Comparison of Effect of Cutting Parameters during Dry and Wet Turning of AISI 1020 Steel

By: Boki Dugo Bedada

A Thesis Submitted to
The Department of Mechanical Design and Manufacturing Engineering

School of Mechanical, Chemical, and Material 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

July, 2021
Adama, Ethiopia

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Co-advisor: Dr. Moera Gutu

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Declaration

I hereby declare that this Master Thesis entitled "**Comparison of Effect of Cutting Parameters during Dry and Wet Turning of AISI 1020 Steel**" 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

Boki Dugo Bedada	________________________	________________
Name of the student	Signature	Date

Recommendation

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "**Comparison of Effect of Cutting Parameters during Dry and Wet Turning of AISI 1020 Steel**" prepared under our guidance by **Boki Dugo Bedada** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Manufacturing Engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Guteta Kebeta	______________________	_______________
Major Advisor	Signature	Date
Dr. Moera Gutu	______________________	_______________
Co-advisor	Signature	Date

Approval Page

We, the advisors of the thesis entitled "**Comparison of Effect of Cutting Parameters during Dry and Wet Turning of AISI 1020 Steel**" and developed by **Boki Dugo Bedada**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Major Advisor	Signature	Date
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Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Boki Dugo Bedada** have read and evaluated the thesis entitled "**Comparison of Effect of Cutting Parameters during Dry and Wet Turning of AISI 1020 Steel**" and examined the candidate during 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 and Abbreviations

AA: Arithmetic Average

AISI: American international system standard

ANOVA: Analysis of variance

CBN: Cubic boron nitride

C_c: Coolant Cost

C_e: Energy Consumptions Cost

C_L: Lighting Cost

C_m: Machine Depreciation Cost

C_o: Overhead Cost

C_{op}: Operator Cost

C_t: Tool Cost

C_T: Total Cost

CLA: Central Line Average

CNC: Computer Numerical Control

CVD: Chemical Vapor Deposition

DMTG: Dalian Machine Tool Group

DOE: Design of experiment

DoF: Degree of freedom

f: Feed Rate

HRC: Rockwell Hardness

MQL: Minimum Quantity Lubrication

MRR: Material removal rate

N: Spindle Speed

OA: Orthogonal Array

p-value: Probability

PVD: Physical Vapor Deposition

R_a: Average Surface roughness

rpm: Revolution per Minute

SiN: Silicon nitride

S/N: Signal to Noise

SS: Sum of Square

MSS: Mean Sum of Square

t: Depth of Cut

t: Time

t_m: Machining Time

v: Cutting Speed

Abstracts

Cutting fluids application in turning operation helps to remove heat during cutting, to achieve better tool life, and to facilitate flushing of chips. On the other hand dry turning is important due to saving cost of cutting fluids, safety of operator and clean environment. Producing parts with a better surface finish is the major challenges in manufacturing industry. In this work, experiment was conducted to compare the effect of cutting parameters (spindle speed, feed rate and depth of cut) on surface roughness and to investigate the optimum cutting parameters for surface roughness during dry and wet turning of AISI 1020 steel using cemented carbide tool on CNC lathe machine. Analysis of cutting temperature, tool life, and machining cost were also done to for dry and wet turning. Surface roughness and cutting temperature were measured by VOGEL surface roughness tester and infrared thermometer respectively. L9 Taguchi orthogonal array design was selected for design of experiment. The effect of each cutting parameters on responses were identified by the analysis of variance (ANOVA). The result shows that Surface roughness decreased with increasing of spindle speed, and decreasing feed rate and depth of cut. Increasing in cutting parameters was resulted in increased cutting temperature and reduced tool life. But application of coolant highly minimize the cutting temperature and increase tool life. Surface roughness, cutting temperature and tool life are highly affected by spindle speed both in dry and wet turning, while total machining cost highly affected by spindle speed in dry turning and by feed rate in wet turning. Wet turning results in lower surface roughness, cutting temperature and longer tool life, but machining cost of wet turning was 56% greater than that of dry turning.

Keywords: *Cutting Parameters, Dry Turning, Wet Turning, AISI 1020 Steel, Surface Roughness, Cutting Temperature, Tool Life, Machining Cost.*

CHAPTER 1

1. INTRODUCTIONS

1.1. Background of the Study

Machining is the most commonly used method of all manufacturing process. It involves the cutting of metals to obtain the desired geometry with accurate dimensional tolerances and proper surface finish. Turning is the machining operation in which a cutting tool fed linearly parallel to the axis of rotation of the spindle to remove material from the surface of a rotating cylindrical workpiece. Turning is carried out on a lathe machine that provides the power to turn the workpiece at a given rotational speed and to feed the cutting tool at a specified rate and depth of cut. Therefore, three cutting parameters, i.e. spindle speed, feed rate, and depth of cut are the most effective cutting parameters in turning operations (Wegener et al. (2016)).Therefore, three cutting parameters, i.e. cutting speed, feed rate, and depth of cut are the most effective cutting parameters in turning operations (Shivade et al. (2014)).

Nowadays metal cutting industry is looking for producing parts with high quality at minimum cost processes in a short period. Dry machining is ecologically desirable and is considered a necessity for manufacturing enterprises. However, in dry machining, the friction and adhesion between chip and tool results in higher cutting temperatures and, consequently high cutting tool wear rates which cause shorter tool life (Ogendenpe et al. (2018); Kumar et al. (2015)). To overcome these problems, manufacturers most of the time used wet machining to reduce cutting temperature and improve the tool life and surface quality. However dry machining was found to be appropriate for cost reduction and for protecting the environment and health of the workers. The cost of cutting fluid was founded to be about 17% of the total manufacturing cost, which can easily exceed the cost of cutting tools (Weinert et al. (2004); Klocke and Eisenblaetter (1997)).

1.2. AISI 1020 Steel

AISI 1020 mild steel is low carbon steel which characterized by a combination of high ductility and good strength and its ability to be easily machined. Due to these properties, it is applicable in general engineering machinery components such as shafts, cams shafts, pins, spindles, gears, pinions, bolts, and nuts which are manufactured by machining.

1.3. Turning Operation, Turning Parameters and Turning Machine

1.3.1. Turning Operation

Turning is the removal of material from the outer diameter of a rotating cylindrical workpiece using a single-point cutting tool which is held stationary on the tool post and moved parallel to the workpiece axis with suitable Speed, Feed, and Depth of Cut, Turning is used to produce a cylindrical surface on the workpiece. In turning the diameter of the workpiece, usually to a specified dimension and the length of the workpiece remains the same. Figure 1.1 Shows the turning operation.

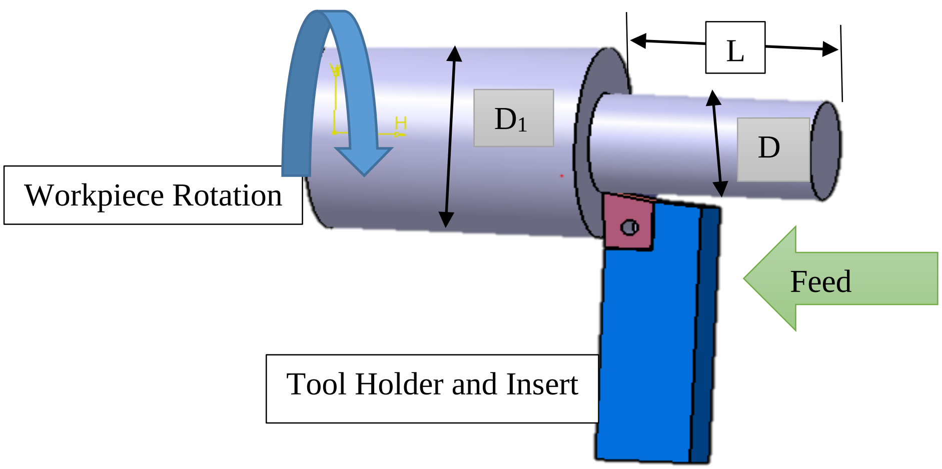


Figure 1.1. 3D Catia Schematic Representation of Turning Operation

Where,

D1= initial diameter of the work piece before machining

D2= final diameter of the work piece after machining

L = machining length of the work piece

1.3.2. Turning Parameters

The three primary factors in any basic turning operation are speed, feed, and depth of cut.

a) Spindle Speed (N)

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (RPM) it tells their rotating speed. It is the amount of full rotation of the spindle in one minute time. But the important feature for a particular turning operation is the surface speed/cutting speed, or the speed at which the work piece material is rotating fast against the stationary cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. Every different diameter on a work piece will have a different Speed, even though the rotating speed remains the same.

b) Feed Rate

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in millimeter per minute (mm/min).

c) Depth of Cut:

Depth of Cut is practically self-explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the Depth of Cut because this layer is being removed from both sides of the work

1.3.3. Turning Machine

The turning machines are every kind of lathes. The lathe machine used in manufacturing can be classified as engine, turret, automatics, and numerical control, etc. They are heavy-duty machine tools and have a power drive for all tool movements. Their size commonly ranges from 12 to 24 inches swing and from 24 to 48 inches center distance but swings up to 50 inches and center distances up to 12 feet are not uncommon. Most engine lathe machines are equipped with chip pans and coolant circulating systems. Figure 1.2 shows a lathe machine.

Figure 1.2. Lathe machine

1.4. Dry Machining and Machining with Cutting Fluid

Cutting fluids are employed in machining operations to enhance the tribological processes, which occur when two surfaces, the tool, and workpiece are in contact. The cutting fluid improves the tool life, surface roughness of the workpiece, and therefore the process as an entire. It also helps to carry away the warmth and debris produced during machining. On the other hand, cutting fluids have many detrimental effects. Machining experiences high temperatures because of friction between the tool and workpiece, thus influencing the workpiece dimensional accuracy and surface quality.

Machining temperatures are often controlled by reducing the friction between the tool-workpiece and tool–chip interface by using effective lubrication. Cutting fluids are the conventional option to act as both lubricants and coolants. However, their application has several negative effects like environmental pollution, dermatitis to operators, water pollution, and oil contamination during disposal (Diniz and Micaroni, (2002); Buongiorno (2010)). Further, the cutting fluids also incur a major portion of the entire manufacturing cost. These factors prompted investigations into the utilization of biodegradable coolants or coolant-free machining. Hence, researchers worked with dry machining, coated tools, cryogenic cooling, minimum quantity lubrication (MQL), and solid lubricants as an alternative to cutting fluids.

Dry machining has been reported to be capable of eliminating cutting fluids with the advancement of the cutter materials (Ogedengbe et al. (2018)). Dry machining requires less power and produces a smoother surface than wet machining at specified cutting conditions (Kumar et al. (2015)). In tribological applications of hard protective coatings, the toughness is as important as their hardness, since both properties greatly influence the wear resistance of coated tools (Weinert et al. 2004)). This study was focused on the comparison these two material removals methods and the effect of the main cutting parameters such as spindle speed, feed rate, and depth of cut on the surface roughness, cutting temperature, tool life, and analysis machining cost.

1.5. Statement of Problem

Increasing the quality of machined components is the major challenges in the industry. Surface roughness remain the main indicator of machined component quality as it is related with surface quality. The increasing importance of turning operation in industry efforts are made to improve the surface roughness of the material. In turning, higher values of cutting parameter offered opportunities for increasing productivity but it also involves greater risk of deterioration in surface quality and shorter tool life, if there are improper process parameters were used. Cutting parameters such as spindle speed, depth of cut and feed rate are the most common factors which affects the result of machining particularly the surface finish of the product. Higher surface roughness leads to unacceptable product with poor dimensional accuracy, less precision of surface finish, quick wear of part and crack formation. Due to the increasing demand of higher precision components for its functional aspect, and production price reduction, it is important to study the effect of cutting parameters on surface roughness and machining cost in the metal turning operation process. Therefore, to minimize the failures of materials due to properties like corrosion, wear and fatigue it is important to study the effect of cutting parameters on the surface roughness of AISI 1020 steel in dry and wet turning process.

1.6. Objective

1.6.1. General Objective

The general objective of this study is to compare the effect of cutting parameters (depth of cut, feed rate and spindle speed) on surface roughness, cutting temperature, tool life and machining cost during dry and wet turning of AISI 1020 steel.

1.6.2. Specific Objectives

To achieve this general objective the following specific objectives will be required;

1. To compare the effect of cutting parameters on surface roughness and optimize cutting parameters for surface roughness using Taguchi Method for dry and wet turning of AISI 1020 steel.
2. To investigate the effect of cutting parameters on cutting temperature for dry and wet turning of AISI 1020 steel.
3. To analyze tool life for dry and wet turning of AISI 1020 steel.
4. To analyze machining cost for dry and wet turning of AISI 1020 steel.

1.7. Significance of the Study

Studying effective cutting parameters that affects surface finish, cutting temperature and tool life for dry and wet turning of AISI 1020 mild steel is very important to produce high quality products and to obtain longer tool life. Presence and absence of cutting fluid have a great effect on general product qualities and tool life. This study will also be important to obtain optimum cutting parameters that produce high surface finish both in dry and wet turning. Generally, the significances of the study are the following;

- To obtain better surface finish.
- To increase precision of product.
- To obtain longer tool life.
- To enable customer satisfaction

1.8. Scope and Limitations of the Study

This study is focus on turning of AISI 1020 steel to compare the effect of cutting parameters (spindle speed, feed rate and depth of cut) on surface roughness, cutting temperature, and tool life and identifying most significant cutting parameter that affect surface roughness, cutting temperature and tool life in dry and wet turning condition. Besides, analysis of machining cost was also performed for dry and wet turning of AISI 1020 steel on CNC lathe machine. But in this study the effect of cutting force and machine vibration on the surface roughness was not included because of difficulties to measure cutting force without dynamometer and difficulties to measure vibration frequencies.

1.9. Structure of the Thesis

This thesis entitled as Comparison of Effect of Cutting Parameters during Dry and Wet Turning of AISI 1020 Steel has five chapters. This chapter presents background of the study. Chapter 2 presents related literature works on dry and wet machining of different materials, surface roughness and effect of cutting parameters on surface roughness, tool life, cutting temperature, machining cost, problem of the statement, Research gap, objectives, significance of the study, scopes and limitations of the study. Chapter 3 discussed the experimental procedures, equipment used and materials used for the study. Chapter 4 presents result and discussion of major findings of this experimental work. Chapter 5 discussed or summarize the study, conclude from overall study, recommendation and future research directions.

1.10. Research Motivation

In any manufacturing industries surface quality and cost of machined product plays a vital role to increase the customers demand and the competitiveness between the manufacturers. Without surface quality it is difficult to talk about high production rate, long life of product without defect, crack formation and corrosion resistance. Besides surface quality plays a vital role in the applications of assembly parts in which movable parts are used. Thus, the motivation of this work is mainly due to the above said reasons.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Introduction

AISI 1020 steel is characterized by a combination of high ductility, good strength, and its ability to be easily machined. This property makes it used in a variety of engineering applications, which include axles and automotive parts, and cams that are manufactured by machining. Turning is a single-point cutting process in which a cutting tool is used to remove material from a rotating cylindrical workpiece. After the machining process, the resulting surface roughness is very important due to its role in evaluating the quality of the manufactured component. Irregularities in the machined product surface, which may form sites for nucleation of corrosion and cracks, can affect its performance. Therefore, the selection of optimized cutting parameters is fundamental to achieve the required product surface quality (Zurita et al. (2017); Tulasiramarao(2013)).

2.2 Surface Roughness and Effect of Cutting Parameters on Surface Roughness

Surface roughness is an important factor that determines the quality of a machined product surface. It depends on many parameters such as cutting condition, machine tool vibration, cutting tool, and work holding devices. The cutting speed, feed, and depth of cut have a major influence on the surface roughness of the finished component. A lot of research work has been directed towards improving the surface quality of the machined component.

The surface quality of the contacted surface highly determines the efficiency of the interfaced machine parts. This quality is generally characterized as the surface roughness (Suker et al. (2016)). It is influenced by factors such as spindle speed, feed rate, depth of cut, workpiece hardness, stability of the machine tool, and the workpiece set up (Rao and Venkatasubbaiah (2016); Nurhaniza et al. (2016); Ezugwu et al. (2016). This was for end milling, the same is true for turning process. Improper selection of cutting conditions during machining could result in surfaces with high roughness, therefore; a proper estimation of surface roughness has been the focus study of several researchers in the past three decades (Ravi et al. (2015)). Yusuf et al. (2010) performed an experimental investigation on the effects of cutting parameters such as feed rate, depth of cut, and cutting speed and they reported that cutting speed is the most significant factor followed by the depth of cut and feed rate.

Suker et al. (2016) investigated the effect of cutting conditions in the turning process on surface roughness for different materials and claimed that cutting speed was the most influencing process parameter. Debnath et al. (2016) studied the influence of cutting fluid conditions and cutting parameters (cutting speed, feed rate, and depth of cut) on surface roughness and tool wear in turning of mild steel bar using a TiCN + Al2O3 + TiN coated carbide tool insert in the CNC turning process using Taguchi method. It is concluded that feed rate is the most influential factor (34.3%) on surface roughness while cutting speed contributed the most (43.1%) to tool wear. Besides cutting fluid also showed a significant contribution to surface roughness (33.1%) as well as to tool wear (13.7%). They concluded that dry machining is applicable for conventional machining on steels, steel alloys, and cast irons except for aluminum alloys. Even so, the high friction between the tool and the workpiece in dry cutting conditions significantly increases in temperature causes a higher level of abrasion, diffusion, and oxidation.

Rodrigues et al. (2012) conducted an experimental study on turning Mild steel using a High-speed cutting tool. The turning parameters considered in this work are cutting speed, feed, depth of cut and the response are surface roughness and cutting force. Experimental design is the Response surface method. This work predicted that feed rate and depth of cut have a significant influence on both surface roughness and cutting force. Deva et al. (2015) studied the experimental investigation of machining parameters such as cutting speed, feed rate, and depth of cut influence over surface roughness parameters during turning AISI 4340 steel using Taguchi's technique Signal-to-Noise ratio (S/N ratio) and Analysis of Variance (ANOVA) to determine the most contributing factor. It was concluded that the feed rate is the most significant factor contributing by 70.50%, depth of cut by 18.54%, and cutting speed by 9.15%. Muamar et al. (2021) studied the cutting parameters (spindle speed, feed rate and depth of cut) and their effect on the surface roughness of low carbon steel workpiece machined under dry and wet turning conditions, using carbide cutting tool with a constant tool nose radius. Results revealed that, surface roughness is highly affected by the cutting parameters and also the cooling conditions.

