from the design of the experiment and experimental results. The selected optimum parameters in this study were at higher cutting speed, at medium feed, and at a minimum depth of cut for both tools which, is at $A_3B_2C_1D_1$

Table 4.6: Optimum parameters setting levels and their values.

Cutting parameters	Level selected	Value of level	Rank of affecting the response
Cutting Speed (m/rev)	3	150	1
Feed (mm/rev)	2	0.1	2
First depth (mm)	1	0.15	3
Second depth (mm)	1	0.05	4

4.2.8. Confirmation Test

Once the optimal combination of process parameters and their levels was obtained, the final step was to verify the predicted result against the experimental result. If the optimal combination of parameters and their levels coincidently match with one of the experiments in the Orthogonal Array, then no confirmation test is required. By considering this, a confirmation test was not required in this case study because the optimum combination of parameters obtained. Table 4.7 presents the confirmation experiment and predicted results

Table 4.7: Optimum and predicted machining parameters

Response	Optimum level	Predicted value		Experimental value	
		Mean	SNR	Mean	SNR
Surface Roughness (μm)	$A_3B_2C_1D_1$	0.98	-0.117	1.02	-3.29

From Table 4.7 the result between the experimental result and the predicted results is very small. The values predicted by using the Taguchi approach are approximately near to the value which is experimentally obtained. This verifies that the experimental results of surface roughness are strongly correlated with the predicted results.

4.3. Optimization of Cutting Parameters in Wet Turning

Used the same cutting parameters for both cutting conditions, finally compared the obtained result. The cutting parameters and their levels were given in Table 4.8 below.

Table 4.8: Machining parameters and their levels

Cutting Parameters	Level 1	Level 2	Level 3
A - Cutting speed (m/min)	90	120	150
B - Feed (mm/rev)	0.05	0.10	0.15
C - Primary depth of cut (mm)	0.15	0.20	0.25
D - Secondary depth of cut(mm)	0.05	0.10	0.15

4.3.1. Experimental Values of Surface Roughness.

Table 4.9: Experimental results for mean and signal to noise ratio.

No	Cutting Parameters				Surface Roughness (μm)	S/R
	Speed (m/min)	Feed (mm/rev)	Depth-1 (mm)	Depth - 2 (mm)		
1	90	0.05	0.15	0.05	1.03	-0.34
2	90	0.10	0.20	0.10	1.08	-0.80
3	90	0.15	0.25	0.15	1.12	-0.99
4	120	0.05	0.20	0.15	1.11	-0.94
5	120	0.10	0.25	0.05	1.22	-1.85
6	120	0.15	0.15	0.10	1.04	-0.57
7	150	0.05	0.25	0.10	0.81	1.65
8	150	0.10	0.15	0.15	0.98	0.16
9	150	0.15	0.20	0.05	0.82	1.49

From the figure 4.10 the minimum surface roughness value was found to be at the experiment number seven was 0.81µm whereas the maximum surface roughness value found at the experiment number five was 1.22µm.

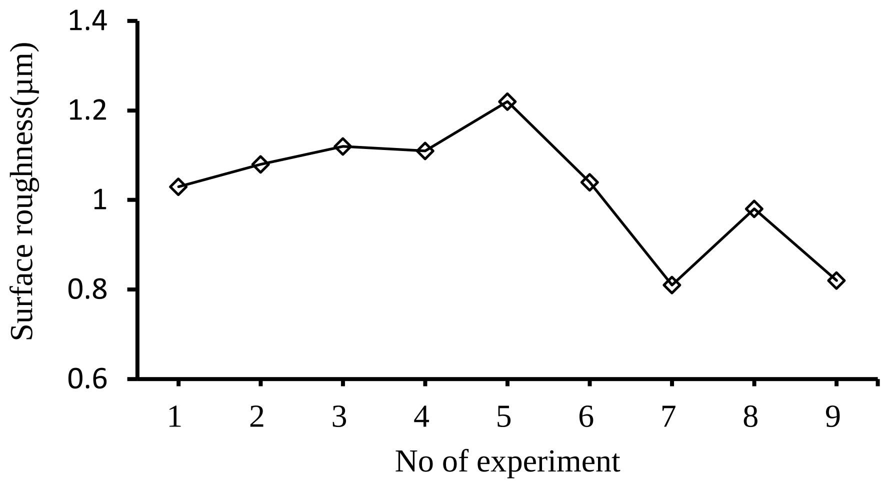


Figure 4.10 Minimum and maximum surface roughness

Figures 4.10 illustrate the relationships between surface roughness and several experiments in double cutting tool turning of AISI 1045 steel during machining with cutting fluid. As shown from the figure 4.10 the irregular tendency of surface roughness values explained by the randomized distribution of cutting parameters due to the design of the experiment. In this figure it can be seen, that surface roughness decreased with increasing cutting speed at experiment number eight the smallest value of surface roughness was observed due to maximum cutting speed (150m/min). The highest value of surface roughness has been obtained at experiment number five due to minimum cutting speed (120rpm) of cutting speed.

4.3.2. Response Tables and Analysis of Mean

Using the same producers with the previous methods the mean value of surface roughness for each factors such as cutting speed, feed, first depth of cut, and Second depth of cut at each level are obtained and the result is listed in response in Table 4.10.

An example calculation is shown for factor A (Cutting Sped):

At level 1(A_1) $=\frac{(1.03+1.08+1.12)}{3} = 1.076$

At level 2 (A_2) $= \frac{(1.11+1.22+1.04)}{3} = 1.123$

At level 3 (A_3) $= (\frac{0.81+0.98+0.82}{3} = 0.870$

Table 4.10: Response table for mean effects plot for smaller is better

Level	A	B	C	D
1	1.076	**0.983**	1.016	1.023
2	1.123	1.093	**1.003**	**0.976**
3	**0.870**	0.993	1.050	1.070
Delta	0.25	0.11	0.05	0.10
Rank	1	2	4	3

The result taken from the above data shows as smaller is better is selected for best surface roughness value. The factor with the greatest effect on the mean is cutting speed (Delta = 0.25, Rank = 1), and feed (Delta = 0.11, Rank = 2) is the second. The factor with the least effect on the mean is first depth of cut (Delta = 0.05, Rank = 4)). At $A_3B_1C_2D_2$ taken as a possible parameter combination for better surface roughness (minimum value).

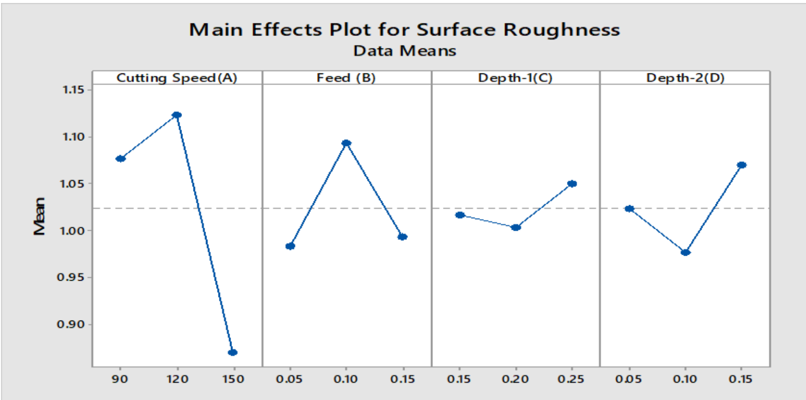


Figure 4.11 Main effect plot for means

As observed from Figure 4.11 the minimum point in the graph for each turning parameter is the optimum condition. The minimum point for cutting speed is at level three, for feed the minimum point on this graph was at level one, for first and second depth of cut at level two is the optimum values are obtained. This is due to the identified optimum turning parameter was at high cutting speed, low feed, and medium depth of cut which is $A_3B_1C_2D_2$.

4.3.3. Interaction Effect

Combined effect is clearly shows that a variation of surface roughness at different cutting parameters. Figure 4.12. Shows the effect of cutting speed on surface roughness at a different feed. As increasing cutting speed from 90m/min to 120 m/min the surface roughness also increased at both constant feed of 0.05 mm/rev and 0.1 mm/rev. But at 0.15mm/rev feed the surface roughness was decreased with increasing cutting speed from 90m/min to 150m/min and then cutting speed is further increased to 150m/min the surface roughness value is decreased at 0.05mm/rev and 0.1mm/rev. The result indicates that by increasing cutting speed, the surface finish can be improved. It is because the occurrence of Built-Up Edge (BUE) is very rear when machining a material at high cutting speeds. During machining at low cutting speed the material that machined is being pressure welded to the cutting tool this is affect the quality of surface finish.