Johari (2008) studied the effect of cutting parameters (cutting speed, feed rate, and depth of cut) during dry turning of EN8 using an ordinary lathe machine deducing that the spindle speed (the most significant factor) contributed 63.90%, depth of cut (second most significant factor) contributed only 11.32% and feed rate contribution was least with 8.33% for Ra. The contribution for feed and RPM was 60.91% and 29.83%, whereas the depth of cut contributed only 7.82% for material removal rate, in dry turning of EN8 on lathe concluded that speed and depth of cut had a negligible effect on the surface roughness and feed rate for surface roughness shows an increasing trend. Senthil et al. (2010) has conducted an experimental study on turning and facing Inconel 718 using an uncoated carbide insert considering cutting parameters as cutting speed, feed, depth of cut, and the responses as are surface roughness and flank wear. It is predicted that for turning, cutting speed and depth of cut are dominant factors, and for facing cutting speed, feed is dominant factors. Isik (2010) has conducted an experimental study on turning of AISI 1050 steel using CVD coated carbide Tic+Al2O3 +TiN insert (ISO P25). This work focuses on the cutting parameters cutting speed, feed, depth of cut, and the responses flank wear, tool life, tool wear, and surface roughness. The experiment was carried out in both dry and wet cooling conditions, the tool wear is measured in terms of flank wear (VB). It was concluded that the reduction in tool wear increases the tool life and in turn, reduces cutting zone temperature with a favorable change in chip tool interaction. Besides cutting fluid reduces the main cutting force due to the improved and intimate chip tool interaction.

Harsimran et al. (2012) have investigated an experimental study on turning mild steel using a carbide cutting tool. The parameters considered in this work are cutting speed, feed rate, depth of cut and the response is surface roughness. The experiment is designed using the Taguchi DOE. This work predicted that for turning cutting speed, depth of cut, and feed rate are dominant factors for the best value of the surface. Suleiman et al. (2011) have conducted an experimental study on turning of AISI 1045 steel using a molybdenum high-speed steel turning tool. The turning parameters considered in this work are depth of cut, feed rate, spindle speed, and the response is surface roughness. The experiment was designed using the Box Benhenken experimental design. It is suggested that high cutting speed and spindle speed has a positive effect on surface roughness against feed rate.

Hardeep et al. (2011) have conducted an experimental investigation on turning of EN-8 using a carbide cutting tool. The cutting parameters focused in the work are depth of cut, feed rate and the response are surface roughness and material removal rate. Taguchi methodology has been applied to optimize cutting parameters is applied to analyze surface roughness. The experimental results were analyzed using analysis of variance (ANOVA) for identifying the level of significance of input factors. From the result it is concluded that spindle speed is the most significant factor, depth of cut is the second most significant factor, and the feed rate has the least factor on surface roughness. Upinder et al. (2012) has conducted an experimental study on turning of Medium Carbon Steel AISI 1045 using STALLION-100 HS CNC lathe. The turning parameters considered in this work are cutting speed, feed rate and depth of cut and the response is surface roughness. The experimental design used in this work is the L27 OA Taguchi design. In this work, the result shows that the surface roughness is mainly affected by feed rate and cutting speed. With the increase in feed rate the surface roughness increases and with a decrease in cutting speed the surface roughness increases.

Kagade et al. (2012) have investigated an experimental study on turning of High Carbon High Chromium steel (HCHC) using CNMG 09 03 08-PF carbide insert tool. The cutting parameters considered in this work are cutting speed, depth of cut, feed rate and the outcomes considered are surface roughness and spindle load. This work has revealed a conclusion that speed has maximum effect and depth of cut has minimum effect on surface roughness. Butola et.al (2017) studied the effect on surface properties of mild steel during dry turning and wet turning on the lathe. The result shows that the surface property was improved when the mild steel was turned in wet conditions.

2.3 Dry and Wet Machining

Dry machining is ecologically desirable and it is considered a necessity for manufacturing enterprises. Metal fabrication industries is compelled to consider dry machining to enforce environmental protection laws for occupational safety and health regulations. The advantages of dry machining include non-pollution of the atmosphere (or water); no residue on the chip which will be reflected in reduced disposal and cleaning costs and no danger to health. Moreover, it offers machining cost reduction. However, in dry cutting operations, the friction and adhesion between chip and tool tend to be higher, which causes higher temperatures, higher wear rates, and, consequently, shorter tool life. On the contrary, machining using cutting fluids has the advantage of better part quality and less tool wear. Cutting fluids have been utilized during the cutting process with the purpose to improve the characteristics of the tribological processes which are always present on the contact surfaces between the tool and the workpiece. Generally, the use of cutting fluids increases the tool life, contributes to a more economical cutting speed, and generally improves the efficiency of the production systems (Galanis et al. (2008)).

A tour of most factories will demonstrate that some cutting operations are carried out dry. However, in many other cases, a flood of liquid is directed over the tool, to act as a coolant and/ or a lubricant. These cutting fluids perform a very important role and many operations cannot be efficiently carried out without the correct fluid (Liew et al. (2017)). They are used to prevent the tool, workpiece, and machine from overheating and distorting, increase tool life, improve surface finish and clean the chips from the cutting area.

2.3.1 Dry machining

Dry machining is a machining process without the use of any cutting fluid during machining. It is usually used for machining steel using hard-cutting tools. According to Avila and Abrao (Avila and Abaro (2001)), lower thermal conductivity and fracture toughness of ceramics may lead to early tool fracture due to thermal and mechanical shock. For this reason, dry cutting is the best choice for ceramics cutting tools. However, Arulraj et al. (2014) found that dry cutting is very difficult to be implemented on the existing shop floor as it needs an extremely rigid machine tool and ultra-hard cutting tool. Dilbag and Rao (2008) pointed out that dry turning can enhance the surface finish, but the tool life and wear problems are corresponding with it.

Das et al. (2013) found that the most significant parameter during dry turning of hardened AISI 4340 steel with CVD (TiN + TiCN + Al2O3 + ZrCN) multilayer coated carbide inserts was cutting speed. The interactions of the factors were also found to be significant between cutting speed-feed and depth of cut-feed on surface roughness. They conclude that cutting speed harms surface roughness performance. By the given range of parameters, surface roughness is principally affected by feed and the depth of cut has a negligible impact. Azwadi et al. (2017) mentioned that by using dry machining, the manufacturing cost up to 7–17% can be reduced when compared to cutting fluid. However, in dry machining, a high level of friction between the two surfaces (tool-workpiece and tool-chips), can be brought to a high temperature in the machining zone. The high temperature at the machining zone will eventually lead to tool life problems and inaccurate dimensions of the workpiece. Therefore the disadvantages associated with it should be compensated to pursue dry machining (Bhuiyan et al. (2014)).

2.3.2 Wet Machining

Wet machining is a machining technique in which a cooling jet is aimed at the active zone for cooling, lubricating, and gets rid of chips produced during machining. It is suitable for the grinding and turning process where high temperatures or sparks may occur can be avoided due to the water content of the coolant, which is present in the emulsion used (Anton et al. (2015)). During their study on analysis of the cutting fluid, Adler et al. (2006) found one of the advantages of cutting fluids in machining operation is the ability to transfer heat. Heat transfer can give a great benefit in the reduction of error surface, where the size of the machined surface irregularities of a surface is produced under ideal conditions. In addition, mechanical energy is used to form the chip to generate heat and high temperatures in the cutting region. The increase in temperature results in the faster it wears. The main purpose of using cutting fluids in machining processes is to reduce the cutting temperature (Aggrawal et al. (2008)).

2.4 Cutting Fluids

Cutting fluids are used in machining with the sole aim of lubricating and cooling to reduce friction and wear which occurs on the surface between the tool point and the machined object, remove heat from the workpiece and the cutting zone, carrying away chips from the cutting area and prevent erosion. (Liu et al. (2014); Feldshtein et al. (2016)). Although the definitions of cutting fluids can be described from those functions, it is widely believed that the main function of a cutting fluid is for lubrication and cooling (Azwadi et al. (2017); Anton et al. (2015)). They studied the tool wear rate during machining with and without coolant and concluded that machining with coolant gave a better surface finish and tool life improved by about 30% when using coolant.

Okokpujie et al. (2015) study the effects of cutting parameters on surface roughness during end milling of Al 6061 under minimum quantity lubrication (MQL) which also claimed that cutting speed is the most influencing process parameter. They conducted a comparative study of dry and MQL conditions where the MQL mixture used is 10% boric acid and base oil SAE 40, which proved that MQL can reduce the surface roughness by 20% when compared with the dry machining. Onuoha et al (2016) used vegetable-based oils while turning carbon steel and got optimal surface reliability using groundnut oil-based cutting fluid. Shetty et-al. (2014) analyzed surface roughness during turning of Ti-6Al-4V under Near Dry Machining and concluded that the influence of lubrication was the highest physical factor influencing surface roughness with about 95.1% significance when turning by using PCBN tool under dry and near dry environment.

2.4.1 Function of Cutting Fluid

As mention before, the most function of using cutting fluids in machining processes is to reduce the cutting temperature and friction wear either through lubrication or through cooling by conduction of heat (Palanisamy et al. (2009)). However conventional cutting fluids growing public health concern worldwide and following these issues, Aggarwal et al. (2008) have written the subsequent limitations:

- Environmental pollution because of chemical divorce/breakup of cutting fluid at high shear.
- Biological (dermatological) problems to the operators like skin problems and respiratory problems when coming in physical contact with the cutting fluid.
- Contamination of water and soil during disposal.
- The need for extra floor space and a further system for pumping, storage, refining, recycling, cooling, etc.
- The cost of disposal of cutting fluids becomes higher as environmental regulations become harder.

Efficient cooling strategies within the metal cutting industry are important for profitable production. The needs for the cooling lubricants as stated by Anton et al. (2008) are:

- the resulting heat absorption process
- cooling of machines, work materials, equipment, and cutting tools
- breaks of chips and transport chips
- reduction of friction
- reduction of the built-up edge formation
- corrosion protection for machine and workpiece

Heat is generated at the cutting zone area during machining. Most of the resulting heat remains within the chip, but a number of it's conducted into the tool and therefore the workpiece (Stephenson et al (2005)). Consistent with O'Sullivan and Cotterell (2001), tool life is greatly suffering from cutting temperature as a little reduction in temperature can prolong tool life. Figure 2.1 shows the regions of heat generation in turning process. Meanwhile, consistent with Sharma et al. (2009), the thermal conductivity of tools, tool design, and cooling methods are the factors that affect the quantity of warmth lost from the cutting zone. However, during dry machining, the cutting fluid to require away the heat generated from the cutting zone is absent, leading to a rise in tool and workpiece temperature (Sreejith et al. (2000)). When cutting fluid is applied during the machining operation, it removes heat by carrying it away from the cutting tool-workpiece interface and reducing the most cutting force and result in improved and intimate chip-tool interaction (Isik (2010)). Therefore, this cooling effect of cutting fluids avoids the tool from heating beyond its critical temperature range beyond which the tool softens and wears rapidly (Debnath et al. (2016)).

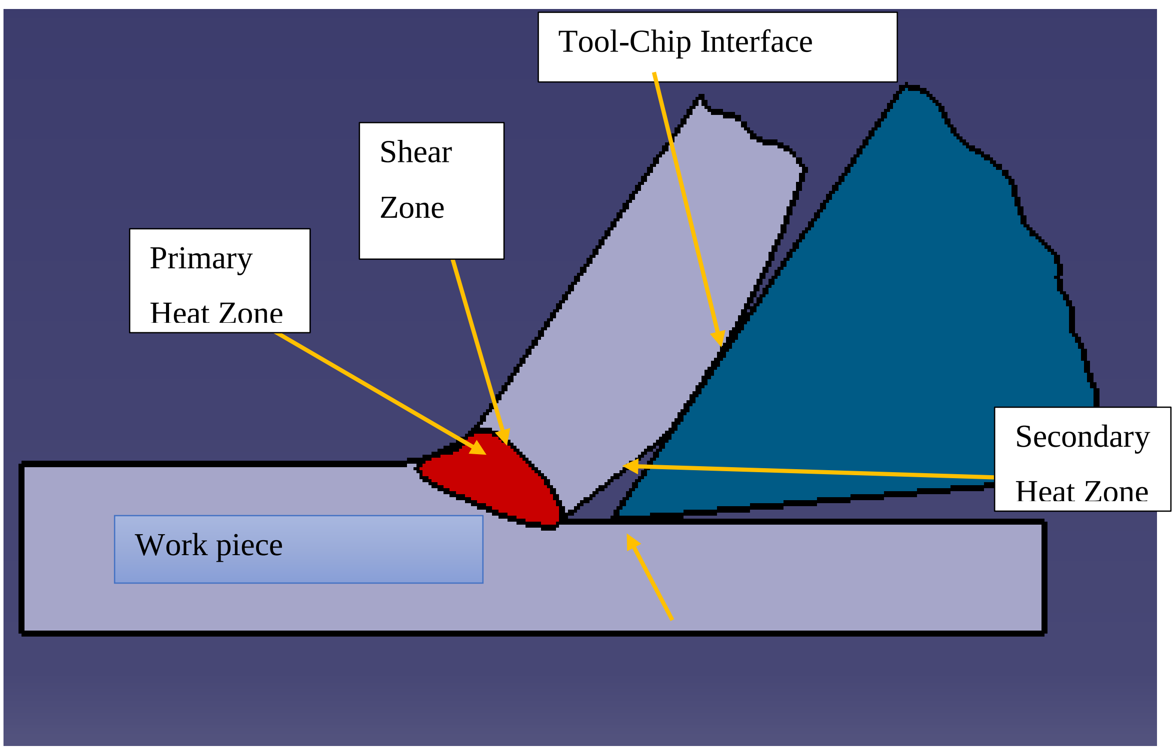


Figure 2.1 Schematic Representation of Regions of Heat Generation in Turning by Catia.

2.4.2 Types of Cutting Fluid

There are four main categories of conventional cutting fluids that differ in their thermo physical properties, the application process, and methods of treatment (Adler et al. (2006); Yardimeden et al. (2007)).

i) Straight oils

Straight oil is made up of entirely mineral oil (neat cutting oil) or vegetable oils (biodegradable) and is used primarily for operations where lubrication is required. Even though straight oils are excellent lubricating oil, their heat transfer capabilities exhibit very low. Highly flammable mineral oil has low efficiency at high cutting speed and relatively high cost. Khan et al. (2009) reported that vegetable oils are non-toxic and environmentally friendly in terms of resource renewability, biodegradability, and performance efficiency in many applications. This is proved by Elmunafi et al. (2015) were, in their research, they found that the use of vegetable oil has shown some positive results.

ii) Soluble oils

Soluble oil is a mixture of oil and water and has increased cooling capacity than straight oil and provided rust/corrosion protection. This type of water-based cutting fluid is suitable for the turning, milling, and grinding process due to the use of new cutting tool materials such as hard metals and high cutting speeds. It is also found that water-based cutting fluids will reduce the effect of generated heat on cutting tool wear (Adler et al. (2006)). Primrose et al. (2016) investigated the machinability of a Ti-48Al- 2Cr-2Nb alloy. They applied low cutting fluid (water and emulsion) volumes to the cutting area in the form of a precision metered droplets mist. They found that the tool life with the emulsion mist is better than that with vegetable oil.

iii) Semi-synthetics

In terms of performance, semi-synthetic is not much different or the same as soluble oil. However, it is different in composition as 30% or less of the total concentration, it contains inorganic material or other water-soluble compounds. Addition of emulsified oil in synthetic cutting fluid results in semi-synthetic fluids that have properties combined. It is also characterized by better maintenance than soluble oil, but tarnishes easily when exposed to other machine fluids and can cause dermatitis risk to workers (Adler et al. (2006)).

iv) Synthetics

Synthetic is a chemical liquid containing inorganic or other chemicals that are soluble in a large quantity of water and offer superior cooling performance. Regarding green manufacturing, biodegradable lubricant plays an important role. The biodegradable lubricant has gradually and steadily replacing synthetic lubricants. Biodegradable cutting fluids that achieve the lowest amount of environmental pollution can provide high reliability and satisfactory economic conditions. In addition, the productions of bio-based cutting fluids are much cleaner and contribute less pollution in the air, thereby reducing the risk of occupational health. While the bio-based cutting fluids are not perfect in all aspects, they have a minimal negative impact on the environment compared with other cutting fluids (Debnath et al. (2016)).

2.5 Cutting Temperature

High production machining of steel materials inherently generates high cutting zone temperature. The rising temperature during cutting processes negatively affects the cutting tool life. It also adversely changes machine parts' quality, such as dimensional accuracy and surface quality (Gupta and Laubscher (2016); Yip and To (2018)). The occurrence of high temperature in the cutting zone is still a problem in machining processes.

During machining, heat is generated at the cutting point from three main sources. Those sources are the primary shear zone; where the major part of the energy is converted into heat, secondary deformation zone; at the chip–tool interface where further heat is generated due to rubbing or shear, and at the flanks due to rubbing between the tool and the finished surfaces as shown in Figure 2.1. The effects of the high cutting temperature are mostly detrimental to both the tool and the job. The major portion of the heat is taken away by the chip materials. But it does not matter since the chips are thrown out. So attempts should be made such that the chips take away more and more amount of heat leaving a small amount of heat to harm the tool and the workpiece. The possible detrimental effects of the high cutting temperature on cutting edge are rapid tool wear, plastic deformation of cutting edges if the tool materials are not enough hard and strong, thermal flaking and fracturing of cutting edges due to thermal shocks, and built-up edge formation. The possible detrimental effects of cutting temperature on the machined workpiece are dimensional inaccuracy of the job due to thermal distortion and expansion-contraction during and after machining, surface damage by oxidation, corrosion, burning, etc.

and induction of tensile residual stresses and micro-cracks at the surface and sub-surfaces. However, high cutting temperature helps in reducing the magnitude of the cutting force and cutting power consumption to some extent by softening or reducing the shear strain. In metal cutting, the magnitude of the cutting temperature at the tool-chip interface is a function of the cutting parameters. This temperature directly affects production (Akhil et al. (2016)).

2.6 Tool Life

Tool life is the time period of machining during which the cutting tool delivers a desired and satisfactory performance. It is the time a tool will cut satisfactorily and is expressed as the minutes between changes of the cutting tool. Tool life is important in machining since considerable time is lost whenever a tool is replaced and reset. Higher tool life leads to higher productivity and decreased machining cost. The process of cutting tool wear and failures increases the surface roughness, and the accuracy of workpiece deteriorates.

In machining the tool life depends mainly on the following factors:

- The material of the machined component
- Cutting tool material and its shape
- Cutting conditions
- The machining process

2.6.1 Taylor's Tool Life Equation

Tool wear is always used as a lifetime criterion since it is easy to determine quantitatively. Most of the time flank wear land is used as the criterion because it influences workpiece surface roughness and accuracy. Taylor tool life formula is as follows (Groover (2013));

$$VT^n = C \tag{2.1}$$

Where *V* is the cutting speed (m/min), *T* is the tool life (min) taken to develop certain flank wear, *n* is an exponent that depends on the cutting parameters and *C* is a constant. The values of '*n*' and '*C*' depend mainly upon the tool work materials and the cutting environment (cutting fluid application).

According to the original Taylor tool life formula, the cutting speed is the only parameter that affects the life of the cutting tool. This is because this formula was obtained using high-carbon and high-speed steel tool material. With the further development of carbides and many other tool materials, it was found that the cutting feed and the depth of the cut are also significant. As a result, Taylor's tool life formula was modified to accommodate these changes as follows (Groover (2013)):

$$VT^n f^a t^b = C \tag{2.2}$$

Where t is the depth of cut (mm) and f is the feed (mm/rev). The exponents n, a, and b are to be determined experimentally for each of the cutting conditions.

2.7 Machining Cost

2.7.1 Total Machining Cost

Achieving an economic machining process is certainly one of the principal strategies to promote sustainable production. To ensure this, an in-depth analysis of the total cost from the beginning to the end of the machining process is very important. The total machining cost (C_T) comprises energy (electricity) consumption cost (Ce), overhead cost (Co), cutting insert cost (Ct), and coolant cost (Cc) which is described by Eq. (2.2) (Gupta et al. (2021)).

$$C_T = C_e + C_o + C_t + C_c \tag{2.3}$$

a) Energy Consumption Cost (C_e)

Machine tools utilized in the manufacturing industry are responsible for consuming a significant portion of the total energy supplied worldwide. Due to the high unit energy price, energy consumption throughout production is a vital index that determines the total cost of the end product. The lowering in energy consumption enables companies to reduce machining costs. Therefore, analysis of the energy demands of the machine tools in different machining parameters and environments is very important. The electricity energy consumption cost by the machine is dependent upon machining time for which the machine is used, spindle motor power, and unit energy cost. C_e can be described by the following relation (Gupta et al. (2021)):

$$C_e = C_{cut} + C_{ncut} \qquad (2.4)$$

$$Ce = \frac{Unit\ Energy\ Cost}{\eta * 60 * 1000} * t_m * (Cutting\ Power + Standyby\ Power) \qquad (2.5)$$

Where C_{cut} = cutting energy cost, C_{ncut} = machine standby cost. While the machining time $t_{m;}$

$$t_m = \frac{Length\ of\ Cut + Machining\ Allowance}{Feed\ Rate * RPM} \qquad (2.6)$$

b) Overhead Cost (C_o)

The machining overhead cost consisted of operator cost (C_{op}), cost of lighting and HVAC (C_L), and machine depreciation cost (C_m) which is given as the following relation (Gupta et al. (2021)):

$$C_o = C_{op} + C_L + C_m \qquad (2.7)$$

Where operator cost is the operating cost during the machining and given as follows;

$$C_{op} = Operator\ Labor\ Rate * t_m * Number\ of\ workers' \qquad (2.8)$$

Similarly, the cost of lighting;

$$.C_L = (Cost\ of\ Lighting\ and\ HVAC\ ) * Unit\ Energy\ Cost * ({}^{t_m}/_{60}) \qquad (2.9)$$

The machine depreciation cost is determined as:

$$C_m = \frac{(Initial\ Cost - Salvage\ Value) * Machining\ Time}{Useful\ Life} \qquad (2.10)$$

c) Tool Cost (C_t)

The need to machine the materials having superior features at higher speeds and in less time encourages the advancement of cutting tool technology day by day. However, this situation also reflects the cutting tool insert production costs of manufacturers, and consequently, to the cutting tool insert sales price. During the mass production of parts by machining, a substantial part of the total cost is the insert cost. Therefore, in order to minimize this to reasonable levels, a number of measures such as reducing cutting parameters and using coolant fluid are taken as a solution by operators. In addition, when the cutting insert attaining a 0.3 mm wear value (VBmax = 0.3

mm), it can be reground and can be sold at a lower price. Therefore, the net cutting tool inserts cost is (Gupta et al. (2021)):

$$C_t = \frac{Insert\ Price - Resale\ Price}{Tool\ Life} * t_m \tag{2.11}$$

d) Coolant Cost (*C_c*)

In machining operations conducted under petroleum-based conventional fluid, coolant cost is responsible for 15–17% of the final part cost (Harsimran et al. (2012)). It has been noted that costs associated with cutting fluids in such operations can be higher than the costs of cutting tools (Suleiman et al. (2011)). The cost of lubricant is dependent upon the cost per liter, flow rate, and machining time. Coolant cost is calculated as (Gupta et al. (2021)):

$$C_c = Coolant\ Cost * FLow\ Rate * t_m \tag{2.12}$$

2.8 Research Gap

Studying comparison of effective cutting parameters during dry and wet turning of AISI 1020 steel is very important due to challenges in machining in terms of surface quality of machined part, cutting temperature, tool life, machining cost, etc. In the above literature survey turning parameters on lathe machines like cutting speed, depth of cut, feed rate, and cutting environment which affects the desired output like surface quality, cutting temperature and tool life for different types of steel were studied. However, there were no experimental studies conducted to compare the effect of cutting parameters on surface finish, cutting temperature, tool life, and machining cost during dry and wet turning of AISI 1020 steel using equal level of cutting parameters. Therefore further studies are still required to clarify the effect of cutting parameters on surface finish, cutting temperature, tool life, and machining cost during dry and wet turning of AISI 1020 steel. This work mainly aimed at providing a better understanding of the influence of cutting parameters such as spindle speed (*N*), feed rate (*f*), and depth of cut (*t*) on the surface roughness during dry and wet turning of AISI 1020 steel, when machined by turning using carbide insert tools. Therefore, it is vital to study the comparison of effective cutting parameters during dry and wet turning of AISI 1020 steel for identifying the cutting parameters at which surface finish is high.

CHAPTER 3

3. MATERIALS AND METHODS

3.1 Introduction

This study was performed to compare the effect of cutting parameters on surface roughness, cutting temperature, and tool life during dry and wet turning of AISI 1020 steel through experimental work. The aim of this chapter is to present the details of the experimental procedures and material used for the study. All machines and instruments were discussed with supporting photographs and schematic diagrams.

3.2 Experimental Procedure

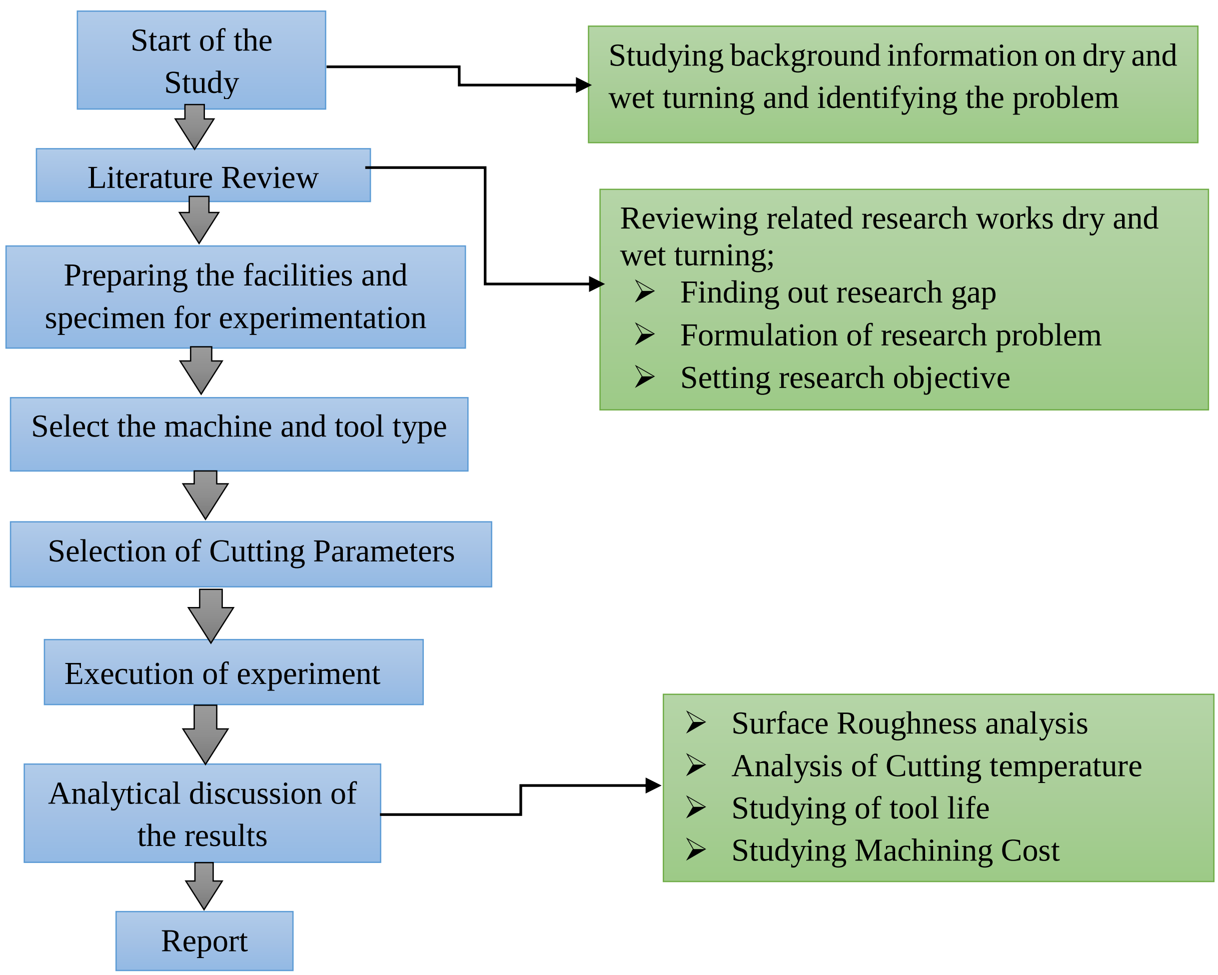


Figure 3.1 Experimental Procedure Flow Chart

3.3 Materials and Composition

Materials used for this study was AISI 1020 grade steel which are characterized by a combination of high ductility and good strength, as well as by its ability to be easily machined. AISI 1020 steel is highly applicable in a variety of engineering applications, including automotive parts, general engineering and machinery parts and components, shafts and cams shafts, pins and spindles, space spare parts, gears, pinions, bolt and nuts, high speed screw machine parts etc. The chemical composition, physical properties and mechanical properties of the material are shown Table 3.1 , 3.2 and 3.3 respectively (Kawthar et al. (2016)).

Table 3.1 Chemical composition of AISI 1020 Steel Material (wt %).

C	Si	Mn	P	S	Cr	Ni	Al	Co	Cu	Fe
0.20	0.0046	0.386	0.018	0.02	0.025	0.0077	0.0757	0.0157	0.014	99.3

Physical Properties

Table 3.2 Physical properties of AISI 1020 Steel

Physical Properties	Metric	Imperial
Density	7.87gm/cm^3	0.284lb/in^3

Mechanical Properties

Table 3.3 Mechanical properties of AISI 1020 Steel

Mechanical properties	**Metric**	**Imperial**
Hardness, Brinel	111	111
Hardness, Rockwell	64	64
Hardness, Vicker	115	115
Tensile Strength, Ultimate	394.72MPa	57249psi
Yield Strength	294.74MPa	472748psi
Elongation at Break (in 50mm)	36.5%	36.5%
Reduction Area	66.0%	66.0%
Modulus of Elasticity	200GPa	29000ksi
Bulk Modulus	140GPa	10300ksi
Poison Ratio	0.290	0.290
Izod Impact	125J	92.2ft-b
Shear Modulus	80.0GPa	11600ksi

3.4 Selection Cutting Tool

The tool is selected accordingly the work material and machining properties. The work material is AISI 1020 steel which is low carbon steel and this material is used for medium size components so the machining time of these components is more. According to cutting conditions and tool manufacturer's recommendation cemented carbide tool insert (CNMG120408) with a chemical composition of (65% W, 14 % Ti, 9 % Co and 12 % C) were used in this experimental study. The tip has a tool angle of 30^0 and a nose radius of 1.6 mm. Cemented carbide tool insert was used in this study because of their chemical inertness, low thermal conductivity, resistance to high temperature, resistance to flank and crater wear and ceramics are suitable coating materials for tools. Table 3.4 shows the properties of cemented carbide tool insert material (Kawthar et al. (2016)). Figure 3.2 and 3.3 shows the cemented carbide inserts and holder of the tool respectively, which was used for this experimental study.

Table 3.4 The Properties of Cutting Tools

Hardness (HV)	Thermal Conductivity (W/m.k)	Rupture Strength (MPa)	Density (g/cm^3)	Young's Modulus (MPa)
1500	25	1860	11.6	480

Figure 3.2 Cemented Carbide Tool Insert

Figure 3.3 Tool Holder

3.5 Cutting Fluid Specification

High production machining of steel inherently generates high cutting zone temperature. Such high temperature causes dimensional deviation and premature failure of cutting tools. It also impairs the surface integrity of the product by inducing tensile residual stresses and surface and subsurface micro cracks in addition to rapid oxidation and corrosion. Therefore application of cutting fluid during machining is very important to solve such problems during turning. In this study the commercial vegetable cutting fluid (CVCF) was used due to its superior lubrication property, boiling point and viscosity (Mia et al. (201)). The characteristics of commercial vegetable cutting fluid was shown as in Table 3.5 below;

Table 3.5Characteristics of Commercial Vegetable Cutting Fluid

Kinematic viscosity @ 20 °C(cSt)	Specific gravity @20 °C	Boiling point (ºC)	Melting point (ºC)	Acid value (mgKOHg⁻1)	Iodine value (mglg⁻1)	Saponificatio n value (mgKOHg⁻1)
84	0.911	300	−6	0.8	80	190

3.6 Selection of Process Parameter

In turning process, the important task is to select cutting parameters for achieving high cutting performance. For experimentation purpose, cutting parameters for AISI 1020 steel were selected depending on knowledge found in the literature, according to the recommendations of tool manufacturer, manufacturer’s handbook recommended for the tested material, current industrial practice and experience (Debnath et al. (2016); Isik (2010); Kagade (2011)). The selected cutting parameters were shown in Table 3.6.

Table 3.6 List of Parameters and their Levels

Cutting Parameters	Designations	Levels		
		1	2	3
Depth of Cut (mm)	t	0.25	0.5	0.75
Feed Rate (mm/min)	f	60	80	100
Spindle Speed (rpm)	N	500	800	1100

3.7 Tools and Equipment

3.7.1 Turning Machine

Turning machines typically referred to as lathes, can be found in a variety of sizes and designs. While most lathes are horizontal turning machines, vertical machines are sometimes used, typically for large diameter work pieces. Turning machines can also be classified by the type of control that is offered. A manual lathe requires the operator to control the motion of the cutting tool during the turning operation. Turning machines are also able to be computer controlled, in which case they are referred to as a computer numerical control (CNC) lathe.

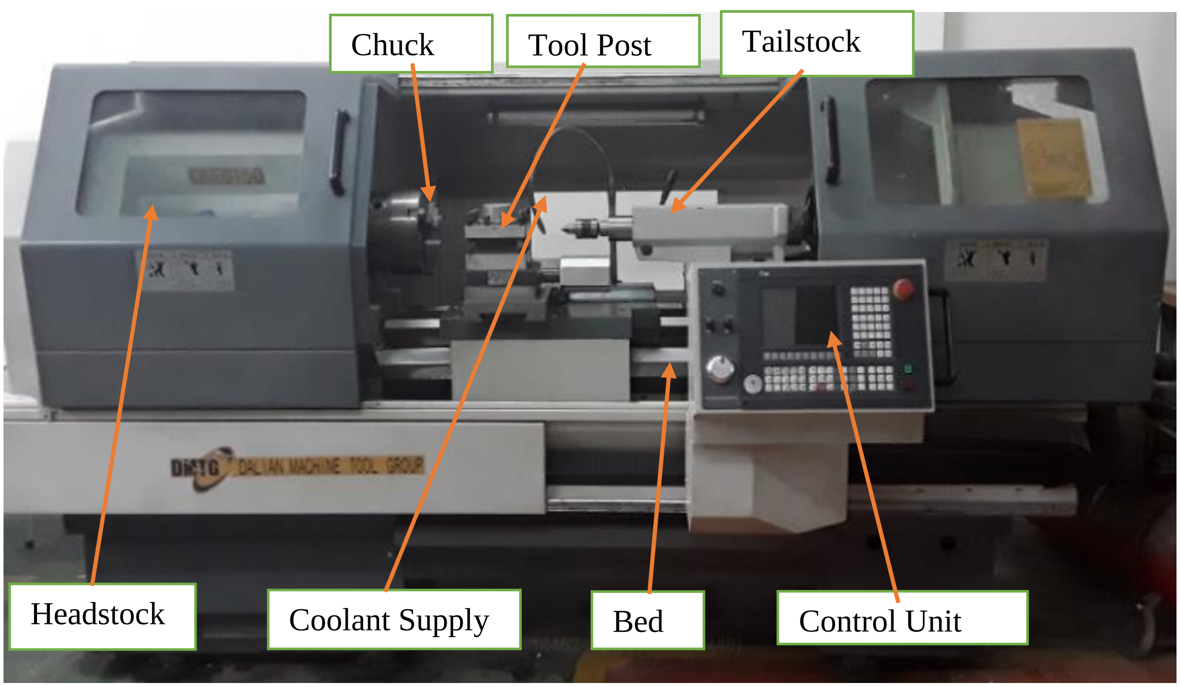


Figure 3.4 DMTG CNC Lathe Machine

CNC lathes rotate the work piece and move the cutting tool based on commands that are preprogrammed and offer very high precision. The DMTG CNC lathe machine with CKE 6150 model and power 7KW with specification Ø500x1000mm was used for this study. General view of a Dalian CNC lathe machine with its main components is shown in the Figure 3.4. Generally, the equipment's and tools used for the study are;

- DMTG CNC lathe machine with model CKE 6150.
- Dial Gauge
- Infrared thermometer
- Surface roughness tester
- Design of Experiment(DOE)

3.8 Surface Roughness Measurement

Surface roughness is the most decisive parameter in machining process, as it is considered as basis of the product quality. It measures the refined inadequacy of the surfaces. The quality of the surface made using conventional and non-conventional machining is important because a smooth surface (better finished components) reduces the chances of surface damage caused by wear, corrosion, improves fatigue strength, creep failure, increase the productivity & economics of the industry. Likewise, quality of a part made by turning operation can affect the performance of the surface for wear and corrosion prevention. There are many ways to define surface roughness depending on its applications like R_a, R_q, R_z, and Rt. But average surface roughness Ra is widely used in industry for the mechanical components for indication of surface roughness, also known as arithmetic average (AA) or centre line average (CLA) is the area between surface profile and centre line hence in this study Ra was used for indication of surface roughness.