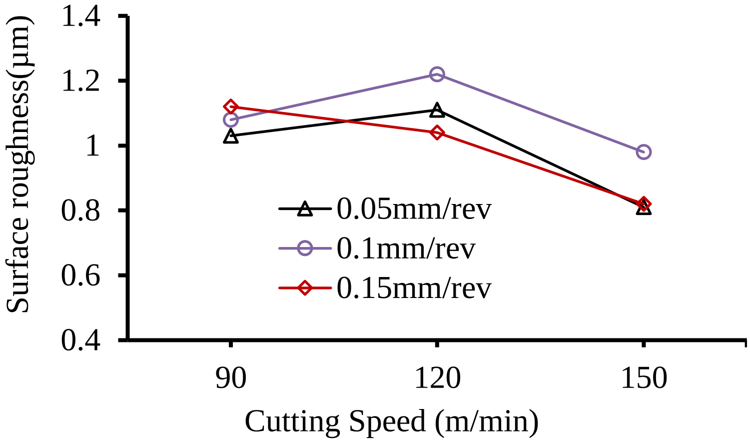


Figure 4.12 Shows the effect of cutting speed on surface roughness

As observed from Figure 4.13 shows that the effect of feed, and cutting speed on surface roughness (Ra) at feed increased from 0.05mm/rev to 0.1mm/rev the value of surface roughness also increased. When feed is increased to 0.25mm/rev surface roughness is also increased at cutting speed of 90m/min, but decrease at cutting speed of 120m/min and 150m/min.

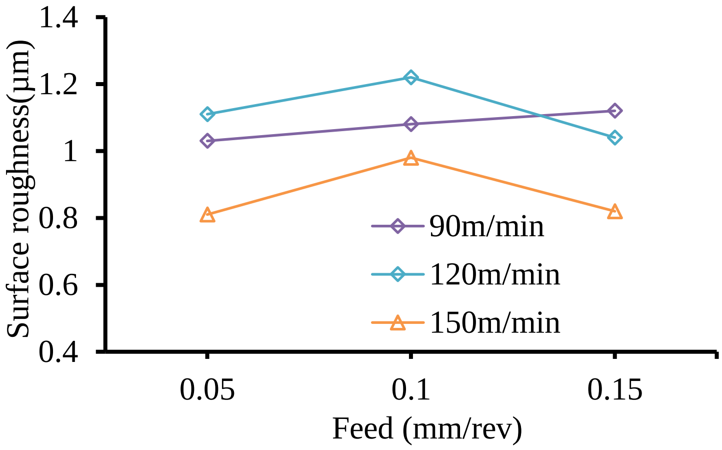


Figure 4.13 Shows the effect of feed on surface roughness at different speed

From figure 4.14 observed that as the first depth of cut is increased from 0.15 mm to 0.2 mm the surface roughness was increased at 90m/min and 120m/min, and decreased at 150m/min. when further increased to 0.15mm the surface roughness is continuously decreased at 120mm/rev cutting speed and decreased at cutting speed of 150mm/rev cutting speed.

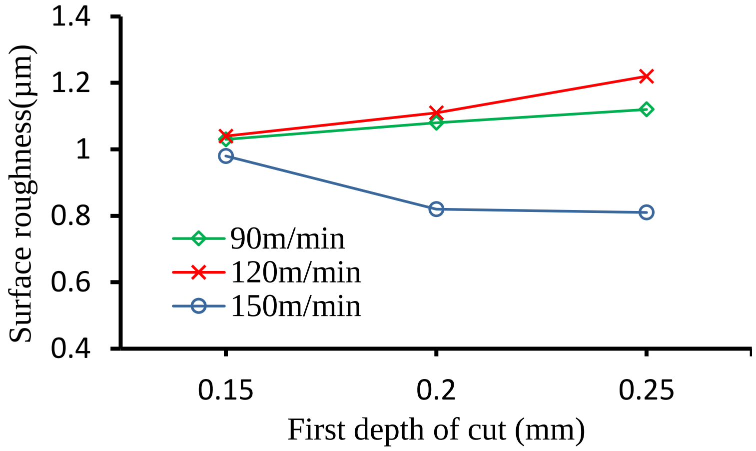


Figure 4.14 Shows the effect of primary depth of cut on surface roughness.

From Figure 4.15 shown that as increasing secondary depth of cut from 0.05 mm/rev to 0.1 mm/rev, the surface roughness was decreased at cutting speed of 120m/min and 150m/min, but increased at cutting speed of 90m/min. When second depth of cut further increased to 0.15mm the value of surface roughness increased at the given three cutting speeds.

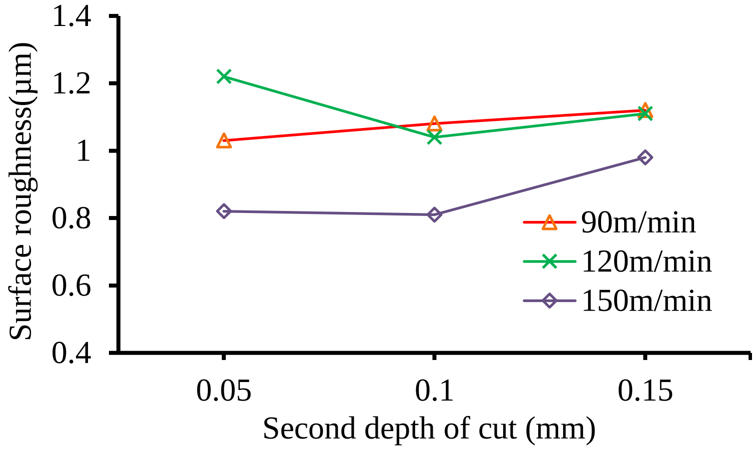


Figure 4.15 Shows the effect of secondary depth of cut on surface roughness.

The variation of surface roughness with respect to the cutting parameters indicates that the surface roughness fluctuated for various cutting speed, feed rate, and depth of cut. As observed from the result surface roughness was better at high spindle speed, so the influence of cutting speed on surface roughness was highly significant.

4.3.4. Response Tables and Analysis of S/N ratio

Table 4.11: Response table for Signal to Noise Ratios

Level	Speed(A)	Feed(B)	Depth-1(C)	Depth-2(D)
1	-0.710	**0.123**	-0.250	-0.233
2	-1.120	-0.830	**-0.083**	**0.093**
3	**1.10**	-0.023	-0.396	-0.590
Delta	2.22	0.95	0.31	0.68
Rank	1	2	4	3

By looking at the surface roughness response in Table 4.11 and the main effect plot for the signal to noise (S/N) ratios, the cutting speed weight percentage has the greatest effect (Delta = 2.22, Rank = 1), the factor with the second effect on the S/N ratio is feed (Delta = 0.95, Rank = 2), third is the second depth of cut (Delta = 0.68, Rank = 3) and the least effect on the (S/N) ratio was the first depth of cut (Delta = 0.31, Rank = 4). The optimal parameter combination is $A_3B_1C_2D_2$, for increasing the surface quality of AISI 1045 steel.

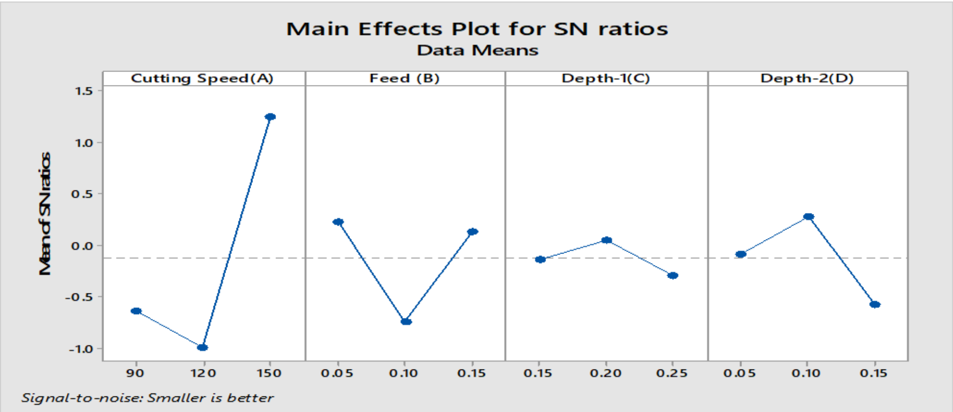


Figure 4.16 Main effect plot for means

4.3.5. Predict the Performance of Optimum Level

For predicting the optimum response, four factors of parameters are selected by small mean values at $A_3B_1C_2D_2$ is the optimum levels of parameters for surface roughness value. For predicting the optimum response approximately. To find out the predicted value of the responses (surface roughness value) linear regression equation 4.2 was used and obtained 0.77 predict for mean value and 1.713 predict for S/N ratio.

4.3.6. Analysis of Variance (ANOVA) for Surface Roughness

The purpose of the analysis of variance (ANOVA) was to find which parameters significantly affect the quality characteristic. ANOVA is the statistical technique used to find the influence of all control parameters. In the analysis of variance, the percentage contributions of each control factor were used to measure the corresponding effects on the performance characteristics.

Table 4.12: Analysis of variance (ANOVA) for surface roughness

Source	DOF	SS	MSS	F-value	P-value	%C	Significance (α=0.05)
Speed	2	0.9501	0.475	18.06	0.064	49%	Highly Significant
Feed	2	0.417	0.208	7.12	0.101	21.5%	Significant
Depth -1	2	0.190	0.095	1.14	0.426	9.8%	Less Significant
Depth -2	2	0.302	0.151	4.40	0.34	15.6%	Significant
Error	2	0.075					
Total	10	1.94					

4.3.7. Determine the Optimum Condition

From Table 4.10, observed that optimum level value for cutting speed is 150m/min, feed 0.05 mm/rev, first depth of cut 0.2mm and second depth of cut is 0.1mm. The selected optimum parameters in this experimental investigation were at higher cutting speed, low feed, and medium depth of cut for both cutting tools. The combination was at $A_3B_1C_2D_2$.