Surface roughness was measured by the VOGEL Surface Roughness Tester with 65711 model which is manufactured by "Germany" shown in Figure 3.5. This surface roughness tester displays roughness value in micro meter (µm). The measuring range of VOGEL Surface Roughness Tester 65711 is 0.02µm to 50µm. A stylus attached to the detector unit of tester will trace the minute irregularities of work-piece surface. The vertical stylus displacement during the trace is processed and digitally displayed on the liquid crystal display of instrument.

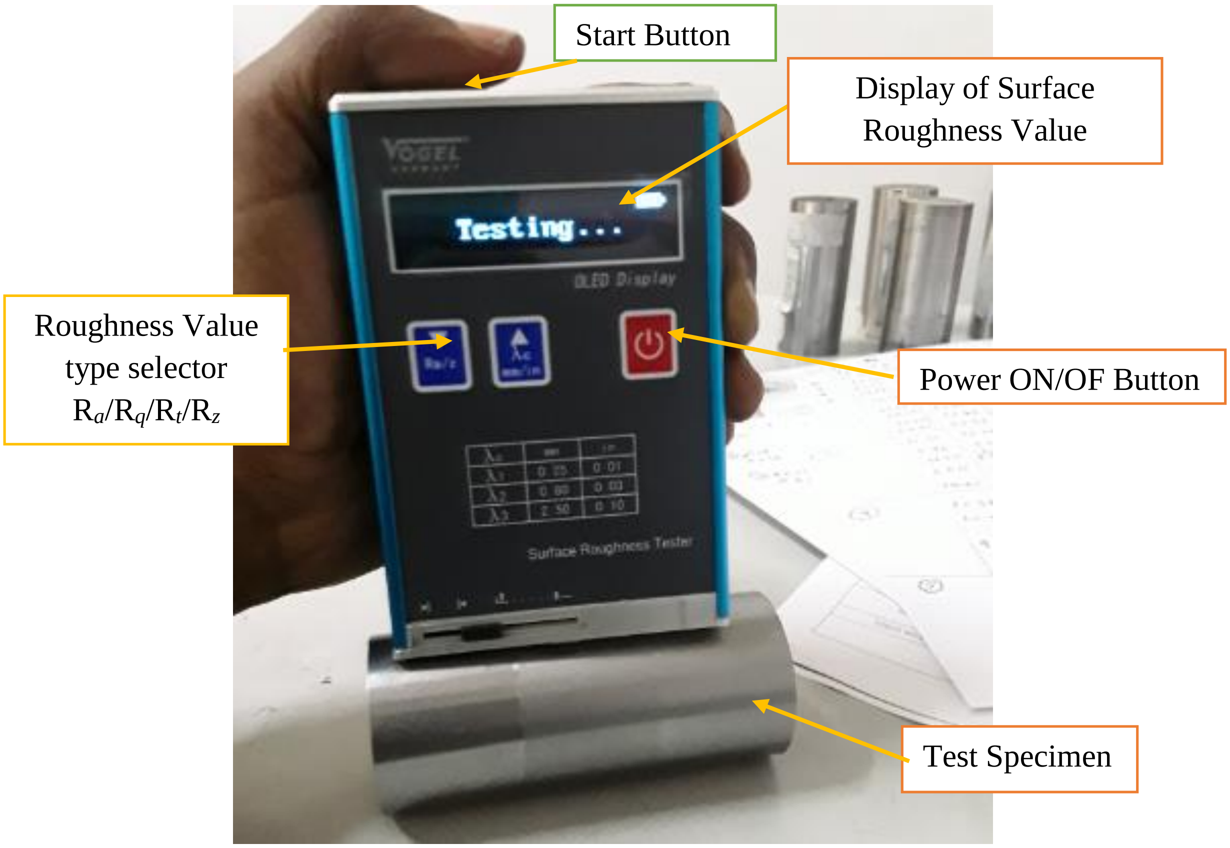


Figure 3.5 Surface-Roughness Testing Equipment

3.9 Temperature Measurements

To achieve aim of measuring and analyzing the cutting temperature, the infrared thermometer was used. The temperature of cutting zone was measured during the machining time of every set of parameter at each turning conditions (dry and wet). The basic working principle of infrared thermometer is, it measures the surface temperature of an object. The unit optics sense emitted, reflected and transmitted energy, which is collected and focused onto a detector. The unit electronics translate the information into a temperature reading which is displayed on the unit. In units with a laser, the laser is used for aiming purposes only. Hold the meter by its handle grip and point it towards the surface to be measured. Pull and hold the trigger to turn the meter on and being tested. While continuing to push the trigger the laser pointer is concentrated at the cutting zone. Release the trigger and the hold, display will appear on the LCD indicating that the reading is being held. We can select the temperature units ^{0}C and ^{0}F. Infrared thermometer with IR130VH model and measurement range of -50 to 1300^{0}C was used for the temperature measurement.

Figure 3.6 Temperature Measuring Instrument

3.10 Research Methodology

By using the materials mentioned above through the following method the experimental work was done. Under research methodology the way of specimen preparation, design of experiment procedure, selection of orthogonal array and analysis of variance would be explained.

3.10.1 Specimen Preparation

The workpiece materials used for this study was AISI 1020 grade steel which, is highly applicable in a variety of engineering applications, including automotive parts, general engineering and machinery parts and components, shafts and cams shafts, pins and spindles, space spare parts, gears, pinions, bolt and nuts, high speed screw machine parts etc. Two AISI 1020 mild steel specimen of 400mm in length and 30mm in diameter was prepared and it was gone to turning process with 1mm depth of cut to remove any irregular parts on the surface for 300mm of length. Nine specimen with length of 30mm and 0.75, 0.5 and 0.25mm of depth of cut, 60, 80 and 100mm/min feed rate and 500, 800 and 1100rpm were operated with different level of feed rate and spindle speed for experimental study with different cutting parameters which were selected by using orthogonal array as shown in Figure 3.7 bellow. Cutting parameters were identical for both machining in order to achieve the direct comparison of the corresponding results.

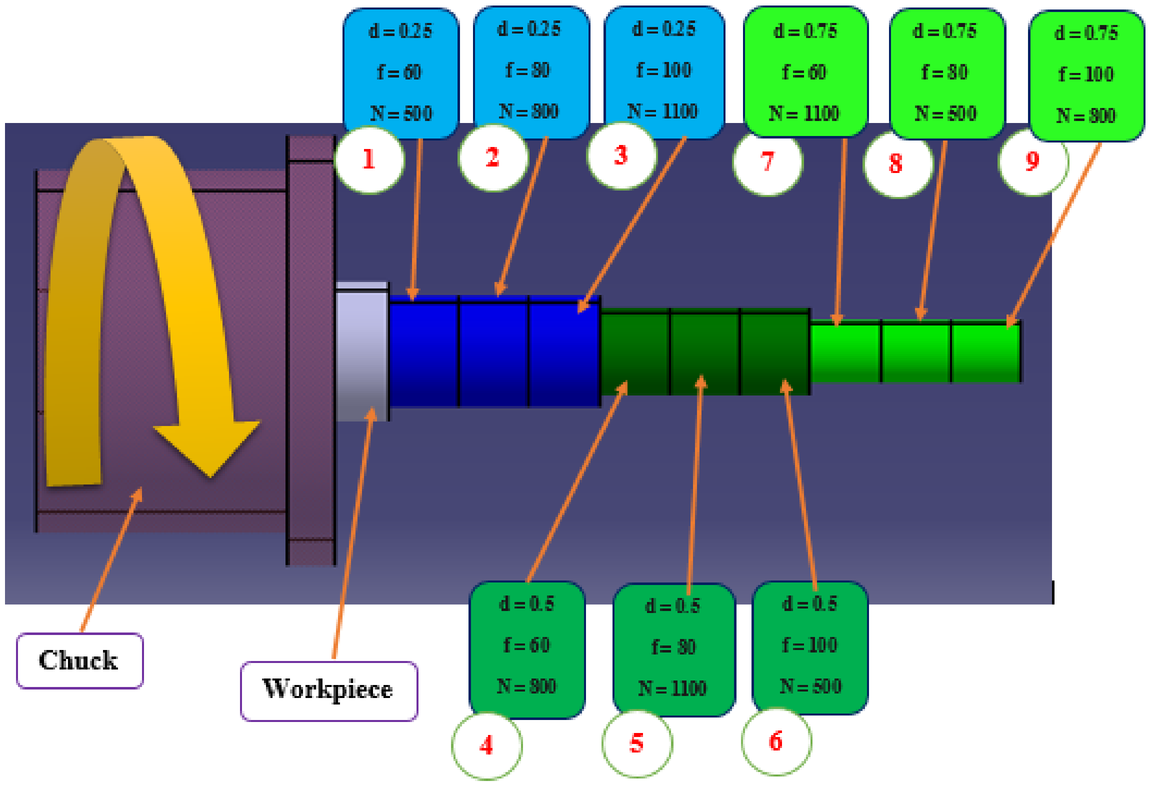


Figure 3.7 Schematic Representation of Specimen Preparation Plan by Catia

3.11 Design of Experiment

The experiment was conducted by varying the cutting parameters such as spindle speed, feed rate, depth of cut, and the cutting parameters have been split into different level values. In the design of the experiment, the Taguchi method is mostly used in optimization of machining parameters because it is a problem-solving tool that can improve the performance of the product, process design, decrease the experimental time, reduce the cost, and find out significant factors in a shorter time (Johari (2008); Upinder et al. (2012); Onuoha et al. (2016)). To observe the most influential cutting parameters in dry and wet turning of AISI 1020 steel process each cutting parameters at three levels were considered in the case of this study. These level values of control factors were selected based on knowledge found in the literature, experience, and according to the recommendations of a tool manufacturer. These levels were then oriented according to the Taguchi L9 orthogonal array (OA) which is shown in Table 3.6. Taguchi based orthogonal array has the property of reducing the number of experiments without affecting the outcome significantly (Johari (2008); Onuoha et al. (2016)).

The following are steps related to the Taguchi-based experiments (Krishnahiah and Shahabudeen (2007)):

- State the problem
- Determine the objective
- Determine the response and its measurement
- Identify factors influencing the performance characteristic
- Separate the factors into control and noise factors
- Determine the number of levels and their values for all factors
- Identify control factors that may interact
- Select the Orthogonal Array
- Assign factors and interactions to the columns of OA
- Conduct the experiment
- Analyze the data
- Interpret the results
- Select the optimal levels of the significant factors
- Predict the expected results
- Run a confirmation experiment

Taguchi uses the S/N ratio to measure the quality characteristics deviating from the desired value and it offers three categories of signal to noise ratio as follows (Upinder et al. (2012));

Nominal is the best characteristics,

$$\frac{S}{N} = 10log\left(\frac{\bar{Y}^2}{S^2}\right) \tag{3.1}$$

Smaller is the better characteristics,

$$\frac{S}{N} = -10log[\frac{1}{n}\sum_{i=1}^{n} {Y_i}^2] \tag{3.2}$$

Larger is the better characteristics,

$$\frac{S}{N} = -10log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{Y_i}^2}\right) \tag{3.3}$$

Here Y = observation n = total number of observation, $\bar{Y}$ = the average of observed data, S^2 = the variation of Y and Y_i = ith response.

- ✓ Larger is the better is suitable for determining the profit, material removal rate, production rate etc.
- ✓ Smaller is the better is appropriate for surface roughness, cutting temperature, unit cost etc.
- ✓ Nominal is the better is applicable for current.

The S/N ratio was calculated for surface roughness in each of the nine trial conditions to see the effect of each parameter on the response in dry and wet turning conditions. Thus, the L9 orthogonal array delivered by Minitab 18 to make further experimentations as shown in Table 3.7 and this array specifies nine experiments. The steps to go through are as follows:

- Selection of factors to be evaluated
- Selection of number of levels
- Selection of appropriate orthogonal array
- Conduct the experiment and analyze the results

3.12 Selection of Orthogonal Array and Column Assignment

The turning experiments were carried out on CNC lathe machine by using cemented carbide tools for dry and wet turning of AISI 1020 steel workpiece with selected cutting parameters within three levels given in the Table 3.7 according to recommended cutting parameters.

The selection of a particular orthogonal array was based on the number of levels of various factors. Here, to conduct the experiments 3 factors each at 3 levels were selected. However, the total number of DOF of the orthogonal array (OA) should be greater than or equal to the total DOF required for the experiment. This setup allows the testing of all three variables without having to run $27=3^3$ for both dry and wet turning. Nine different samples were manufactured with different parameters and at different levels both for dry and wet turning.

Now the Degree of Freedom (DOF) can be calculated by the formula as given below.

For OA;

$$DOF = a - 1 \tag{3.4}$$

= 9-1 = 8

For an experiment;

$$DOF = P * (L - 1) \tag{3.5}$$

Where, DOF= degree of freedom, P = number of factors and L = number of levels

DOF = 3*(3-1) = 6.

Therefore, 8>6; i.e. DOF of OA is greater than DOF of the experiments.

Table 3.7 Experimental Layout Using an L9 Orthogonal Array

Exp. No	Depth of Cut (mm)	Feed rate (mm/min)	Spindle Speed (rev/min)
1	0.25	60	500
2	0.25	80	800
3	0.25	100	1100
4	0.5	60	800
5	0.5	80	1100
6	0.5	100	500
7	0.75	60	1100
8	0.75	80	500
9	0.75	100	800

3.13 Analysis of Variance (ANOVA)

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. The significance level of 5 %, i.e. for 95 % level of confidence was considered in this analysis. ANOVA results indicate whether there is statistically significance in difference or not in output characteristics. ANOVA analysis involves when α values is below 0.05 is significant and above 0.05 is not significant. Percent contribution measures the percentage contribution of each model term relative to the total sum of squares. The percentage contribution is often a rough but effective guide to the relative importance of each model term. From analysis of variance percentage contribution of each influential parameter was calculated by the following formula (Debnath (2016)):

$$P = \frac{SS}{SST} * 100 \tag{3.6}$$

Where, P: Percentage contribution of individual factor,

SS: Sum of squares or treatment sum of squares,

SST: Total sum of squares.

CHAPTER 4

4. RESULTS AND DISCUSSIONS

4.1 Introductions

Experimental work was conducted to study the effect of cutting parameters, such as spindle speed, feed rate and depth of cut, on the surface roughness, to compare the surface roughness, investigate cutting temperature and analyze and compare machining cost during dry and wet turning of AISI 1020 grade steel. The outcomes of the experiment were discussed in this chapter. The Taguchi design of the experiment were used to compare the effect of cutting parameters on surface roughness and to identify the most influential cutting parameters on surface finishing in dry and wet turning of AISI 1020 steel. All nine experiments with different cutting parameters but with the same length of cut 30mm after turning process of AISI 1020 steel are given in Figure 4.1 for both dry and wet turning. The diameter of the workpiece prepared for experimental work is 30mm. Experiment numbers 1, 2, and 3 were operated by a depth of cut of 0.25mm, but with different feed rates (60, 80, and 100) mm/min, respectively and spindle speeds (500, 800, and 1100) rpm respectively both for dry and wet turning. By similar manner experiment number 4,5and 6 were operated by similar depth of cut of 0.5mm, but with different feed rates (60, 80, and 100) mm/min and spindle speeds (800, 1100 and 500) rpm. Lastly, the experiments numbers 7,8, and 9 were also operated by a similar depth of cut of 0.75 mm, but with different feed rates (60, 80, and 100) mm/min, respectively and spindle speeds (1100, 500 and 800) rpm respectively. The surface roughness result obtained from the experiment was shown as in Table 4.1 and 4.2 for dry and wet turning condition respectively.

Figure 4.1 The Dry and Wet Turned Specimens

Figure 4.1 shows the machined specimen of three different depth of cut for dry and wet turning each specimen with 30mm length of cut. The first piece with W1, W2 and W3 was the wet turned specimens with first level depth of cut (0.25mm), the second piece with W4, W5 and W6 was the wet turned specimens with the second level depth of cut (0.5mm) and the third piece with W7, W8 and W9 was the wet turned specimens with third level depth of cut (0.75mm) different spindle speed and feed rate. In similar manner the first piece with D1, D2 and D3 consists of three dry turned specimens with first level depth of cut (0.25mm), the second piece with D4, D5 and D6 was the wet turned specimens with the second level depth of cut (0.5mm) and the third piece with W7, W8 and W9 was the wet turned specimens with third level depth of cut (0.75mm) different spindle speed and feed rate.

4.2 Comparison of Surface Roughness for Dry and Wet Turning

Table 4.1and 4.2 presents the experimental results of surface roughness (Ra) values for dry and wet turned each specimens. In this study, each surface roughness (Ra) trial value is the average of three trial reading.

Table 4.1 Experimental Results of Surface Roughness R_a for Dry Turning

Exp't No.	Cutting Parameters			Surface Roughness (R_a)				
				Dry Turning				
	t (mm)	f (mm/min)	N (RPM)	I	II	III	Average	S/N ratios
1	0.25	60	500	2.19	2.25	2.22	2.2	-6.8485
2	0.25	80	800	1.89	1.85	1.87	1.87	-5.4368
3	0.25	100	1100	2.10	2.15	2.14	2.13	-6.5676
4	0.5	60	800	1.97	1.92	1.97	1.95	-5.8007
5	0.5	80	1100	1.76	1.85	1.70	1.77	-4.9595
6	0.5	100	500	4.06	3.91	4.00	3.99	-12.0195
7	0.75	60	1100	1.68	1.82	1.78	1.76	-4.9103
8	0.75	80	500	3.19	3.24	3.32	3.25	-10.2377
9	0.75	100	800	3.08	2.88	2.95	2.97	-9.4551

Table 4.2 Experimental Result of Surface Roughness R_a for Wet Turning

Exp't No	Cutting Parameters			Surface Roughness (R_a)				
				Wet Turning				
	t (mm)	f (mm/min)	N (RPM)	I	II	III	Average	S/N ratios
1	0.25	60	500	2.12	1.87	1.94	1.98	-5.9333
2	0.25	80	800	1.48	1.54	1.58	1.53	-3.6938
3	0.25	100	1100	2.04	1.85	2..01	1.97	-5.8893
4	0.5	60	800	1.65	1.26	1.91	1.61	-4.1365
5	0.5	80	1100	1.36	1.32	1.50	1.39	-2.8603
6	0.5	100	500	3.68	3.16	2.98	3.27	-10.2910
7	0.75	60	1100	1.30	1.32	1.26	1.29	-2.2118
8	0.75	80	500	2.69	2.72	2.75	2.72	-8.6914
9	0.75	100	800	2.19	2.42	2.35	2.32	-7.3098

Surface roughness under dry and wet machining at different conditions was shown in Figure 4.2. Comparing the right and left panes (i.e., dry and wet) in the graph, it was clearly shown that the surface roughness produced under wet turning is less than that produced under dry turning. Considering the average of all roughness results measured under dry and wet turning, the surface roughness achieved with wet machining is 17.41% lower than dry machining. The previous study by Kaynak et al. (2014) concluded that the role of wet turning on surface roughness was explained as; wet machining diminishes tool wear compared to dry machining, wet machining helps to preserve the tool geometry for a long time by reducing or eliminating possible built-up-edge (BUE) formation and wet turning prevents a possible distortion of the workpiece due to the high-temperature effect. The high tool workpiece interface temperature effect in dry cutting results in the chips attached loosely to the surface being eliminated easily which contribute to the improvement of the surface roughness. The penetration of coolant into the cutting zone reduces friction between the contacting elements and lowers the temperature. Other researchers obtained similar results stated that the need to cool the cutting zone with cutting fluid was to reduce friction by lubricating the contacting surfaces during machining (Yildrim et al. (2020); Bagherzadeh and Budak (2018)).

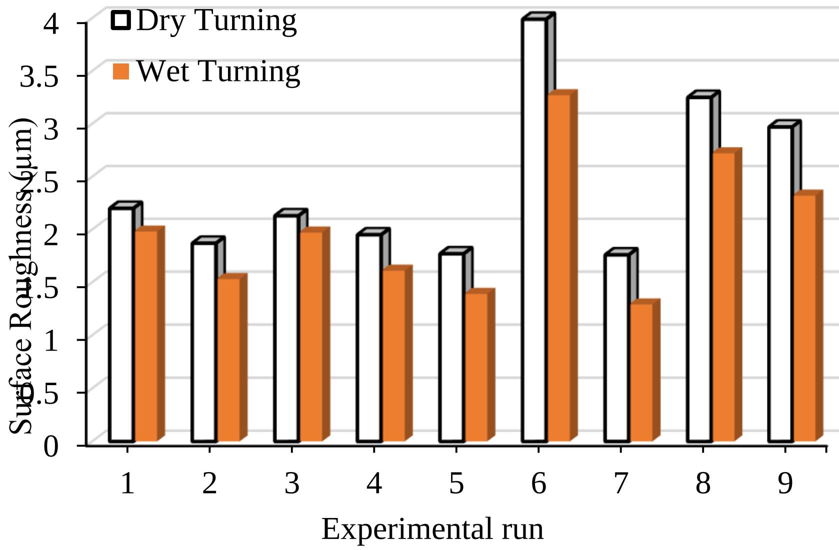


Figure 4.2 Surface Roughness for each Experimental Run

As shown in Figure 4.2 above the surface roughness of dry turning was higher than surface roughness of wet turning. The average of surface roughness of nine experimental run of wet turning and dry turning were 2.01µm and 2.43µm respectively. The result shows that the average of surface roughness of wet turning was 17.41% lower than the average of surface roughness of dry turning.

4.3 Effect of Cutting Parameters on Surface Roughness

4.3.1 Effect of feed Rate on Surface Roughness

The effect of feed rate on surface roughness (Ra) was shown as in Figure 4.3, 4.4, and 4.5 at spindle speed of 500rpm, 800rpm and 1100rpm respectively. The average surface roughness (y) and the feed rate (x) are represented by the polynomial curve fitted equation. R^2 is called the coefficient of determination. It measures how well the curve fits the data points. When R^2- value is approach to 1, the experiment and mathematical curve fitting values well agreed. As observed from the Figure 4.3, 4.4 and 4.5 the fitted curve is very good since R^2-value is exactly 1.

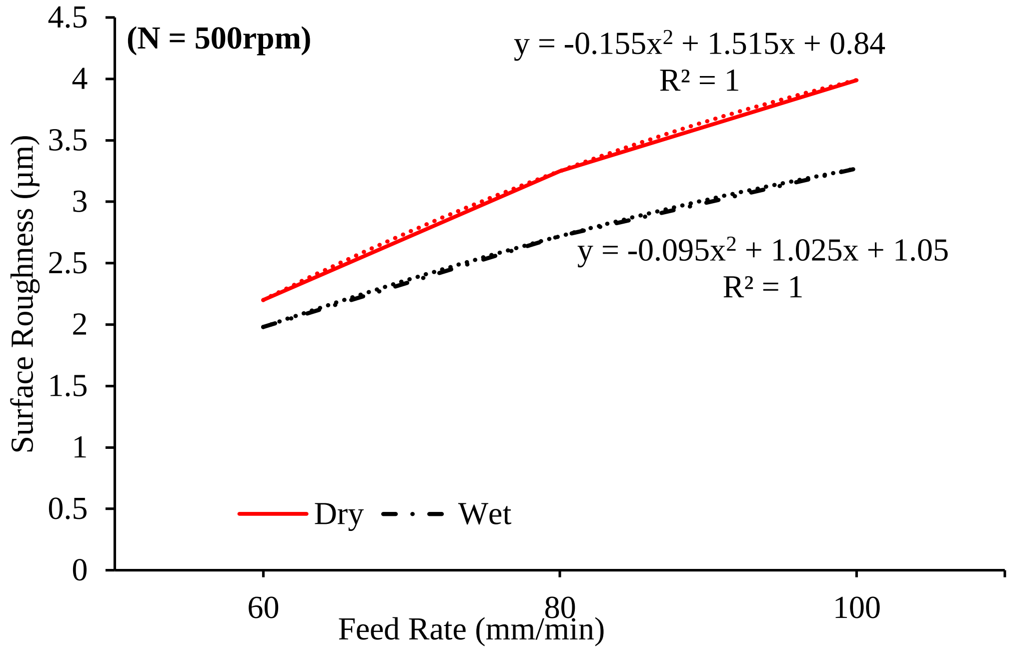


Figure 4.3 Effect of Feed Rate on Surface Roughness at N = 500 rpm.

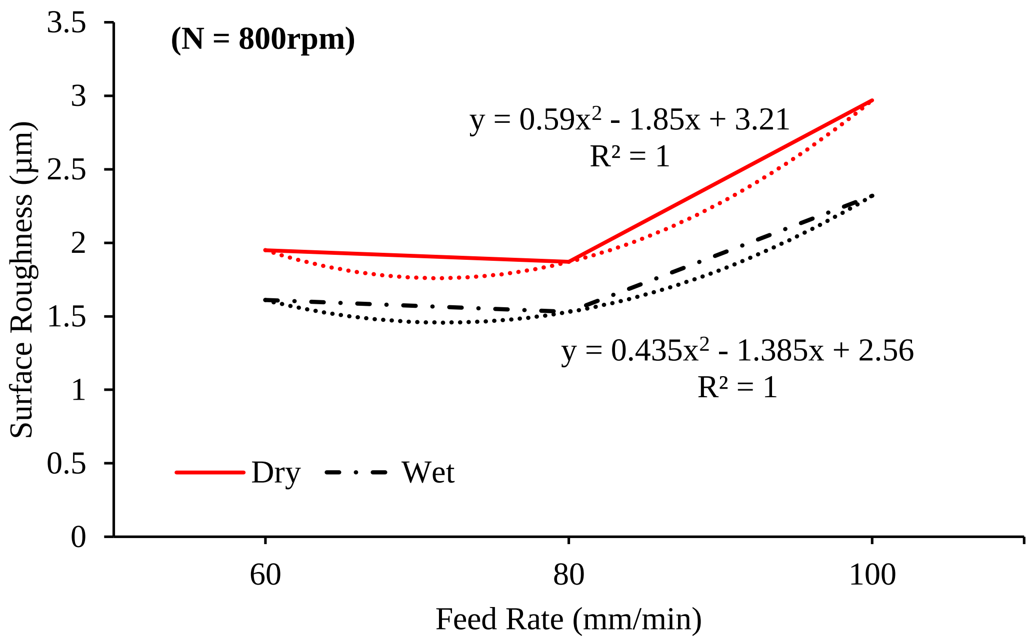


Figure 4.4 Effect of Feed Rate on Surface Roughness at N = 800 rpm.

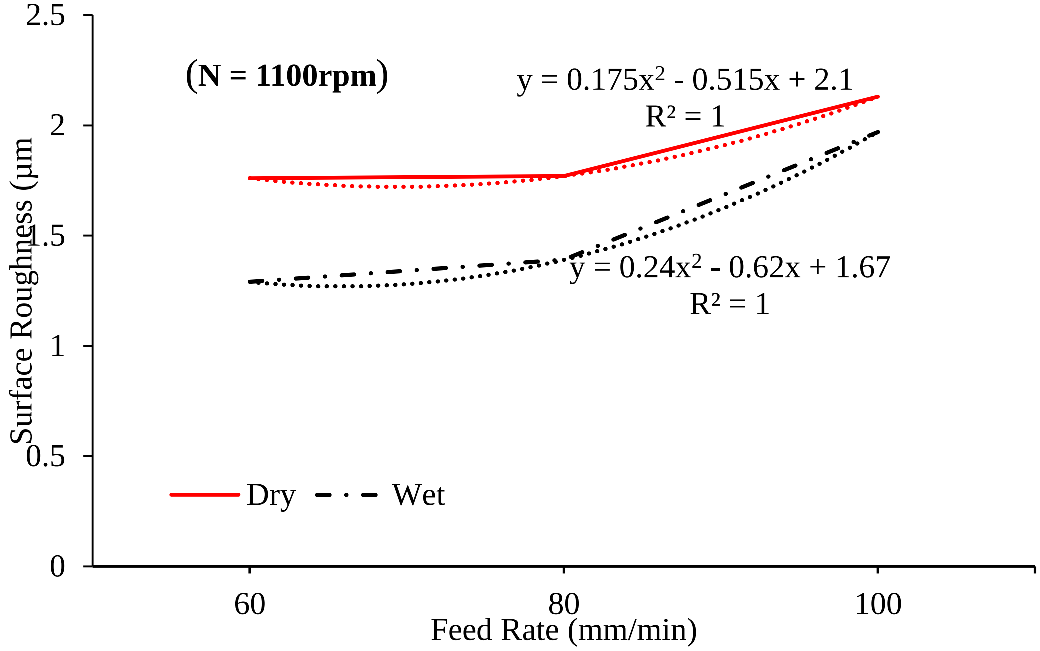


Figure 4.5 Effect of Feed Rate on Surface Roughness at N = 1100rpm.

As shown in Figure 4.3, 4.4 and 4.5 as feed rate increase at constant spindle speed the surface roughness become increased both for dry and wet turned specimen. Higher feed rates means more material in contact with the cutting tool hence higher cutting force evolution which causes in the appearance of the vibration, which leads to high surface roughness. Higher feed rates also cause in increasing the cutting temperature, which leads to the appearance of the tool wear hence undesired surface roughness (Rodrigues et al. (2012)). At higher spindle speed surface roughness become minimized. As spindle speed increased the surface roughness become minimized, i.e the maximum surface roughness at 100 mm/min feed rate and 500 RPM spindle speed was 2.20 µm (for dry turning) and 1.98 µm (for wet turning). It became decreased to 1.76 µm (for dry turning) and 1.29 µm (for wet turning) when spindle speed increased to 1100 RPM. However, due to its excellent feature of reducing the cutting temperature and friction at tool-work interface wet turning was found to reduce the surface roughness as compared to dry machining which is similar to result obtained by Muamar et al. (2021).

4.3.2 Effect of Depth of cut on Surface Roughness

Figure 4.6, 4.7 and 48 indicate the effect of depth of cut on surface roughness at spindle speed of 500 RPM, 800 RPM and 1100 RPM respectively, for dry and wet turning of AISI 1020 steel. Since, R^2 (coefficient of determination) value is equal to 1, the fitted curve is very good, i.e. the experiment and mathematical curve fitting values well agreed.

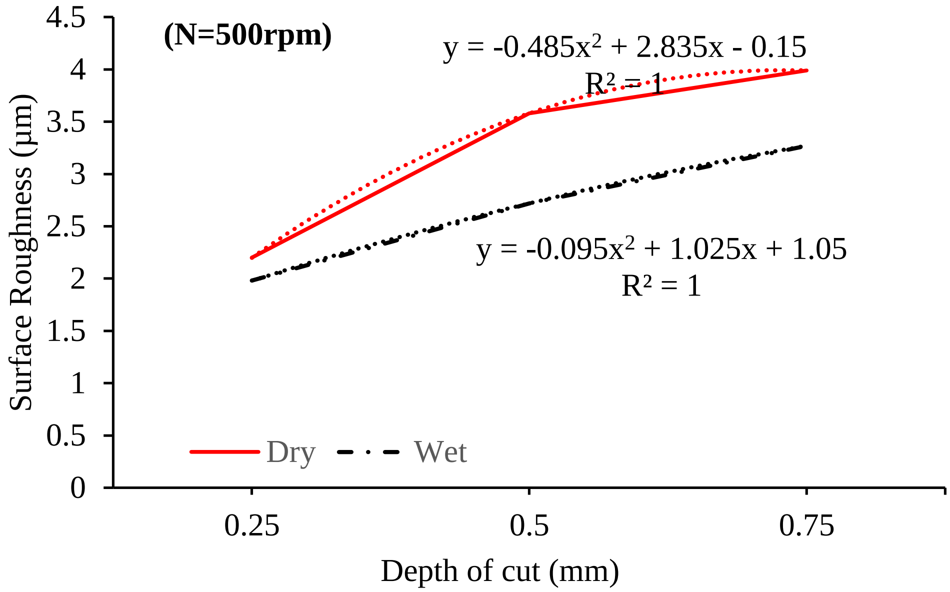


Figure 4.6 Effect of Depth of Cut on Surface Roughness at N = 500rpm

As the previous procedure for the feed rate Figure 4.7, 4.8, and 4.9 indicates the effect of depth of cut on the surface roughness for dry and wet turning of AISI 1020 steel. Each figure illustrates the relationship between the depth of cut and the surface roughness, with constant spindle speed values for dry and wet turning. As depth of cut increased at constant spindle speed the surface roughness become increased. Because at higher depths of cut, higher cutting forces are demanded to remove the bigger amount of the material. Increasing of cutting forces leads to the appearance of the machine tool vibration which affects negatively the surface roughness (Muamar et al. (2021); Upinder et al. (2012))

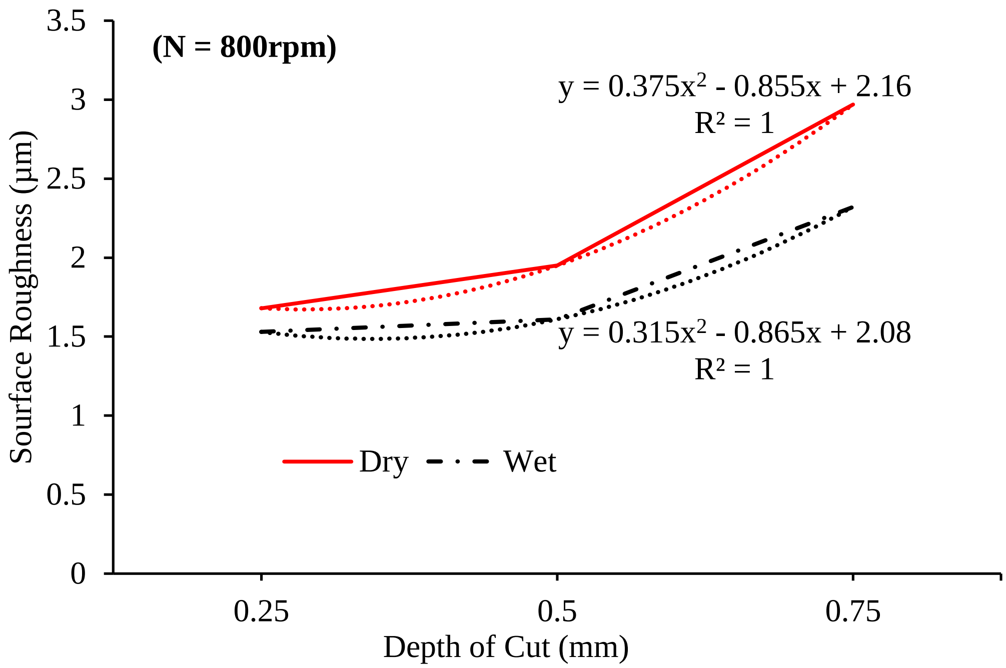


Figure 4.7 Effect of Depth of Cut on Surface Roughness at N = 800RPM

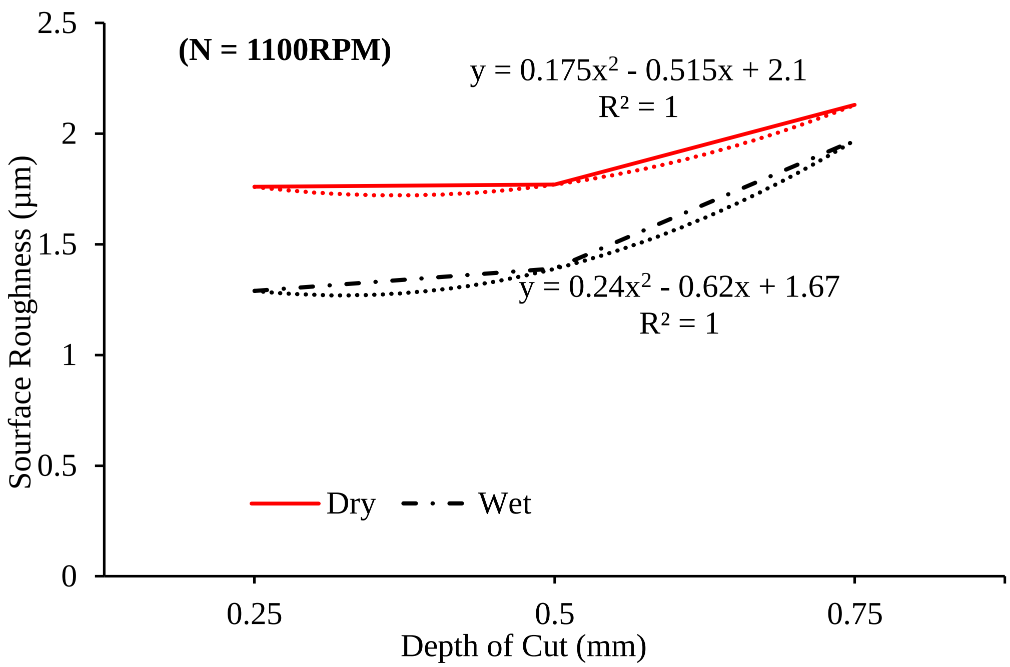


Figure 4.8 Effect of Depth of Cut on Surface Roughness at N = 1100rpm.

As spindle speed increased the surface roughness become minimized, i.e the maximum surface roughness at 0.75mm depth and 500 rpm spindle speed was 3.99 µm (for dry turning) and 3.27 µm (for wet turning). It became decreased to 1.76 µm (for dry turning) and 1.29 µm (for wet turning) when spindle speed increased to 1100 rpm.