Table 4.13: Optimum parameters setting levels and their values for wet machining.

Factors	Level selected	Value of level	Rank
A	3	150	1
B	1	0.05	2
C	2	0.2	4
D	2	0.1	3

4.3.8. Confirmation Test

The obtained optimal combination of process parameters was verifying with the predicted result. The optimum combination of parameters obtained from Table 4.13 was ($A_3B_1C_2D_2$) at 50 m/min cutting speed, 0.3 mm/rev feed, and 0.2 mm first depth of cut and 0.2mm second depth of cut.

Table 4.14: Optimum and predicted values cutting parameters

Response	Optimal parameter	Predicted value		Experimental value	
		Mean	SNR	Mean	SNR
Surface Roughness (μm)	$A_3B_1C_2D_2$	0.77	1.713	0.81	-0.24

From Table 4.14 the result between the experimental value and the predicted value is very small. The values predicted by using the Taguchi approach are approximately near to the value which is experimentally obtained. This verifies that the experimental results of surface roughness are strongly correlated with the predicted results.

4.4. Analysis of Material Removal Rate

Material removal rate (MRR) is the amount of material removed per unit time. MRR in metal cutting is a volume of chips removed in one minute, and it is measured in a three dimensional quantity. MRR is also a measure of productivity of metal cutting. Such volume is based on the area of a circular ring of a cylinder and its length of cut. The number of materials removed during the double tool turning process of AISI 1045 steel for each experiment is calculated by using equation 3.4 and listed in the Table 4.15 below. In the present investigation, the following formula has been used to compute the material removal rate.

Material Removal Rate (MRR) = Vc x f x ap,

Where V_c: -Cutting speed

f: -feed

ap: - total depth of cut.

As observed from Table 4.15 below and Figure 4.20 material removal rate is maximum at experiment number nine (V_c = 90m/min, f = 0.05mm/rev, d_1 = 0.2mm and d_2 = 0.05mm) and minimum material removal rate is obtained at experiment number one (V_c = 150m/min, f =

0.15mm/rev, d_1 = 0.15mm and d_2 = 0.05mm). Material Removal Rate (MRR) is important for increasing the productivity of machining operations by increasing the amount of chips removed from the machined workpiece or product.

Table 4.15: Material removal rate

Exp. No	Speed (mm/sec)	Feed (mm/rev)	Depth-1 (mm)	Dept-2 (mm)	MRR (mm^3 /sec)	S/R Ratio
1	1,500	0.05	0.15	0.05	15	20.1720
2	1,500	0.1	0.2	0.1	45	31.6526
3	1,500	0.15	0.25	0.15	90	40.1720
4	2,000	0.05	0.2	0.15	25	31.5498
5	2,000	0.1	0.25	0.05	70	35.9868
6	2,000	0.15	0.15	0.1	75	29.9662
7	2,500	0.05	0.25	0.1	35	35.9037
8	2,500	0.1	0.15	0.15	75	25.8007
9	2,500	0.15	0.2	0.05	93.75	41.3637

Machining parameter optimization is highly necessary. Based on experimental outcomes, the material removal rate obtained at the optimum cutting parameters which as 75mm^3/sec in dry turning and 35mm^3/sec during machining with cutting fluid. Since the optimum cutting speed at which best surface finish obtained is at highest level values at this level. maximum amount of MRR which was obtained 93.75mm^3/sec.

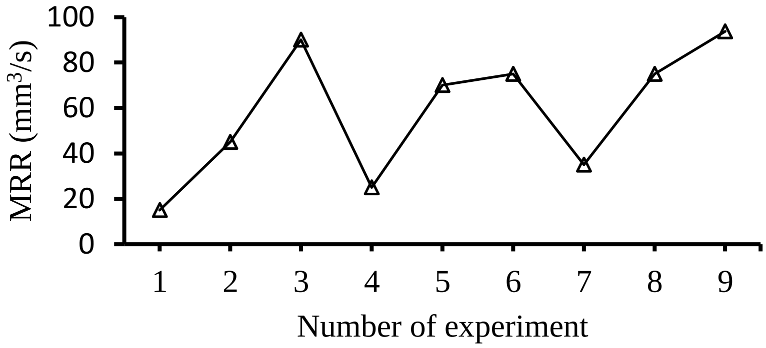


Figure 4.17 Variation of MRR during the experiment

From Table 4.16 response table for mean of material removal rate analysis observed that the amount of material removes during machining operations is mainly affected by feed when compare to other cutting parameters. At experiment number three (0.15mm/rev), six (0.15mm/rev) and nine (0.15mm/rev) obtained the maximum material removal rate at this point the value of feed is maximum and minimum material removal rate was obtained at experiment number one (0.05mm/rev), four (0.05mm/rev) and (0.05mm/rev) in these number of experiment the value of feed is minimum from this concluded that feed was highly significant for material removal rate.

Table 4.16: Response Table for the mean of MRR larger is better

Level	Speed	Feed	Depth-1	Depth-2
1	40.41	33.00	22.86	**47.95**
2	38.30	35.70	49.60	38.28
3	**50.33**	**60.33**	**56.58**	42.80
Delta	12.03	27.33	33.72	9.68
Rank	3	1	2	4

The most significant factor that affects MRR value for turning of AISI 1045 during double tool turning process was feed, feed affects highly level of surface finish followed by first depth of cut. While the cutting speed was the third influential factor and second depth of cut was lest significant factor that affects material removal rate.

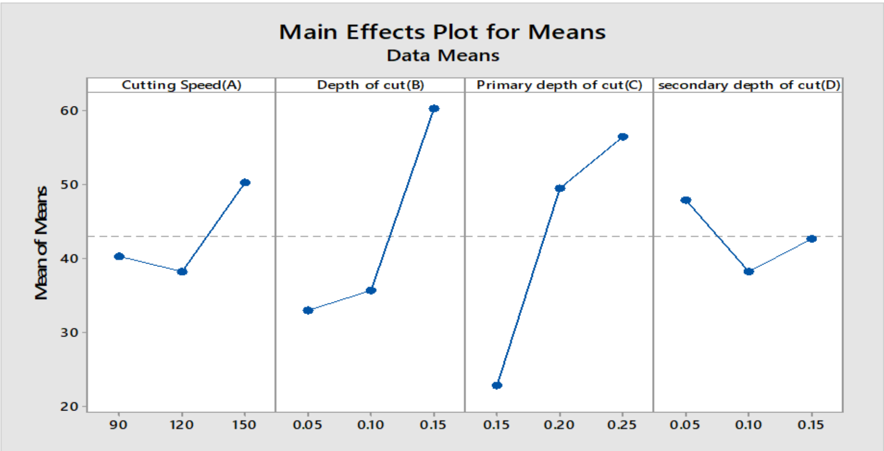


Figure 4.18 Main effect plot for mean

As observed from Figure 4.19 material removal rate was affected by feed, while increasing feed, the material removal rate was increased and also the material removal rates increase with an increase in cutting speed. Generally, the higher feed was achieved higher material removal rate. From this feed was the main significant factor for improving rate of productivity during double tool turning of AISI 1045 steel.

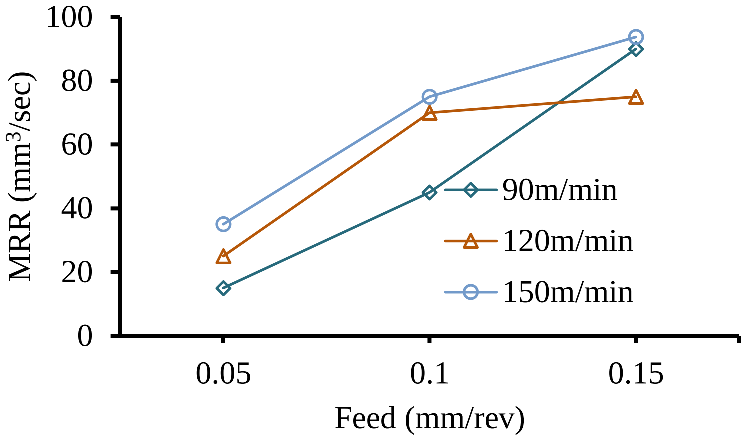


Figure 4.19 Effect of feed on MRR

Figure 4.20 shows the effect of feed, and cutting speed on material removal rate. As increasing cutting speed from 90 m/min to 150 m/min the material removal rate also increases at constant feed 0.05 mm/rev and 0.1 mm/rev. But at 0.15mm/rev of feed the material removal rate was decreased initially with increasing cutting speed from 90 m/min to 120 m/min and then increased when cutting speed was increased to 150 m/min as shown in Figure 4.22.

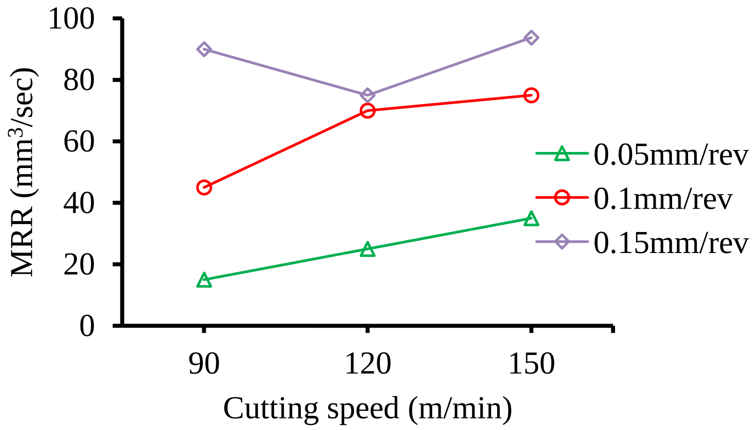


Figure 4.20 Effect of cutting speed on MRR

As observed from Figure 4.21. when first depth of cut is increased from 0.15mm to 0.2mm the material removal rate is increased at 0.05mm/rev and 0.15mm/rev feed but decrease at 0.1mm/rev. And first depth of cut further increased to 0.25mm the material removal rate was increased at 0.15mm/rev and 0.1mm/rev but decreased at 0.15mm/rev. from figure 4.21 concluded that, at feed of 0.15mm/rev the amount of material removal rate is continuously increased.

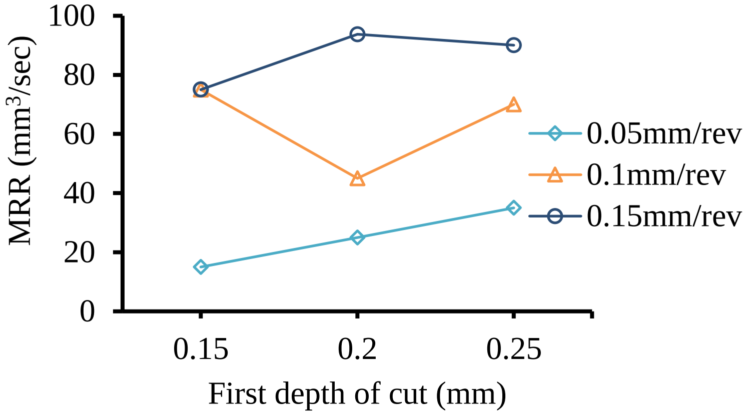


Figure 4.21 Effect of primary depth of cut on MRR

Figure 4.22 shows that the effect of secondary depth of cut on material removal rate (MRR) in double tool turning operations at different feed. When second depth of cut increased from 0.05mm to 0.1mm the MRR is increased at 0.05mm/rev of feed and decreased at 0.1mm/rev and 0.15mm/rev of feed respectively. And then depth of cut is increased to 0.15mm MRR is increased at 0.05mm/rev and 0.1mm/rev feed respectively.

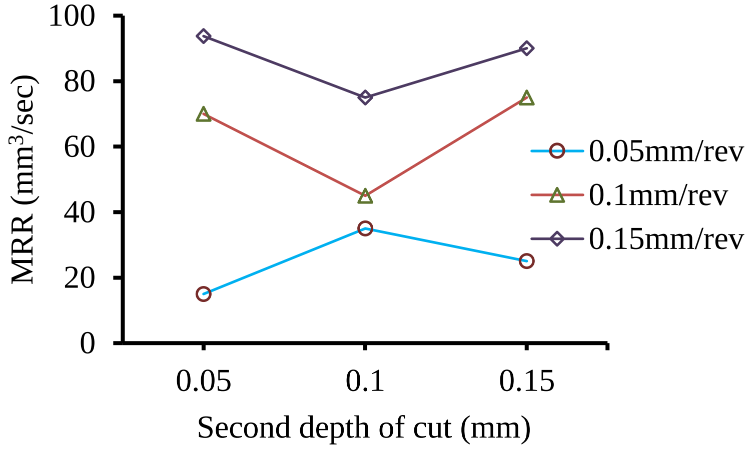


Figure 4.22 Effect of secondary depth of cut on MMR.

As observed from the analysis material removal rate was affected by cutting speed, feed, and both depth of cut. While increasing cutting parameters, the material removal rate was increased. The higher cutting parameters the higher the material removal rate achieved. This can be justified by the relation shown in equation (3.4). Maximum material removal rate obtained the optimum material removal rate is at experiment number nine (93.8mm^3/sec) at this trial the value of cutting parameters were 150m/min cutting speed, 1.15mm/rev feed, 0.2mm first depth of cut and 0.05mm second depth of cut.

4.5. Analysis of Cutting Tooltip Temperature

During the external turning process, the heat was generated due to friction created between the cutting tool and workpiece. The quantity of heat produced during the machining process varies with the type of workpiece material being machined, cutting parameters used and machining conditions. The turning of AISI 1045 steel using a ceramics tool was characterized by the moderate temperature at the tooltip. Table 4.17 presents the obtained temperature for various cutting parameters at tooltip during dry turning.

Table 4.17: The measured temperature at tooltip

Exp. No	Cutting speed (m/min)	Feed (mm/rev)	Depth -1 (mm)	Depth-2 (mm)	Aver. T^o(^{o}C)	
					Tool-1	Tool-2
1	90	0.05	0.15	0.05	46.5	44.4
2	90	0.10	0.20	0.1	51.3	48.2
3	90	0.15	0.25	0.15	62.1	56.8
4	120	0.05	0.20	0.15	68.1	60.4
5	120	0.10	0.25	0.05	69.8	68.2
6	120	0.15	0.15	0.1	64.2	60.1
7	150	0.05	0.25	0.1	80.3	72.3
8	150	0.10	0.15	0.15	67.5	66.3
9	150	0.15	0.20	0.05	75.5	72.1

As observed from Table 4.17 and Figure 4.23 the tooltip temperature readings were taken the average reading. The maximum average temperature 80.3^{0}C for fist cutting tool and 72.3^{0}C for second cutting tool was founded at experiment number seven on the machining parameters were 50m/min cutting speed, 0.05mm/rev feed, 0.25mm first depth of cut and 0.1mm second depth of cut. The minimum temperature was obtained at experiment number one 46.5^{0}C and 44.4^{0}C for first and second cutting tools respectively, on the cutting speed (30m/min), feed (0.05mm), first depth of cut (0.15mm) and second depth of cut (0.05mm) machining parameters. Figure 4. 24 confirms the same thing. Therefore, the increase in cutting speed leads to an increase in tooltip temperate generated.

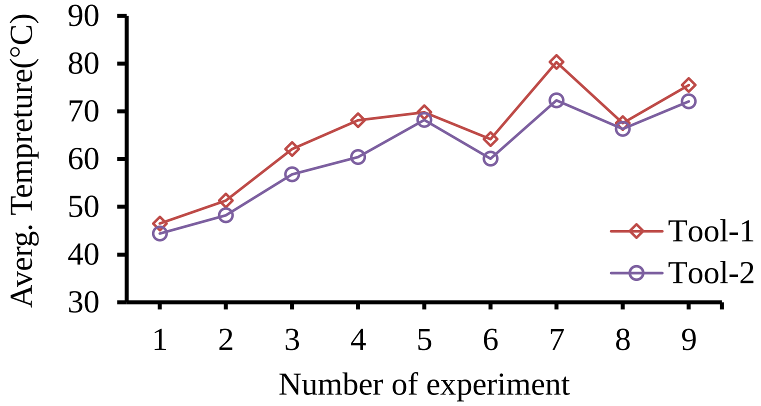


Figure 4.23 Temperature values for 1st and 2nd cutting tool one during dry machining

From figure 4.24 observed that, the variation of cutting tooltip temperature during dry machining of AISI 1045 steel with machining parameters for both cutting tools. Maximum temperature was obtained at cutting speed of 150m/min and 0.05mm feed, minimum temperature was obtained at cutting speed of 120m/min and 0.05mm/rev feed. on the same feed maximum and minimum temperatures are created at the cutting speed of 150m/min and 90m/min respectively.

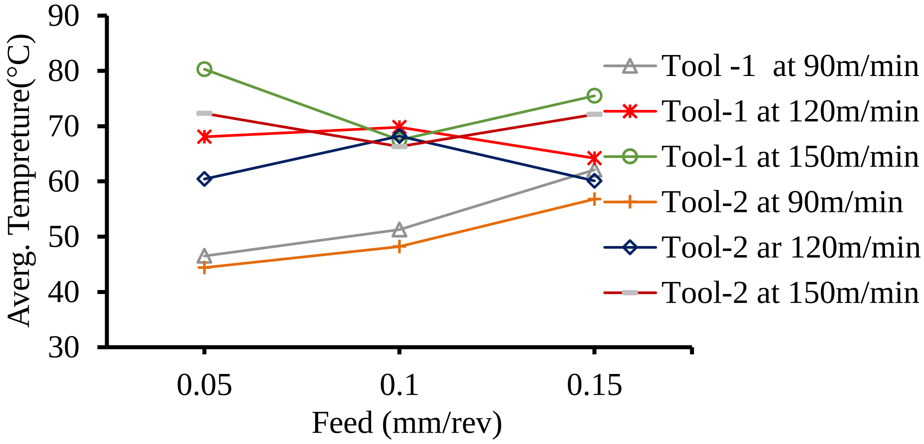


Figure 4.24 Feed Vs Avg. Temperature

Figure 4.25 shows that the effect of feed on the tooltip temperature. It is observed that with an increase in first depth of the cutting temperature is continuously increased from initial up to final value of first depth of cut from this figure 4.25 first depth of cut is directly proportional with the cutting tooltip temperature during ceramics inserted double cutting tool turning operations.