4.3.3 Effect of Spindle Speed on Surface Roughness

The results presented in Figure 4.9, 4.10 and 4.11 are showing the effect of the spindle speed on the evolution of the surface roughness at constant feed rate.

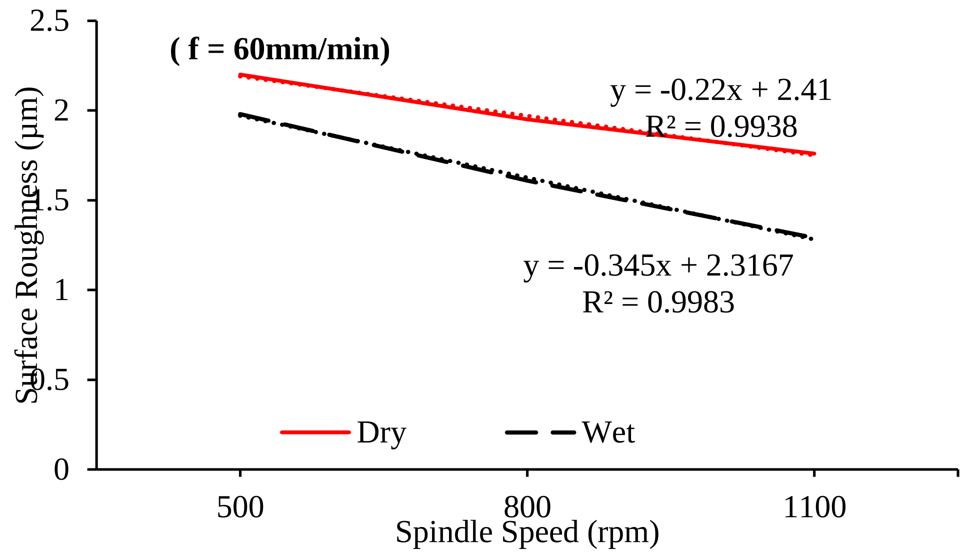


Figure 4.9 Effect of Spindle Speed on Surface Roughness at f = 60 mm/min

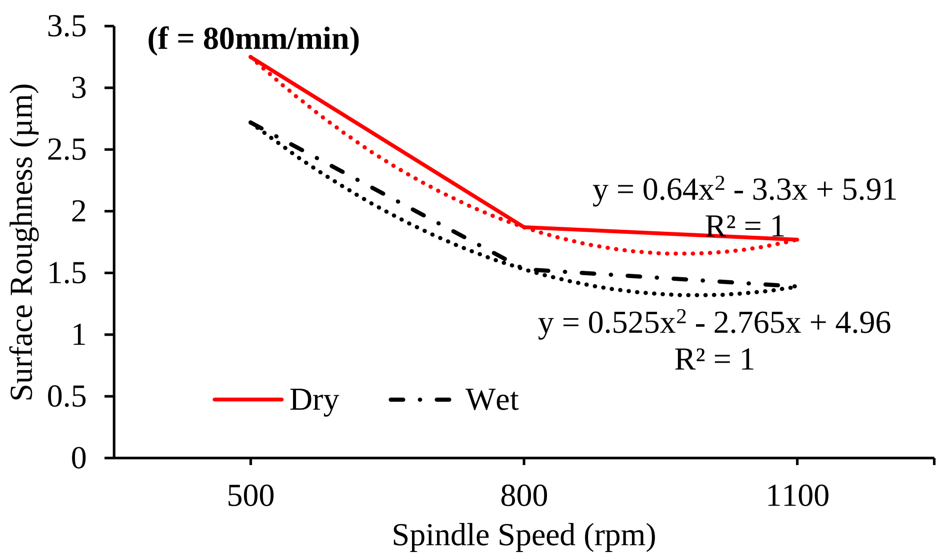


Figure 4.10 Effect of Spindle Speed on Surface Roughness at f = 80 mm/min

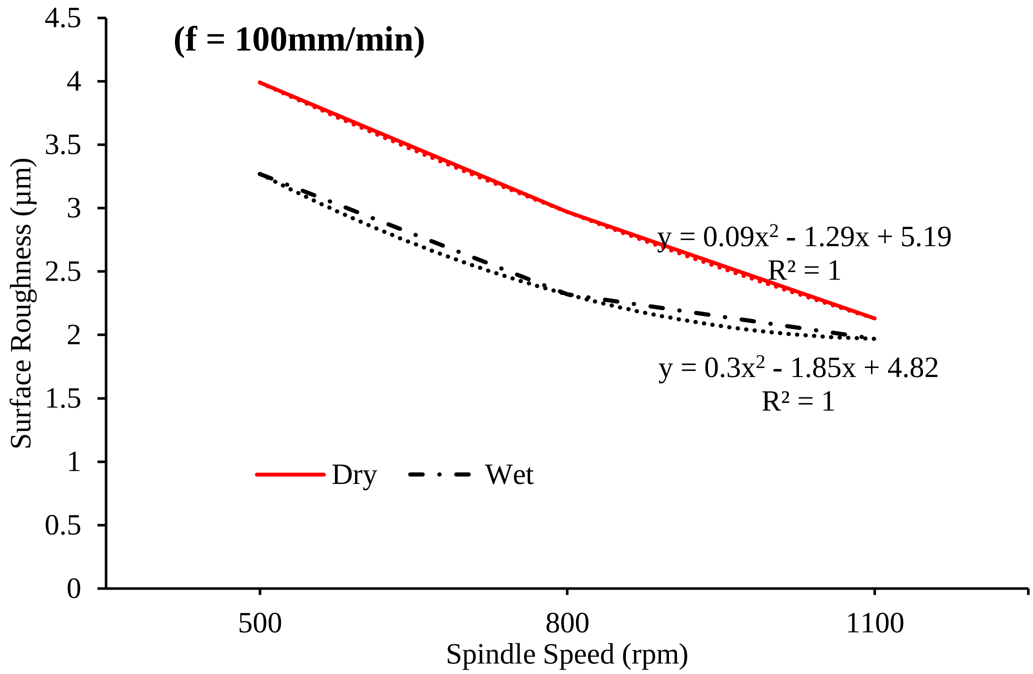


Figure 4.11 Effect of Spindle Speed on Surface Roughness at f = 100 mm/min

It can be observed that by increasing the spindle speed, the roughness of the turned surface became decreasing. At low spindle speeds a larger built up edge (BUE) are formed and also chips are fractured readily generating a rough surface. With increasing spindle speed, the BUE vanishes reducing the chip fracture resulting in better finish (Davis et al. (2012)). The other reason is for this can be that at higher spindle speeds the temperature increases because the material removal is more violent, producing the phenomenon of softening that improves the cutting process and thus diminishes superficial roughness. Moreover, when the turning is performed at a low spindle speed, a subsurface material fracture occurs, which contributes to increasing surface roughness; by increasing the cutting speed this effect disappears (Muamar et al. (2021)). However, surface roughness became increased when it is turned at higher feed rate. The minimum surface roughness at 1100 rpm spindle speed and 60 mm/min feed rate was 1.76 µm for dry turning and 1.29 µm for wet turning. It became increased to 2.13 µm for dry turning and 1.97 µm for wet turning. Therefore, surface roughness was increased with increasing spindle speed while the opposite effect has occurred with increasing feed rate. The results are in line with the result obtained by the previous work of Sarikaya and A. Güllü (2014). Maximum and minimum value of surface roughness was obtained at experiment number 6 and 7 respectively both for dry and wet turning. This is because the maximum feed rate and minimum spindle speed at run number 6 and minimum feed and maximum spindle speed at run number 7.

From Figure 4.2 to 4.11 it was shown that the better surface finish was obtained during wet turning. The results shows that using the coolant liquid reduces the surface roughness. This could be returned to the fact that; coolant liquid plays an essential role in cooling the cutting tool, reducing the friction between the cutting tool and the workpiece and improving the cutting tool life. Moreover, using the coolant liquid might assist in thrusting the chips away from the workpiece surface, which contribute in avoiding the appearance of the built up edge (BUE) of cutting tool that causes rough surfaces finishing (Suke et al (2016); Debnath et al. (2016); Muamar et al. (2021); Isik (2010)).

4.4 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 4.3 for dry turning and in Table 4.4 for wet turning. Percent contribution for each factor was calculated. Where DoF = degree of freedom, SS= Sum of squares, MSS = Mean Sum of squares, and F = F- Ratio generated by using Minitab 18 software.

Table 4.3 Analysis of Variance for Dry Turning

Source	DoF	SS	MSS	F-Value	P-Value	Percent Contribution	Significance (α=0.05)
t	2	0.613	0.307	7.90	0.112	12.35 %	Less Significant
f	2	1.768	0.884	22.78	0.042	35.58%	Significant
N	2	2.509	1.255	32.33	0.030	50.51%	Highly Significant
Error	2	0.078	0.039			1.56%	
Total	8	4.969				100%	

$F_{0.05, 2, 8} = 4.26$

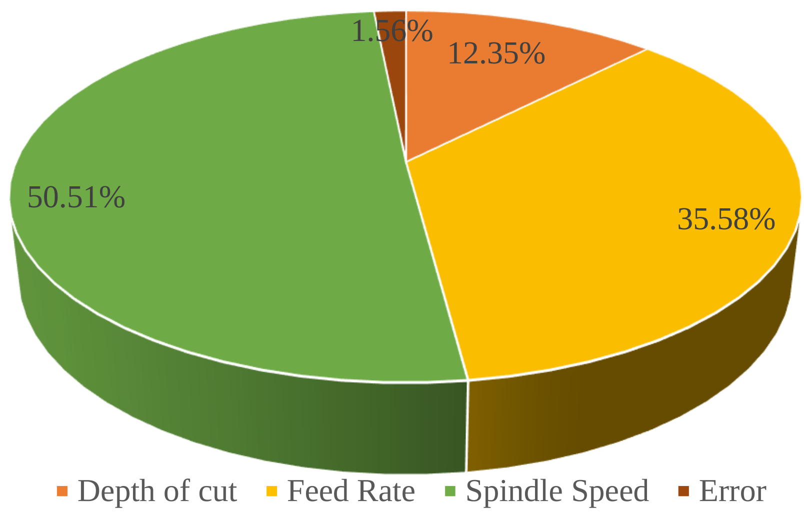


Figure 4.12 Percentage Contribution of Cutting Parameters to R_a for Dry Turning

Table 4.3 presents surface roughness percentage contribution variation of factors t, f and N; where factors represents depth of cut, feed rate and spindle speed respectively during dry turning. It is observed that spindle speed has statistical significances on the surface roughness value during dry turning of AISI 1020 steel at 95% confidence level. From the Table 4.3 and Figure 4.12 it is clearly observed that the depth of cut weight percentage (12.35 %), feed rate (35.58%) and spindle speed (50.51%) have significant influence on the surface roughness of dry turned AISI 1020 specimens.

Table 4.4 Analysis of Variance for Wet Turning

Source	DoF	SS	MSS	F-Value	P-Value	Percent contribution	Significance (α=0.05)
t	2	0.15002	0.07501	2.34	0.299	4.31%	Less Significant
f	2	1.27182	0.63591	19.87	0.048	36.51%	Significant
N	2	1.99762	0.99881	31.20	0.031	57.34%	Highly Significant
Error	2	0.06402	0.03201			1.84%	
Total	8	3.48349				100%	

$F_{0.05, 2, 8} = 4.26$

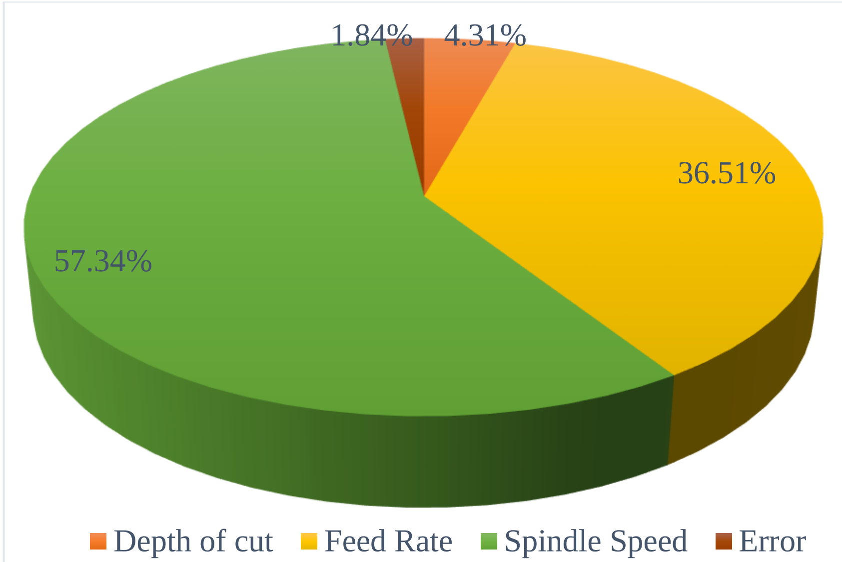


Figure 4.13 Percentage Contribution of Cutting Parameters to R_a for Wet Turning

Table 4.4 and Figure 4.12 presents surface roughness percentage contribution variation of each factors for wet turning. It was observed that the depth of cut weight percentage (4.31%), feed rate (36.51%) and spindle speed (57.34%) have significant influence on the surface roughness. This analysis was undertaken for a level of significance of 5%, i.e. for a level of confidence of 95%. The ANOVA table also consists of the F-values and P-values. By comparing the F-values with the tabulated ones (critical F-value), the significance of the factors can be understood. If the obtained F value of a parameter is greater than the tabulated one, then that particular parameter has a significant influence over the response variable. From Table 4.3 and 4.4, it can be seen that spindle speed has got the most significant influence on surface roughness followed by feed rate at the confidence level of 95%. The analysis of variance (ANOVA) also shows that spindle speed (N) and feed rate (f) are significant factors affecting the surface roughness ($P < 0.05$), while depth of cut (t) has almost no significance ($P>0.05$) in dry and wet turning conditions. And spindle speed has high significant effect on the surface roughness in both dry and wet turning of AISI 1020 steel. Therefore, controlling the spindle speed for turning AISI 1020 steel in dry and wet condition will help to get good surface roughness.

4.5 Optimization of Cutting Parameters for Surface Roughness for Dry Turning

Taguchi's orthogonal arrays are highly fractional orthogonal designs. Orthogonal array designs focus primarily on main effects. These designs are used to estimate main effects using only a few experimental runs. Taguchi Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. In Taguchi method, response variation is studied with the help of signal-to-noise (S/N) ratio.

4.5.1 Analysis of Mean for Surface Roughness for Dry Turning

The average mean value of surface roughness for each factor i.e. depth of cut (t), feed rate (f) and spindle speed (N) for dry turning was calculated using the design of experiments. Table 4.1 and Table 4.2 presents the experimental results of surface roughness (Ra) values for each specimen in dry and wet turning conditions. The mean value of surface roughness for each factor i.e. depth of cut (t), feed rate (f) and spindle speed (N) at each level during dry turning were obtained using Minitab 18 design and analysis of experiment software and the result is listed in response Table 4.5.

Table 4.5 Mean R_a of Cutting Parameters for Dry Turning.

Level	Depth of Cut	Feed Rate	Spindle Speed
	Symbol		
	t	f	N
1	**2.067**	**1.970**	3.147
2	2.570	2.297	2.263
3	2.660	3.030	**1.887**
Delta	0.593	1.060	1.260
Rank	3	2	1

The factor with the greatest effect on the mean from Table 4.5 is spindle speed (Delta = 1.260, Rank = 1). The factor with the least effect on the mean is a depth of cut (Delta = 0.593, Rank = 3). Those parameter levels with better surface finish value during dry turning of specimens that means **t1f1N3** will be taken as a possible parameter combination for better values. The significant factors in the order increasing by affecting surface roughness are spindle speed, feed rate, and depth of cut as it was shown in Table 4.5. The main effect plot for means of surface roughness value variations during dry turning is as shown in the Figure 4.14. The result taken from the above Table 4.5 data shows means as smaller is better is selected for surface roughness value.

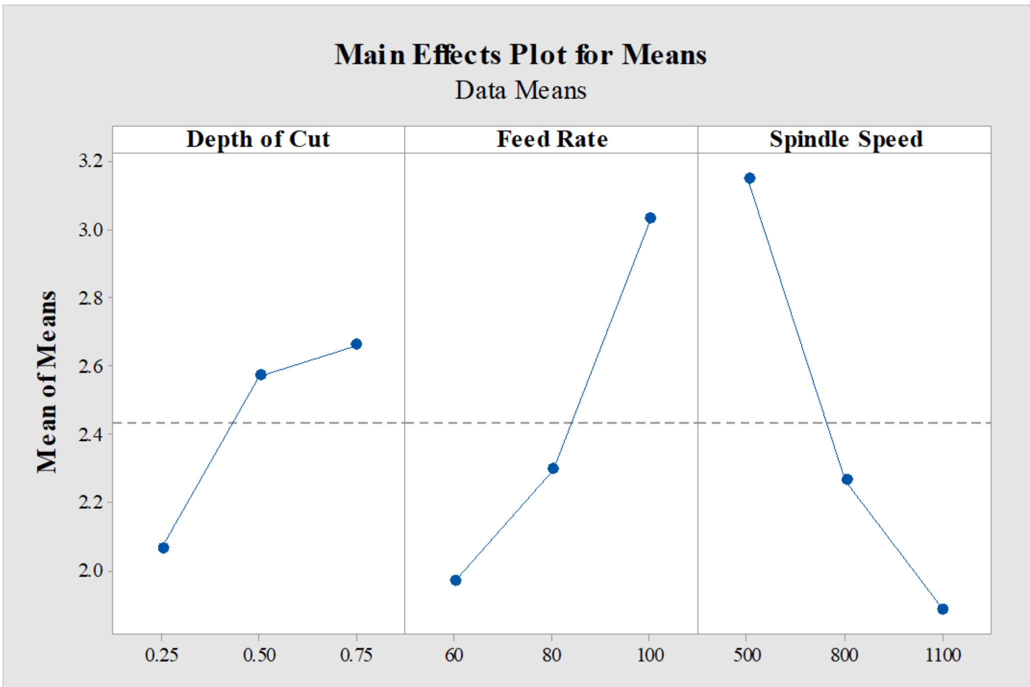


Figure 4.14 Main Effect Plot of Mean Surface Roughness for Dry Turning

From Figure 4.15 it can be seen that within the scope of this study the minimum point in the graph for each turning parameters are the optimum conditions at which better surface roughness is obtained. The minimum point for depth of cut and feed rate are at level one, but for spindle speed the minimum point on this graph was at level three. This is why the identified optimum turning parameter was at low depth of cut, low feed and high spindle speed which is t1f1N3.

For predicting the optimum response, three factors of parameters are selected by the small mean value. **t1f1N3** (i.e 0.25mm depth of cut, 60mm/min feed rate and 1100 rpm spindle speed) is the optimum level of parameters mean value for surface roughness value for dry turning. To find out the predicted value of the responses (surface roughness value) the following linear regression equation is used (Ebrahim et al. (2020)): -

$$Y_{opt} = m + (t1 - m) + (f1 - m) + (N3 - m) \quad (4.1)$$

$$Y_{opt} = t1 + f1 + N3 - 2m$$

where, m is average performance mean value for surface roughness, t1 is optimum level value for parameter t, f1 is optimum level value for parameter f, N3 is optimum level value for parameter N.

. $Y_{opt} = 2.060 + 1.970 + 1.887 - (2 * 2.432)$

$Y_{opt} = 1.083$ (Predicted optimum value of surface roughness for dry turning)

4.5.2 Analysis of S/N Ratio for Surface Roughness for Dry Turning

The Taguchi method uses the S/N ratio to measure the variations of the response values in experimental design. The equations used for calculating the signal to noise ratios are based on the characteristics of the response variables being reported. For surface roughness, the response variables are smaller-the-better. Table 4.1 presents the calculations of S/N Ratios for surface roughness values results for turning using the design of experiments. Table 4.6 presents the signal to noise ratios of surface roughness for smaller is better.

Table 4.6 Signal to Noise Ratios of R_a for Smaller is better for Dry Turning

Level	Depth of Cut	Feed Rate	Spindle Speed
	Symbol		
	t	f	N
1	-6.284	-5.853	-9.702
2	-7.593	-6.878	-6.898
3	-8.201	-9.347	-5.479
Delta	1.917	3.494	4.223
Rank	3	2	1

$$Delta = Maximum\ \frac{S}{N}\ ratio - Minimum \frac{S}{N}\ ratio \quad (4.2)$$

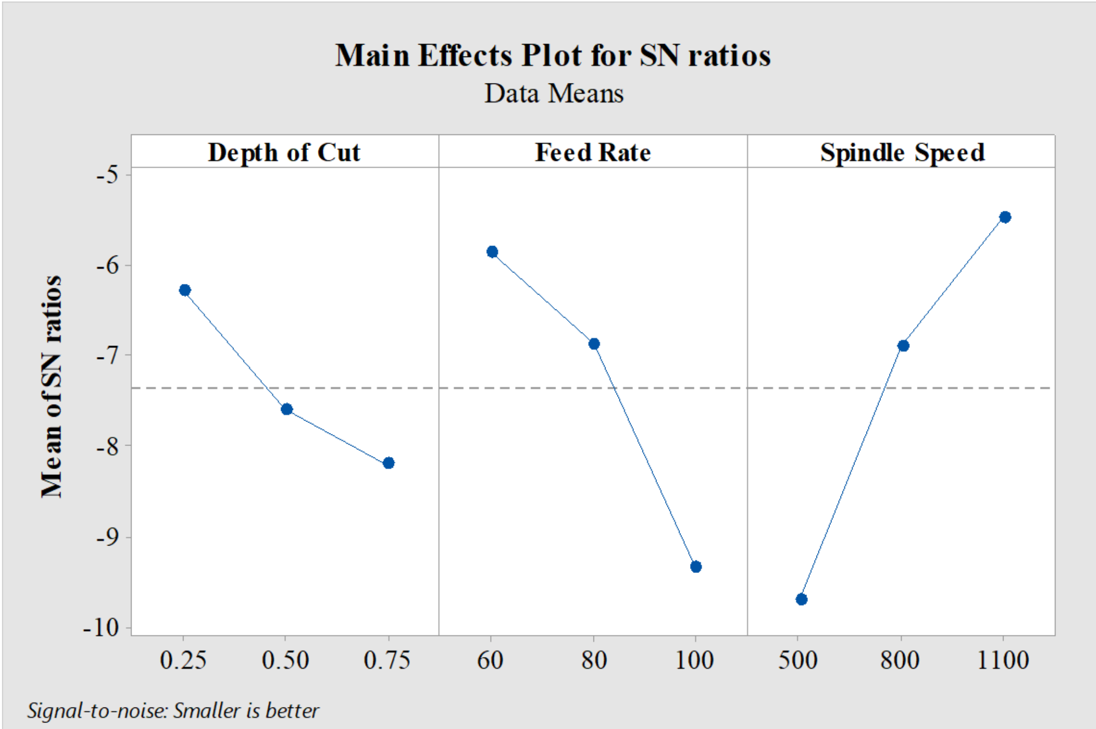


Figure 4.15 Main Effects Plot of S/N Ratio of R_a for Dry Turning

As shown in Table 4.6 and the main effect plot for the signal to noise (S/N) ratios of the dry turning surface roughness response, the spindle speed weight percentage has the greatest effect (Delta = 4.223, Rank = 1). The factors with the least effect on the (S/N) ratio was the depth of cut (Delta = 1.917, Rank = 3). Table 4.5 shows the optimal parameter combination on smaller is the better surface quality character is t1f1N3, and it's a possible parameter combination for increasing the surface quality of dry turned specimens. The control factor's main effect plot for the surface roughness S/N ratio is shown in Figure 4.15. The numerical value of the maximum 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 spindle speed weight percentage when compared with other cutting factors and depth has the least effect on the surface roughness which is similar to the result obtained from analysis of mean. Since, S/N ratio used for this study is smaller is better and smallest S/N ratio was selected as it shown in the graph of Figure 4.15. That is spindle speed at level 3, feed rate and depth of cut at level 1 (t1f1N3) was selected.

4.5.3 Determining the Optimum Condition for Dry Turning

Table 4.7 presents the optimum parameters setting selected for surface roughness obtained from the design of experiment and experimental results for dry turning. The selected optimum parameters in this study were at higher cutting speed, at lower feed and at maximum depth of cut, which is at t1f1N3.

Table 4.7 Optimum Parameter Level And Their Value for Dry Turning

Factors	Level Selected	Value of the Level	Rank of affecting the Response
Depth of Cut (mm)	1	0.25	3
Feed Rate (mm/min)	1	60	2
Spindle Speed (RPM)	3	1100	1

4.6 Optimization of Cutting Parameters for Surface Roughness for Wet Turning

4.6.1 Analysis of Mean for Surface Roughness for Wet Turning

In similar manner to dry turning, the mean value of surface roughness for each factor i.e. depth of cut (t), feed rate (f) and spindle speed (N) at each level were also obtained using Minitab 18 for wet turning and the result is listed in Table 4.8.

Table 4.8 Mean R_a of Cutting Parameters for Wet Turning

Level	Depth of Cut	Feed Rate	Spindle Speed
	Symbol		
	t	f	N
1	**1.827**	**1.627**	2.657
2	2.090	1.880	1.820
3	2.110	2.520	**1.550**
Delta	0.283	0.893	1.107
Rank	3	2	1

During wet turning the factor with the greatest effect on the mean surface roughness from Table 4.8 is spindle speed (Delta = 1.107, Rank = 1). The factor with the least effect on the mean is a depth of cut (Delta = 0.283, Rank = 3). Similar to dry turning the level of cutting parameters minimum surface roughness value during wet turning of specimens that was obtained at t1f1N3(i.e 0.25mm depth of cut, 60mm/min feed rate and 1100 rpm spindle speed)**.** The significant factors in the order increasing by affecting surface roughness are spindle speed, feed rate, and depth of cut as it was seen in Table 4.8. The main effect plot of means of surface roughness value for wet turning is as shown in the Figure 4.16.

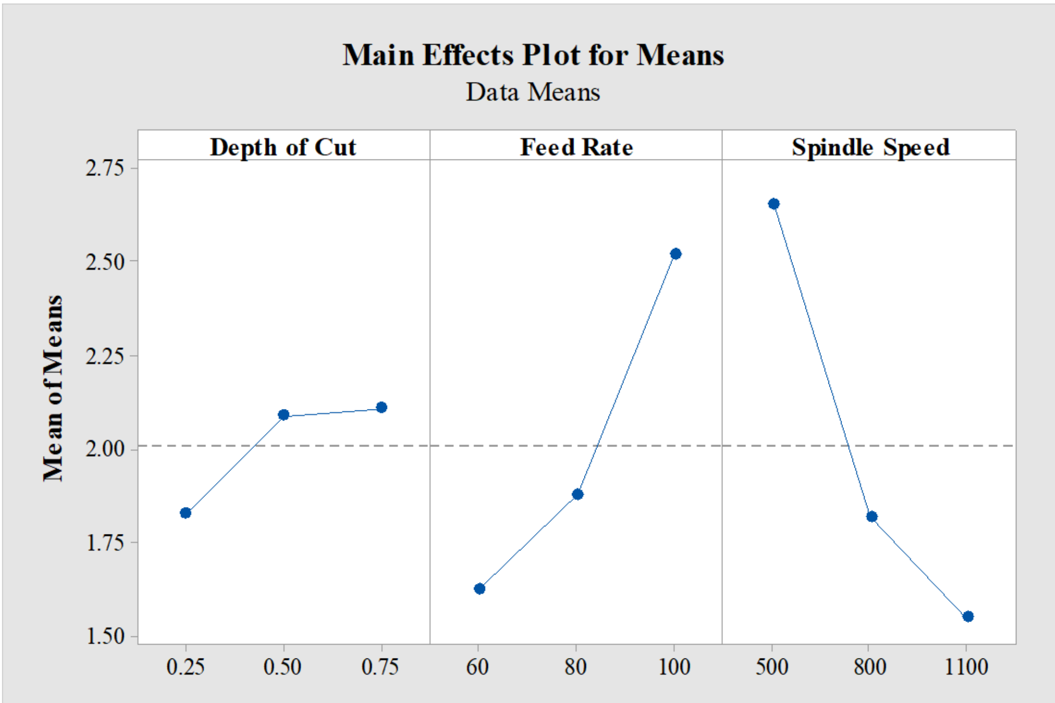


Figure 4.16 Main Effect Plot of Mean Surface Roughness for Wet Turning

It is shown in Figure 4.16 that the minimum point in the graph for each turning parameters are the optimum conditions at which better surface roughness is obtained. The minimum point for depth of cut and feed rate are at level one, but for spindle speed the minimum point on this graph was at level three. This is why the identified optimum turning parameter was at low depth of cut, low feed and high spindle speed which is t1f1N3.

For predicting the optimum response, three factors of parameters are selected by the small mean value. **t1f1N3** is the optimum level of parameters mean value for surface roughness value for wet turning. To find out the predicted value of the responses (surface roughness value) the following linear regression equation (4.1) is used.

$Y_{opt} = 1.827 + 1.627 + 1.550 - (2 * 2.109)$

$Y_{opt} = 0.786$(Predicted mean value for surface roughness of wet turning)

4.6.2 Analysis of S/N Ratio for Surface Roughness for Wet Turning

Table 4.6 presents the response table for a signal to noise ratios of surface roughness for smaller is better for wet turning.

Table 4.9 Signal to Noise Ratios for Smaller is Better R_a for Wet Turning

Level	Depth of Cut	Feed Rate	Spindle Speed
	Symbol		
	t	f	N
1	**-5.172**	**-4.094**	-8.305
2	-5.763	-5.082	-5.047
3	-6.071	-7.830	**-3.654**
Delta	0.899	3.736	4.651
Rank	3	2	1

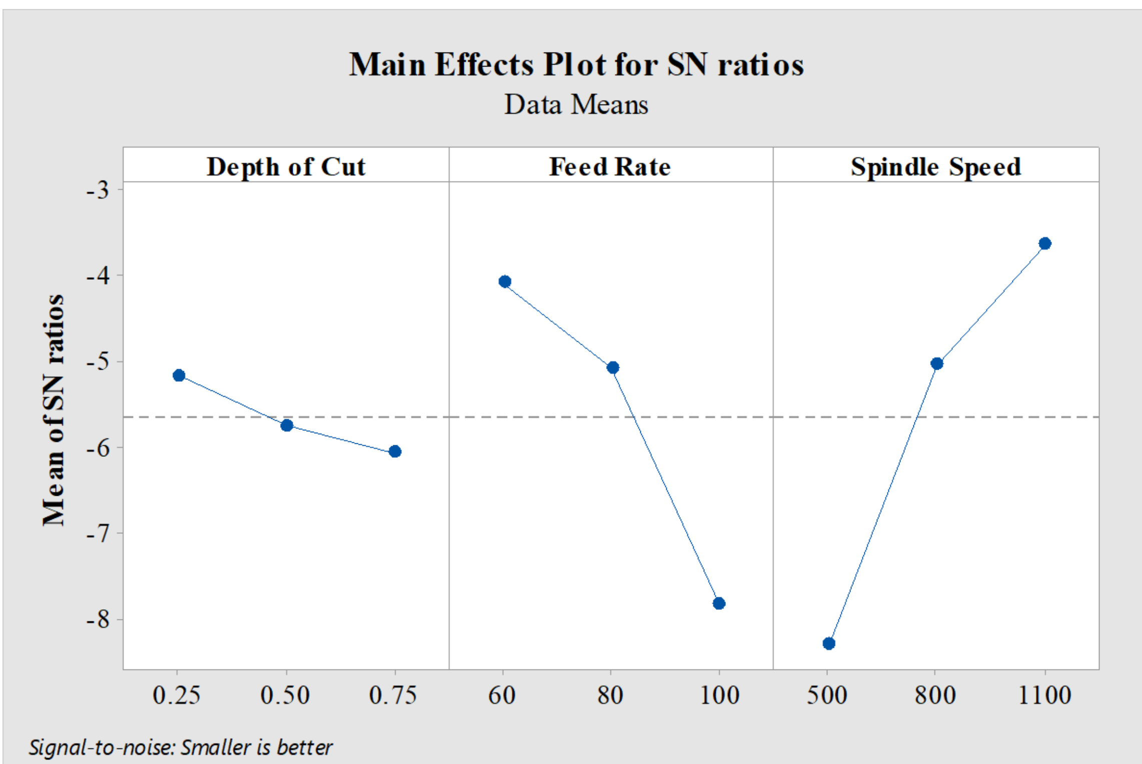


Figure 4.17 Main Effects Plot of S/N Ratio of R_a for Wet Turning

Similar to dry turning, as shown in Table 4.9 and the main effect plot for the signal to noise (S/N) ratios of the wet turned surface roughness response, the spindle speed weight percentage has the greatest effect and depth of cut has the least effect (Delta = 4.651, Rank = 1) on the surface roughness. (Delta = 0.889, Rank = 3). As shown in Table 4.9 the optimal parameter combination on smaller is the better surface quality character is t1f1N3, and it's a possible parameter combination that gives minimum surface roughness for wet turned specimen.

4.6.3 Determining the Optimum Condition for Wet Turning

Table 4.10 presents the optimum parameters setting selected for surface roughness obtained from the design of experiment and experimental results for wet turning. The selected optimum parameters in this study were at higher cutting speed, at lower feed and at maximum depth of cut which, is at t1f1N3.

Table 4.10 Optimum Parameters Levels and Their Values in Wet Turning

Factors	Level Selected	Value of the Level	Rank of affecting the Response
Depth of Cut (mm)	1	0.25	3
Feed Rate (mm/min)	1	60	2
Spindle Speed (RPM)	3	1100	1

4.7 Confirmation of the Optimum Results for Dry and Wet Turning

The purpose of the confirmation experiment in this study were to validate the optimum cutting conditions. As per the DOE analysis and the improvement steps of Taguchi approach, confirmation experiment were performed to check the predictability of the result. By considering this, the optimum parameter are used to perform the confirmation test. The predicted surface roughness at optimum machining conditions resulted by Taguchi analysis. Also based on these machining conditions, experimental values for surface roughness were measured. Confirmation experiments were conducted using the optimum cutting parameters obtained from Taguchi analysis both for dry and wet turning. The result of surface roughness at optimum level of cutting parameter (i.e. t1f1N3) were in Table 4.11 bellow.

Table 4.11 Result of Confirmation Experiments

Turning Condition	Surface Roughness R_a(µm)			
	Trial 1	Trial 2	Trail 3	Mean
Dry Turning	1.17	1.08	1.14	1.13
Wet Turning	0.85	0.80	0.78	0.81

Table 4.12 shows the comparison of the actual surface roughness with the predicted surface roughness using optimal cutting parameters.

Table 4.12 Comparison between Predicted and Experimental Value

Turning Conditions	Predicted Value of R_a (µm)	Experimental Value of R_a (µm)	Error %
Dry	1.08	1.13	4.42
Wet	0.78	0.81	3.70

From Table 4.12 it can be seen that, the difference between experimental result and the predicted results are very small both for dry and wet turning. The values predicted by using Taguchi approach is approximately near to the value which is experimentally obtained. This verify that, the experimental results of surface roughness are strongly correlated with the predicted results. The percentage error is calculated by subtracting predicted value from experimental value, and dividing the result for experiment value. Based on this percentage error was 4.42% and 3.70% for dry and wet turning respectively.

4.8 Analysis of Cutting Temperatures for Dry and Wet Turning

Table 4.13 shows the experimental combinations as designed according to the Taguchi method. The workpiece surface temperature was measured by infrared thermometer for each experiment run. The workpiece highest surface temperature at the cutting zone for each run of the experiment was also shown in Table 4.13. It is evident that the workpiece highest surface temperature was recorded in run number 7 with depth of cut 0.75mm and spindle speed of 1100rpm both in dry and wet turning conditions. Observation of all of the experimental runs indicate that the depth of cut and cutting speed contribute largely to the cutting temperature, while the effect of feed rate is smaller. This could be attributed to the inability of the cutting inserts to maintain their sharp cutting geometry at increased spindle speeds and depth of cut. It was evident from the experiments that the inserts maintained minimum cutting temperatures at minimum depth of cut and spindle speed values. In addition, there is a big chance that built-up edge (BUE) was developed at higher spindle speed, resulting in more dull cutting edges on the tool and consequently, higher cutting temperatures (Reis et al. (2007)).