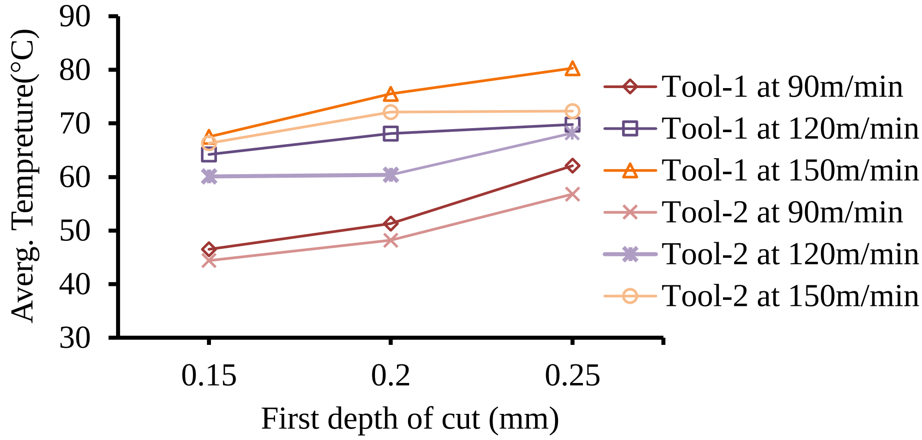


Figure 4.25 First depth of cut Vs Avg. Temperature

From figure 4.26 shown that the relation of second depth of cut with tool tip temperature during dry turning of AISI 1045 steel. Maximum temperature is raised at cutting speed of 90m/min on 0.1mm second depth of cut.

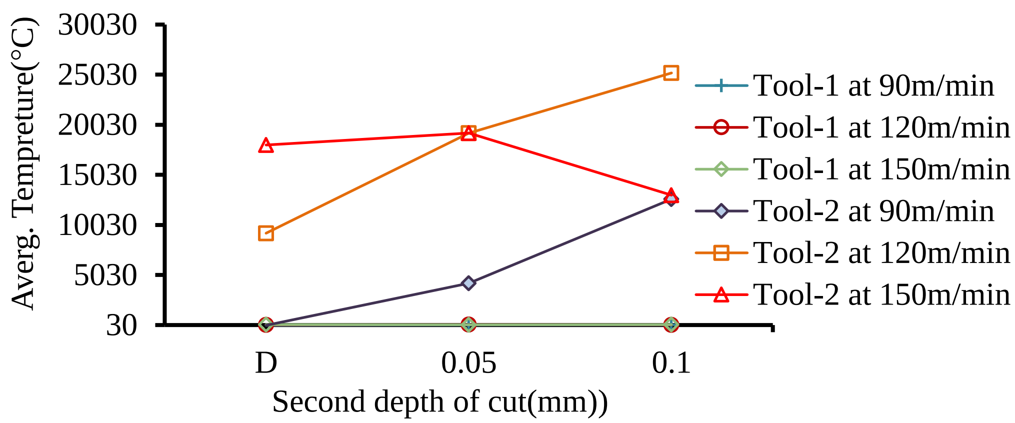


Figure 4.26 Second depth of cut Vs Avg. Temperature

The friction produced between the cutting tooltip and workpiece materials during the machining process influenced on cutting temperature in the cutting tooltip. The undesirable temperature produced in the cutting tool leads to rapid wear of cutting tool materials by softening of the tooltip. The cutting parameters (cutting speed, feed, and depth of cut) have been increased the cutting temperature, as reported. At an optimized feed of 0.4mm/rev, the temperature is reduced to 67.5^{0}C and 66.3^{o}C cutting tool 1 and 2 respectively. Cutting tool temperature is direct proportional with cutting speed as shown from the figure 4.27 increasing cutting speed increases cutting temperature and results in shortening tool life

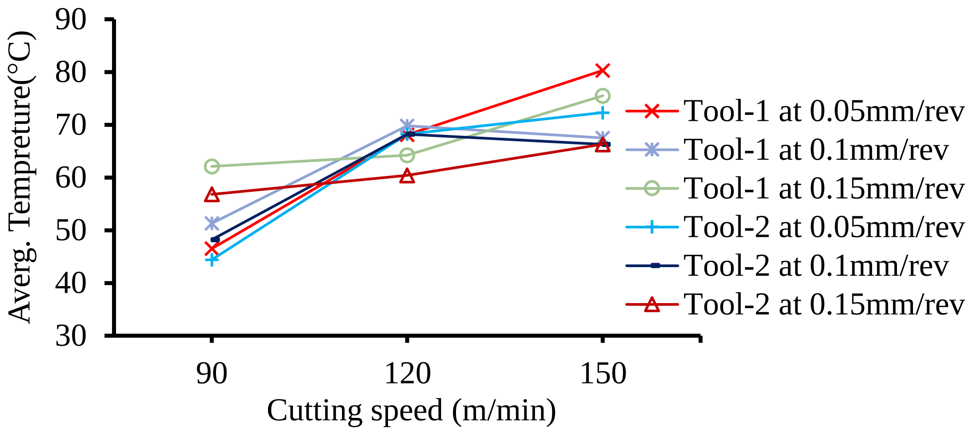


Figure 4.27 Cutting speed Vs Avg. Temperature

During the cutting of metal, the temperature of the interaction area of the cutting tool and workpiece becomes high. The temperature affects not only the rate of wear of the cutting tool but also the integrity of workpiece surface such as residual stress, hardness, and surface roughness. Dimensional inaccuracy of the job due to thermal distortion and expansion-contraction during and after machining. Surface damage by oxidation, rapid corrosion, and burning

4.6. Analysis of Chip Morphology

The chips from the machining test were collected, mounted, and measured. The type of chip is imperative in metal cutting operation because it influences the product accuracy, tool life, surface finish and operator safety. In general, chip control is greatly affected by cutting conditions used during machining operation. Figure 4.28 shows the photographic chip images obtained in machining operation during dry and with cutting fluid. In general, when the feed rate increases, then the chip thickness increases. From the observation of chips morphology was found that in dry machining chip size reduction and superior chip breakability over the wet machining. This impact is because of the viable infiltration of dry machining at the cutting zone, creating significant decreasing of cutting temperatures, reduces the friction between the contact surfaces and decreased bond between the chip and cutting tool coming about the reduction in chip size (Sivaiah & Chakradhar, 2016). At the point, when the feed rate was increased from 0.05 mm/rev to 0.15 mm/rev, it was seen that very long tabulated and very closely curled thin chips were obtained in wet machining. During dry machining conditions at the cutting zone, short tabular and closely curled thin chips were produced due to cutting temperatures and improved chip segmentation. In a dry environment improved chip breakability was observed in contrasted to wet environment, dry machining produced less thickness chips contrasted to wet machining as depicted. Also, dry machining avoids the chip cleaning compared to wet machining.

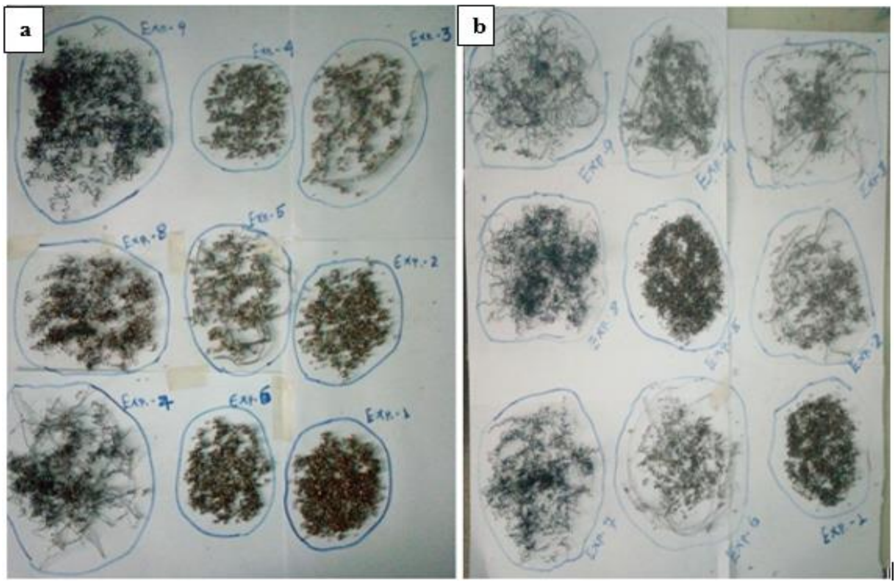


Figure 4.28 Chips generated during a) dry machining b) wet machining

In analysing of chip morphology, Table 4.18 confirmed that as the feed reduced and the cutting speed increased, a reduction of chip thickness has occurred this is due to a substantial contact area on the rake face and a small shear plane area at the low cutting speed which results in thinner chips formation. In contrast, an increase in chip thickness due to increased feed because of severe compressive stresses generated ahead of the tool rake, thereby a large volume of material becomes plastic deformation which resulted in a thick chip. The highest chip thickness which is 0.58 mm was achieved at maximum feed rate value, 0.15 mm/rev, and the lowest chip thickness 0.09 mm was achieved at lower feed rate value of 0.05 mm/rev. Also, the maximum and minimum length of chips were identified as the longest is 10.6 mm and the smallest is 4.8 mm respectively. For each nine experimental study measure the maximum, minimum thickness and length of chips generated from the double tool turning operations of AISI 1045 steel materials in dry and wet machining conditions. From the obtained measurement result maximum length and contineous curled chips obtained during wet machining conditions but minimum length and discontinuous chis mostly formed during dry machining conditions. And also maximum thickness of chips formed during wet machining conditions at maximum feed and depth of cut.

Table 4.18: Obtained chips thickness (t) and length (l)

No of experiment	Cutting Parameters				Double tool turning in dry machining		Double tool turning with cutting fluid	
	Speed (m/min)	Feed (mm/rev)	Depth-1 (mm)	Depth-2 (mm)	l (mm)	t (mm)	l (mm)	t (mm)
1	90	0.05	0.15	0.05	4.8	0.09	5.2	0.11
2	90	0.1	0.2	0.1	5.6	0.13	5.8	0.26
3	90	0.15	0.25	0.15	6.2	0.31	7.8	0.32
4	120	0.05	0.2	0.15	6.8	0.12	7.2	0.16
5	120	0.1	0.25	0.05	6.5	0.18	7.4	0.14
6	120	0.15	0.15	0.1	8.2	0.38	9.3	0.41
7	150	0.05	0.25	0.1	7.8	0.17	8.9	0.16
8	150	0.1	0.15	0.15	7.1	0.26	7.6	0.32
9	150	0.15	0.2	0.05	8.6	0.45	10.6	0.58

4.7. Comparison of Dry and Wet Machining Conditions

4.7.1. Comparison of Surface Roughness Value

In the experimental investigation were conducted on AISI 1045 in double cutting tool turning with ceramics inserted TNGA 160408 with tool holder MTJNR 2020 M10 type cutting tool at varying cutting parameters such as cutting speed, feed, first and second depth of cut under the wet and dry machining environments and performance characteristics of dry machining were compared with wet machining. This study reveals that machining parameters such as cutting speed, feed rate, and depth of cut have significant influence on the surface roughness during double tool turning process. The surface roughness was better at high cutting speed, low feed rate, and medium depth of cut during machining wet machining. In dry turning process surface finish was better at high cutting speed, medium feed, and low depth of cut.

In the present study surface roughness (Ra) was considered as the quality characteristic of the machined surface because it is the mostly using in manufacturing industries. In both cutting environments, increasing pattern was observed for the surface roughness when the machining operations conduct with wet environment obtained good surface quality of product relative to machining operations operated under dry conditions. Minimum surface roughness value was obtained 0.81µm under wet machining environment and obtained 1.02µm under dry machining environment. Cutting peed was highly significant factor in both cutting conditions.

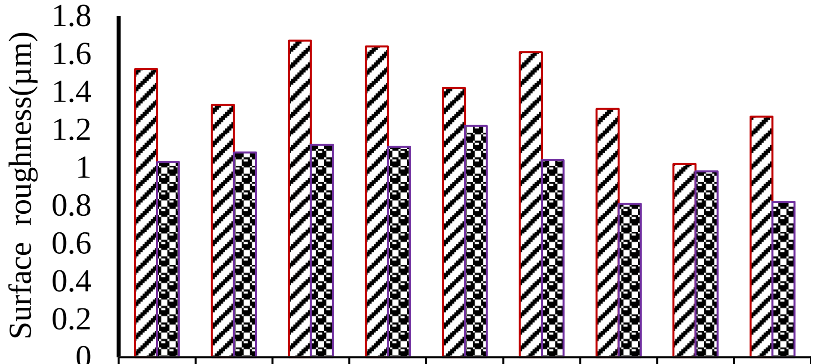
Table 4.19: Percentage reduction of surface roughness in wet machining

Exp. No	Speed (m/min)	feed (mm/rev)	depth1 (mm)	depth2 (mm)	Surface roughness (µm)		Percentage variation
					dry	wet	
1	90	0.05	0.15	0.05	1.52	1.03	32.2%
2	90	0.10	0.20	0.1	1.33	1.08	18.7%
3	90	0.15	0.25	0.15	1.67	1.12	32.9%
4	120	0.05	0.20	0.15	1.64	1.11	32.3%
5	120	0.10	0.25	0.05	1.42	1.22	14.1%
6	120	0.15	0.15	0.1	1.61	1.04	35.4%
7	150	0.05	0.25	0.1	1.31	0.81	38.1%
8	150	0.10	0.15	0.15	1.02	0.98	3.9%
9	150	0.15	0.20	0.05	1.27	0.82	35.4%

Figure 4.29 shows that the comparison value during dry and wet machining environment in terms of surface roughness from this below figure observed that minimum surface roughness was obtained during wet machining conditions. So cutting conditions were one of the factor that affect quality of surface finish.

The minimum surface roughness at experiment number eight was 1.02 µm in dry machining and 0.81µm in wet machining. It was noticed that maximum reduction of surface roughness was 38.1 % at experiment number seven and minimum reductions of surface roughness was

3.9% at experiment number eight in wet machining when compared with dry machining. This variation is due to temperature raised between cutting tool and workpiece material.



	1	2	3	4	5	6	7	8	9
Dry machining	1.52	1.33	1.67	1.64	1.42	1.61	1.31	1.02	1.27
Wet machining	1.03	1.08	1.12	1.11	1.22	1.04	0.81	0.98	0.82

Figure 4.29 Comparison of surface roughness during dry and wet machining

4.7.2. Chips Generated During Dry and Wet Machining Conditions

From the obtained measurement result maximum length and contineous curled chips obtained during wet machining conditions but minimum length and discontinuous chis mostly formed during dry machining conditions. And also maximum thickness of chips formed during wet machining conditions at maximum feed and depth of cut. This variation is due to temperature raised between cutting conditions in case on wet machining the chance of chip breakability was low. The temperature generated in cutting zone was less significant during wet machining for surface roughness.

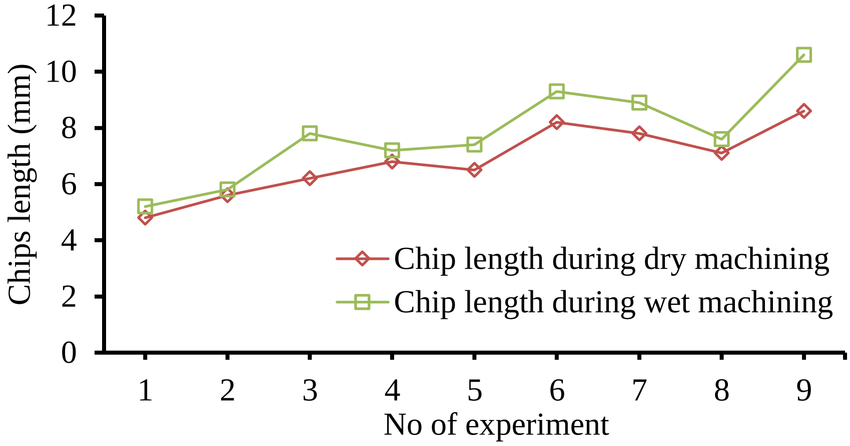


Figure 4.30 Variations of generated chip length during the experiment

From figure 4.31 shows that the variation chip thickness generated during experimental study in dry and wet machining conditions. As observed maximum chip thickness was obtained during wet machining conditions at maximum value of feed.

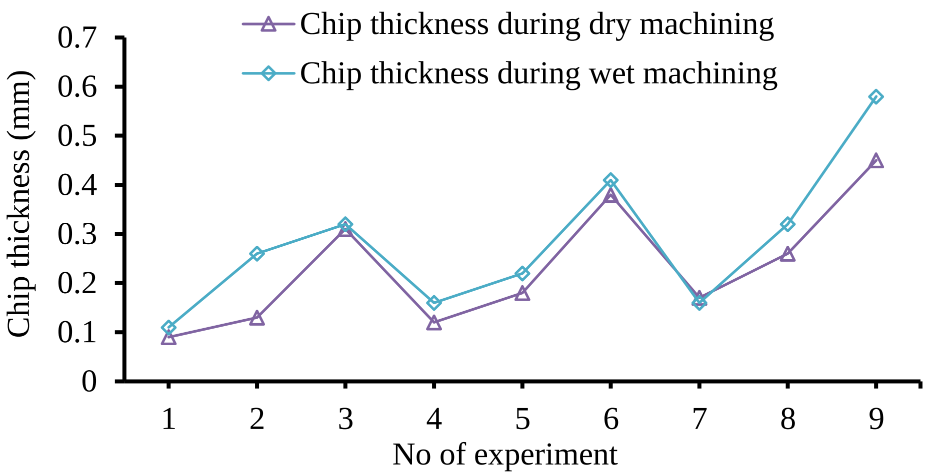


Figure 4.31 Variations of generated chip thickness during the experiment

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

This study was focused on investigation of machining parameters carried out on the double cutting tool turning on AISI 1045 steel with ceramics inserted cutting tools. Taguchi L9 orthogonal array and signal-to-noise ratio method was used for optimization of input parameters such as cutting speed, feed and depth of cut to investigate their effect on surface finish. Therefore, based on the experimental results the following conclusions were made:

- ✓ In the dry turning; least surface roughness of 1.02 µm was achieved at the combinations of cutting parameters 150 m/min cutting speed, 0.1mm/rev feed, 0.2mm first depth of cut and 0.05mm second depth of cut were achieved. During wet turning operations minimum surface roughness of 0.81µm was obtained at the optimum cutting parameters of 150m/min, 0.15mm/rev, 0.2mm first depth of cut and 0.1mm second depth of cut.
- ✓ During dry turning condition the most influential cutting parameter was cutting speed is on 1st rank, the feed is on 2nd rank, first depth of cut is on 3rd and second depth of cut is on 4th rank affecting surface roughness. During wet turning; cutting speed was on 1st rank, the feed was on 2nd rank, second depth of cut was on 3rd and first depth of cut is on 4th rank for surface roughness these ranks were according to percentage contributions on good quality of surface roughness.
- ✓ Analysis of variance (ANOVA) shows cutting speed was the most significant parameter for surface roughness followed by feed rate for both dry and wet cutting conditions. The percentage contribution was 74.57% and 23.02% during dry turning, respectively. Under wet cutting conditions the percentage contributions of cutting speed and feed were 49% and 21.5% respectively.
- ✓ The optimum cutting condition for maximum MRR of 93.75 mm^3/sec was obtained at cutting speed of 150 m/min, feed of 0.15 mm/rev, first depth of cut of 0.2mm and second depth of cut of 0.05mm. The Analysis of Variance justified the rank order of significant parameters from responses for the mean of large was the better feed on 1st rank, first tool depth of cut on 1st rank, speed on 3rd rank and second tool depth of

cut is on 4th rank. The most significant parameter for material removal rate was feed and the next was depth of cut for first cutting tool.

- ✓ During dry machining the maximum average temperature of 80.3^0C on fist cutting tooltip was measured and 72.3^0C was measured on the second cutting tooltip obtained at experiment number seven (cutting speed of 150 m/min, feed of 0.05mm/rev, first depth of 0.25mm and second depth of 0.1mm). At the minimum average temperature obtained for experiment number one conducted by cutting depth of 90m/min, 0.05 mm/rev, 0.15mm first depth and 0.05mm. The minimum temperature measured was 46.5^0C for first cutting tool and 44.4^0C for second cutting tool.
- ✓ The investigation on chips morphology, generated from the wet machining did not show any thermal effect, however, chips produced from the dry machining exhibited bending of chip segments due to thermal softening and fracture. The maximum length and thickness of chips was generated during wet machining conditions.

5.2. Recommendation

Based on the results and conclusions of this study, forwards the following recommendations

- ✓ In this study double tool turning of AISI 1045 steel has been used this can be further extended to other materials types to study the effect of cutting parameters on the surface roughness under different machining environment of double tool turning operations.
- ✓ The industries of machining operations of AISI 1045 products mostly Akaki Basic Metals Industry and other machine shop industries can use the optimized cutting parameters of cutting speed 150 m/min, feed of 0.1 mm/rev, first tool depth of cut at 0.15 mm and second tool depth of cut at 0.15mm during double cutting tool turning of AISI 1045 steel materials.

5.3. Scope for Future Work

As a future research work, the following will be carried out for further study:

- ✓ In this research, only three cutting parameters such as cutting speed, feed and depth of cut have been studied, further researches can be study the effect and analyses of cutting tool geometry, cutting forces exerted and vibrational effect during the double cutting tool turning operation on surface roughness.

- ✓ In this experimental investigations, analysis the machining parameters on surface roughness by using dry and wet machining conditions, but this can further be extended to other cutting conditions like cryogenic, solid lubricant and applying nano-coolant for further optimization of cutting parameters.
- ✓ In the present work double cutting tool turning operation, the work can be extended to another multi-tool machining process like triple cutting tool on turning operations.

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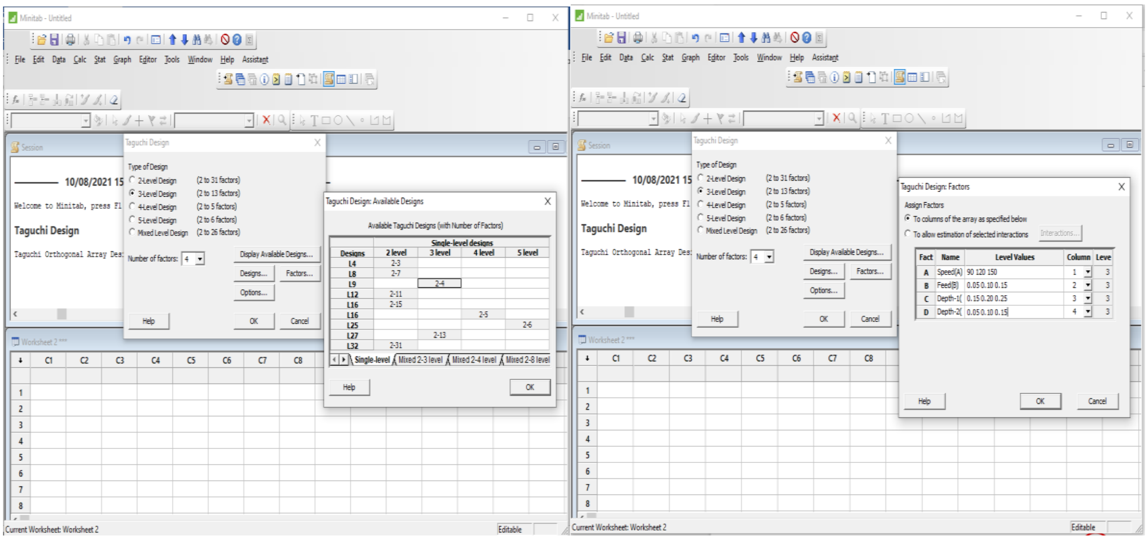
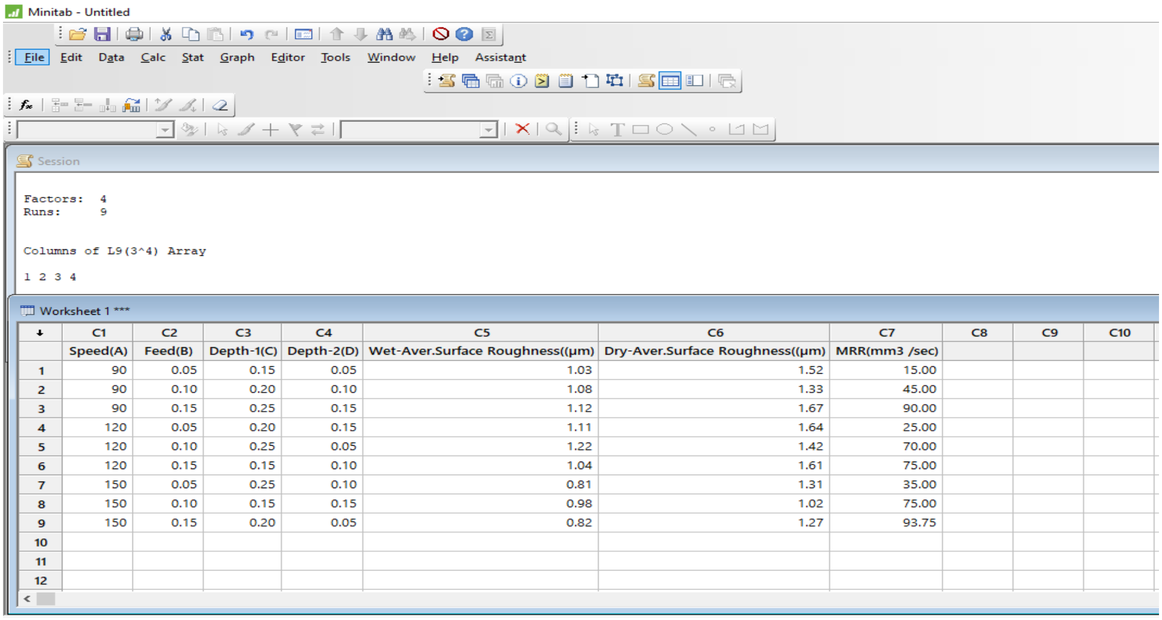
APPENDIXES

Appendix 1: Tool Material Specification

Specifications of Using Tools During the Experiment	
Work piece material(AISI 1045)	AISI 1045 medium carbon steel round bar and (Φ 40 mm x 500mm long). Chemical composition of(C - 0.45%, Mn - 0.60%, S - 0.009%, P-0.011%, Si - 0.30%, Ni - 0.08%,Cr - 0.07%)
Cutting insert	Ceramics insert (ISO specification TNGA 160408)
Tool holder	ISO specification of MTJNR 2020 M10
Cutting insert geometry	-6°, -6°,6°,6°,30°,0°, and 0.8mm tool signature.
Machine Tool	Conventional lathe CM 260 model.
Profilometer	Contact type surface roughness tester Model 657111
Turning process parameter	Cutting speed (90m/min, 120m/min and 150m/min), feed (0.05mm/rev, 0.1mm/rev and 0.15mm/rev), first depth of cut (0.15mm, 0.2mm and 0.25mm) and second depth of cut (0.05mm, 0.1mm and 0.15mm)
Environments	Wet (emulsion based flood cooling 1:20 soluble oil) and dry machining conditions

Appendix 2: Minitab Software and Design of L9 Orthogonal Array




Minitab - Untitled

Session

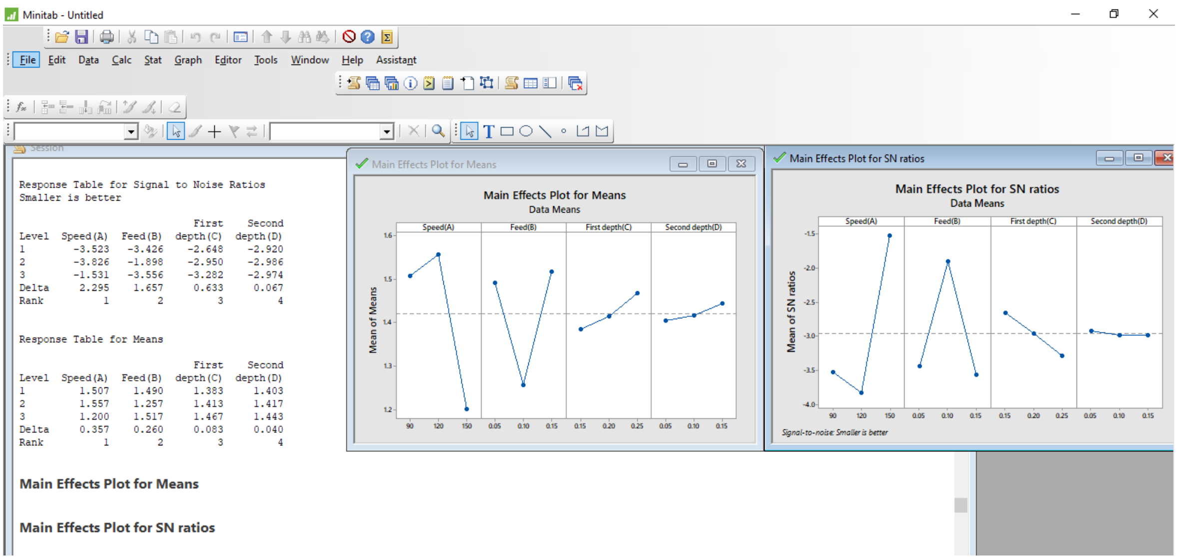
```
Factors:  4
Runs:     9

Columns of L9(3^4) Array

1 2 3 4
```

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	Speed(A)	Feed(B)	Depth-1(C)	Depth-2(D)	Wet-Aver.Surface Roughness((µm)	Dry-Aver.Surface Roughness((µm)	MRR(mm3 /sec)			
1	90	0.05	0.15	0.05	1.03	1.52	15.00			
2	90	0.10	0.20	0.10	1.08	1.33	45.00			
3	90	0.15	0.25	0.15	1.12	1.67	90.00			
4	120	0.05	0.20	0.15	1.11	1.64	25.00			
5	120	0.10	0.25	0.05	1.22	1.42	70.00			
6	120	0.15	0.15	0.10	1.04	1.61	75.00			
7	150	0.05	0.25	0.10	0.81	1.31	35.00			
8	150	0.10	0.15	0.15	0.98	1.02	75.00			
9	150	0.15	0.20	0.05	0.82	1.27	93.75			
10										
11										
12										


Minitab - Untitled

```
Response Table for Signal to Noise Ratios
Smaller is better

                                First    Second
Level  Speed(A)  Feed(B)  depth(C)  depth(D)
1        -3.523   -3.426    -2.648    -2.920
2        -3.826   -1.898    -2.950    -2.986
3        -1.531   -3.556    -3.282    -2.974
Delta     2.295    1.657     0.633     0.067
Rank          1        2         3         4


Response Table for Means

                                First    Second
Level  Speed(A)  Feed(B)  depth(C)  depth(D)
1         1.507    1.490     1.383     1.403
2         1.557    1.257     1.413     1.417
3         1.200    1.517     1.467     1.443
Delta     0.357    0.260     0.083     0.040
Rank          1        2         3         4
```

Main Effects Plot for Means

Main Effects Plot for SN ratios

Appendix 3: Tooltip Temperature Results During Dry Machining

Tooltip Temperature During Dry Machining								
No of Exp.	Temperature for Tool-1 (°C)				Temperature for Tool-2 (°C)			
	T_1	T_2	T_3	**Av.T_a**	T_1	T_2	T_3	**Av.T_a**
1	35.3	36.5	37.8	**36.5**	32	33.6	37.6	**34.4**
2	50.2	49.3	54.4	**51.3**	46.3	48.6	49.7	**48.2**
3	57.4	59.8	63.3	**62.1**	54.5	56.3	57.2	**56.8**
4	63.5	66.9	67.5	**66.1**	58.4	60.5	62	**60.4**
5	69.6	68.5	64.5	**66.8**	67.6	67.6	69.4	**68.2**
6	64	66.2	65.4	**65.2**	58.8	59	62.5	**60.1**
7	78	83.8	79.7	**80.3**	76.1	76.5	76	**76.2**
8	66	68.6	68	**67.5**	72	72.1	72.8	**72.3**
9	75	76.7	73.3	**75.5**	72.1	72.3	72.5	**72.1**

Appendix 4: Values of Surface Roughness Parameters for Both Cutting Conditions.

Experimental Values of Surface Roughness in Dry Machining														
No of Exp.		R_a (μm)				R_z (μm)			R_q (μm)			R_t (μm)		
		R_{a1}	R_{a2}	R_{a3}	Av.Ra	R_{z1}	R_{z2}	R_{z3}	R_{q1}	R_{q2}	R_{q3}	R_{t1}	R_{t2}	R_{t3}
1	D	1.64	1.48	1.60	**1.52**	5.99	5.23	4.35	1.71	1.38	1.16	15.95	7.29	8.04
	W	1.12	1.14	0.83	**1.03**	4.12	4.03	3.21	1.06	1.24	1.01	6.42	4.16	5.12
2	D	1.26	1.35	1.32	**1.33**	8.51	4.17	7.02	2.08	1.08	1.93	19.46	7.38	21.9
	W	1.28	0.85	1.12	**1.08**	4.54	5.54	4.16	0.83	1.03	1.74	8.61	6.32	9.12
3	D	1.78	1.64	1.59	**1.67**	7.42	5.13	6.42	2.04	1.07	1.86	18.7	7.26	19.3
	W	1.67	1.06	1.16	**1.12**	5.64	4.86	6.12	1.89	1.02	1.64	7.6	4.52	6.62
4	D	1.72	1.58	1.62	**1.64**	4.12	6.85	4.63	1.02	2.0	0.99	5.20	8.56	6.66
	W	0.83	1.75	0.76	**1.11**	3.21	5.62	4.12	0.75	1.05	0.89	4.51	8.31	6.02
5	D	1.35	1.40	1.51	**1.42**	5.62	7.06	4.85	1.06	2.05	1.06	4.96	7.26	5.47
	W	1.55	1.08	1.03	**1.22**	4.82	6.54	3.89	1.04	2.01	1.02	4.36	7.16	5.32
6	D	1.74	1.52	1.57	**1.61**	5.71	6.6	4.14	1.30	1.66	1.06	7.79	1.06	5.82
	W	1.05	1.31	0.78	**1.04**	4.21	5.01	3.21	1.01	1.20	0.98	6.20	1.04	5.62
7	D	1.24	1.42	1.27	**1.31**	4.12	3.95	2.89	1.19	0.99	0.79	5.69	5.24	5.51
	W	0.92	0.83	0.68	**0.81**	3.24	2.84	2.56	1.17	1.03	0.62	4.57	5.12	4.42
8	D	1.01	0.96	1.09	**1.02**	4.71	4.43	3.91	1.28	1.28	0.56	7.02	7.24	6.40
	W	0.98	0.86	1.03	**0.98**	4.15	4.23	3.05	0.98	1.36	0.76	6.61	6.93	6.02
9	D	1.36	1.21	1.24	**1.27**	3.42	4.72	3.54	0.87	1.33	0.94	4.80	9.15	6.71
	W	0.73	1.05	0.70	**0.82**	2.62	3.17	2.85	0.79	1.65	1.05	3.85	8.65	5.68

Note: D-Dry machining, W-Wet machining