Table 4.13 Experimental Result of Cutting Temperature for Dry and Wet Turning

Exp’t No	Depth of Cut (mm)	Feed Rate (mm/min)	Spindle Speed (rpm)	Temperature (^{0}C)	
				Dry	Wet
1	0.25	60	500	38.2	24.2
2	0.25	80	800	43.4	25.8
3	0.25	100	1100	53.8	28.3
4	0.5	60	800	45.0	26.4
5	0.5	80	1100	58.3	27.0
6	0.5	100	500	41.8	25.6
7	0.75	60	1100	59.2	28.1
8	0.75	80	500	44.1	26.4
9	0.75	100	800	49.5	27.1

As observed from Table 4.13 the cutting temperature readings were taken for each specimen during dry and wet turning. The maximum cutting temperature (59.2^{0}C) was founded at high spindle speed of (1100rpm), the depth of cut of 0.75mm during dry turning and maximum cutting temperature (28.3^{0}C) was obtained at spindle speed of 1100rpm and feed rate of 100 mm/min for wet turning. The minimum cutting temperature of (38.2^{0}C) was obtained at spindle speed of 500 rpm, depth of cut of 0.25mm and feed rate of 60mm/min for dry turning. In similar manner for wet turning the minimum cutting temperature (24.2^{0}C) was obtained at spindle speed of 500 rpm, depth of cut of 0.25mm and feed rate of 60mm/min. Therefore, the increase in spindle speed leads to an increase in cutting temperate generated. But application of coolant while turning highly minimize the cutting temperature.

4.8.1 Comparison of Cutting Temperature for Dry and Wet Turning

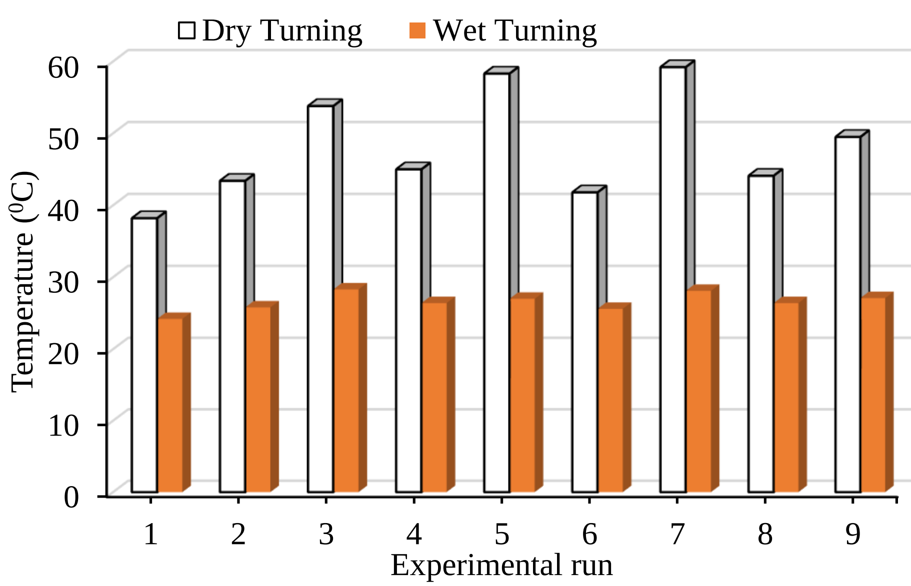


Figure 4.18 Cutting Temperature Value for Each Experimental Run

The comparison cutting temperature for dry and wet turning were shown in Figure 4.18. The bar chart shows that the cutting temperature for wet turning was smaller as compared to dry turning. The average of all temperature results saved under dry and wet turning were computed, the result were 48.14^{0}C and 26.54^{0}C respectively. The result show that average cutting temperature of wet turning is lower by 44.86% than average cutting temperature of dry turning. The cutting fluid penetrate the cutting zone to absorb the heat generated during machining. This cools the workpiece and tool surface. Moreover, the results implies that applying cutting fluids to the cutting zone reduce friction by lubricating the contacting surfaces which tend to reduce cutting temperature.

4.8.2 Analysis of Effect of Cutting Parameters on Cutting Temperature

Table 4.14 shows the means of cutting temperature for each cutting parameters (depth of cut, feed rate and spindle speed) for dry turning. Main effect plot for mean cutting temperature is shown on Figure 4.19.

Table 4.14 Mean Cutting Temperature for Dry Turning

Level	Depth of Cut	Feed Rate	Spindle Speed
	Symbol		
	t	f	N
1	45.13	47.47	41.37
2	48.37	48.60	45.97
3	**50.93**	**48.37**	**57.10**
Delta	5.80	1.13	15.73
Rank	2	3	1

Figure 4.19 Main effects plot of Cutting Temperature for Dry Turning

As shown in Figure 4.19 mean cutting temperature increases with increasing depth of cut and spindle speed. But it was increasing when the feed rate increase from the first level to the second level and decrease when feed rate increase to the third level (i.e. as depth of cut increase from 0.25mm to 0.5mm, the mean cutting temperature increased from 45.13^{0}C to 48.37^{0}C and then to 50.93^{0}C as depth of cut increased to 0.75mm. As feed rate increased from 60mm/min to 80mm/min the mean cutting temperature increased from 47.47^{0}C to 48.60^{0}C and then decreased to 48.37^{0}C when feed rate increased to 100 mm/min. As spindle speed increases from 500rpm to 800 rpm the mean cutting temperature increased from 41.37^{0}C to 45.97^{0}C and then to 57.10^{0}C as spindle speed increased to 1100rpm.) The slope of the main effect plot for mean temperature for dry turning was greater for spindle speed and depth of cut than feed rate. This implies that the cutting temperature was highly affected by spindle speed and depth of cut than by feed rate. The graph also indicates that spindle speed was the most significant factor on the cutting temperature. The same thing was indicated on Table 4.14, i.e. from the value of delta spindle speed was in the first rank followed by depth of cut and feed rate.

Table 4.15 shows the mean effect of each cutting parameters on cutting temperature for wet turning.

Table 4.15 Mean Cutting Temperature for Wet Turning

Level	Depth of Cut	Feed Rate	Spindle Speed
	Symbol		
	t	f	N
1	26.10	26.23	25.40
2	26.33	26.40	26.43
3	27.20	27.00	27.80
Delta	1.10	0.77	2.40
Rank	2	3	1

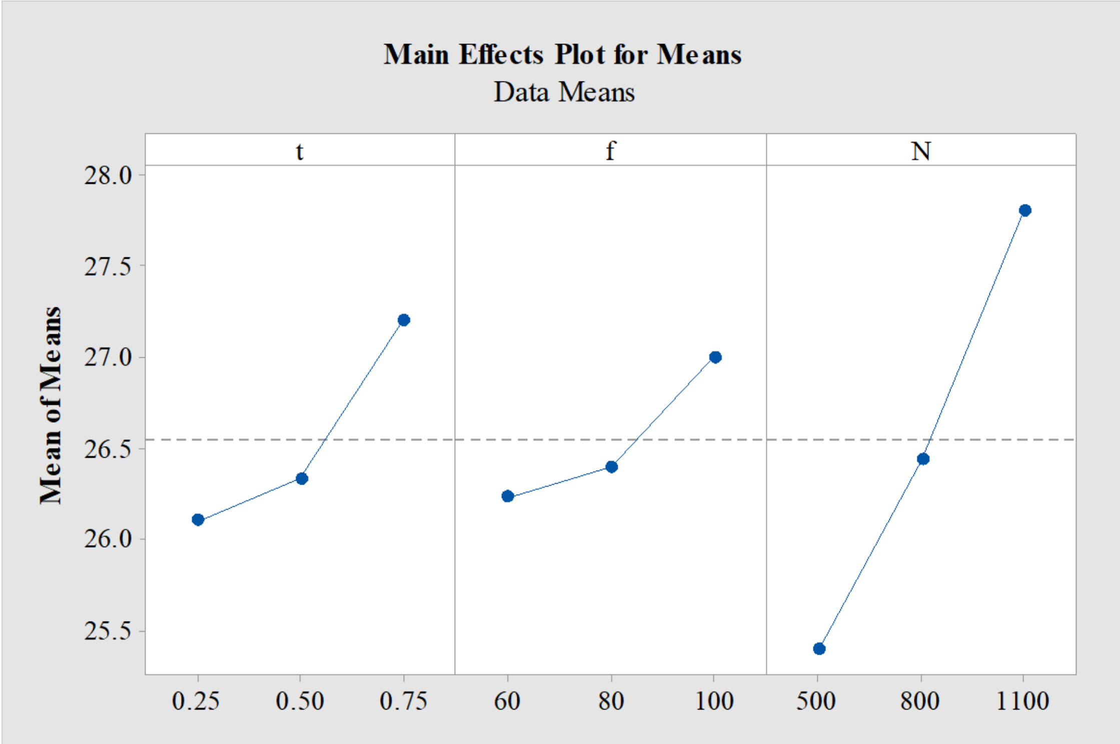
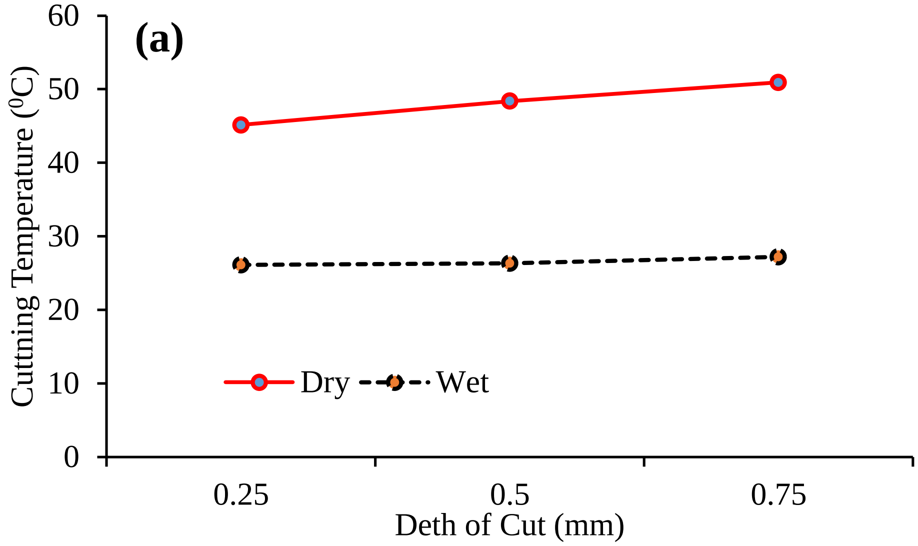
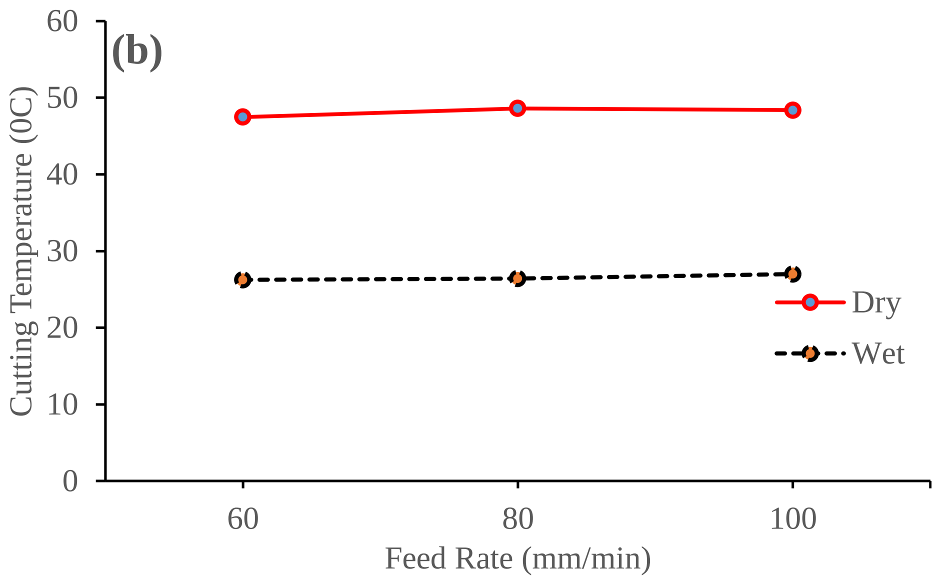


Figure 4.20 Main Effects Plot of Mean Cutting Temperature for Wet Turning

In the same way to dry turning Table 4.15 and Figure 4.20 shows the effect of cutting parameters on the mean cutting temperature for wet turning. The graph shows that the mean cutting temperature was increasing with increasing cutting parameters (i.e. as depth of cut increase from 0.25mm to 0.5mm, the mean cutting temperature increased from 26.10^{0}C to 26.33^{0}C and then to 27.20^{0}C as depth of cut increased to 0.75mm. As feed rate increased from 60mm/min to 80mm/min the mean cutting temperature increased from 26.23^{0}C to 26.40^{0}C and then increased to 27.00^{0}C when feed rate increased to 100 mm/min. As spindle speed increases from 500rpm to 800 rpm the mean cutting temperature increased from 25.40^{0}C to 26.46^{0}C and then to 27.80^{0}C as spindle speed increased to 1100rpm. The slope of main effect plot from Figure 4.20 and the value of delta from Table 4.15 indicates the mean cutting temperature was highly affected by spindle speed followed by depth of cut and feed rate (i.e. spindle speed is at 1st rank with 2.40 delta value, deth of cut is at 2nd rank with delta 1.10 and feed rate is at 3rd rank with delta value 0.77).

Figure 4.21 (a), (b), and (c) shows the comparison of mean effect of each cutting parameters (depth of cut, feed rate and spindle speed respectively) on cutting temperature for dry and wet turning operation.





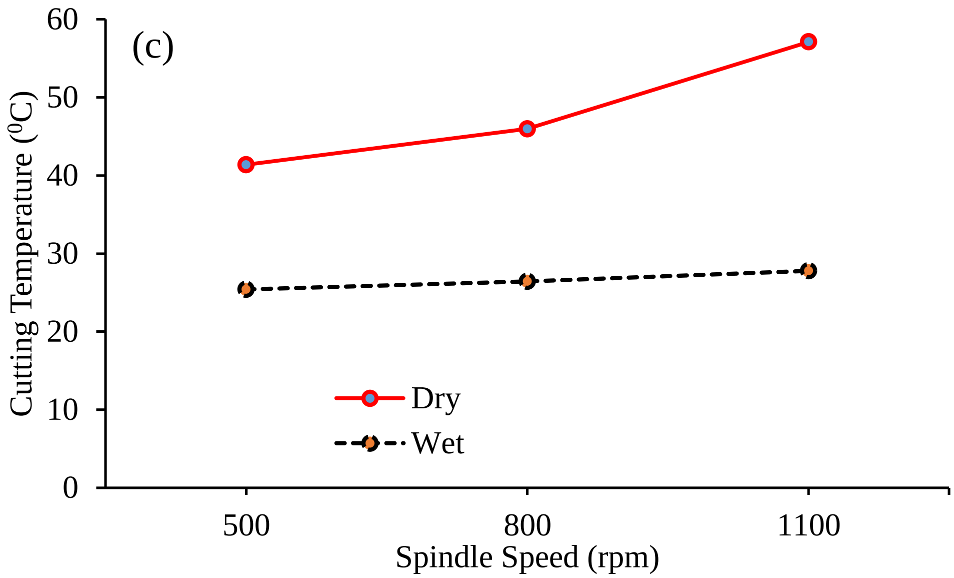


Figure 4.21 Mean Effect of (a). Depth of Cut, (b).Feed Rate, and (c) Spindle Speed Cutting Temperature

Mean cutting temperature increasing with increasing all cutting parameters as shown in Figure 2.21. The cutting temperature was highly reduced for wet turning, due to cooling effect of cutting fluid, which absorb heat from the cutting zone.

4.8.3 Analysis of Variance for Cutting Temperature

Analysis of Variance was done to identify the significant factors which affects the cutting temperature of the dry and wet turned specimens. It was calculated and reported in Table 4.16 and 4.17 for dry and wet turning respectively. Percent contribution for each factor were calculated by Equation (3.4).

Table 4.16 Analysis of Variance of Cutting Temperature for Dry Turning

Source	DoF	SS	MSS	F-Value	P-Value	Percentage Contribution
Depth of Cut (mm)	2	50.682	25.341	31.63	0.031	11.34%
Feed Rate (mm/min)	2	2.149	1.074	1.34	0.427	0.48%
Spindle Speed (RPM)	2	392.649	196.324	245.07	0.004	87.82%
Error	2	1.602	0.801			0.36%
Total	8	447.082				100%

$F_{0.05, 2, 8} = 4.26$

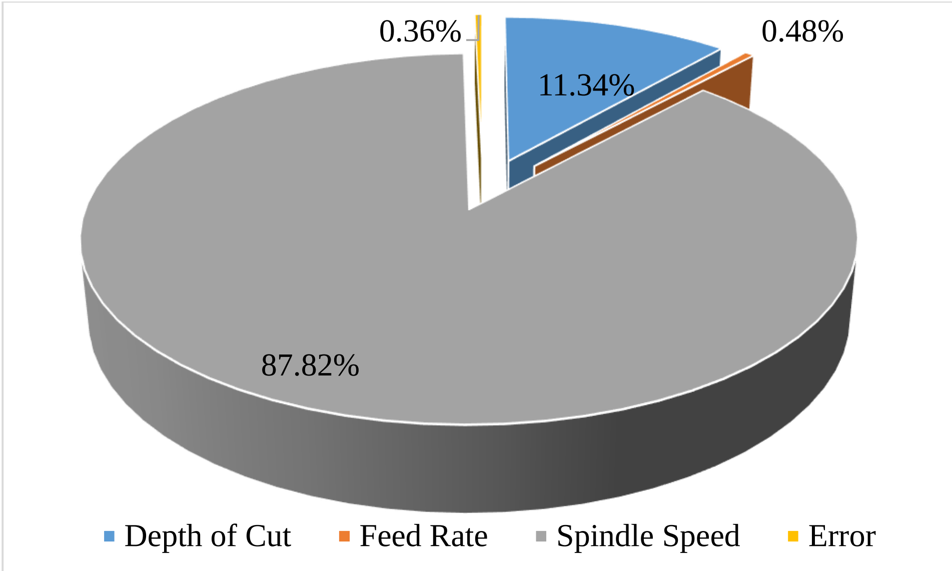


Figure 4.22 Percentage Contribution of Cutting Parameters to Cutting Temperature for Dry Turning

Table 4.16 and Figure 4.22 presents cutting temperature percentage contribution of each factors during dry turning of AISI 1020 specimens. It is observed that the depth of cut weight percentage (11.34%), feed rate (0.48%) and spindle speed (87.82%) have significant influence on the cutting temperature. It can be seen from the result of F-value that spindle speed has got the most significant influence on cutting temperature followed by depth of cut at the confidence level of 95%. But feed has almost no significance on the cutting temperature in dry turning condition.

Table 4.17 Analysis of Variance of Cutting Temperature for Wet Turning

Source	DoF	SS	MSS	F-Value	P-Value	Percentage Contribution
Depth of Cut (mm)	2	2.0156	1.0078	1.53	0.395	15.50%
Feed Rate (mm/min)	2	0.9756	0.4878	0.74	0.574	7.50%
Spindle Speed (RPM)	2	8.6956	4.3478	6.61	0.131	66.88%
Error	2	1.3156	0.6578			10.12%
Total	8	13.0022				100%

$F_{0.05, 2, 8} = 4.26$

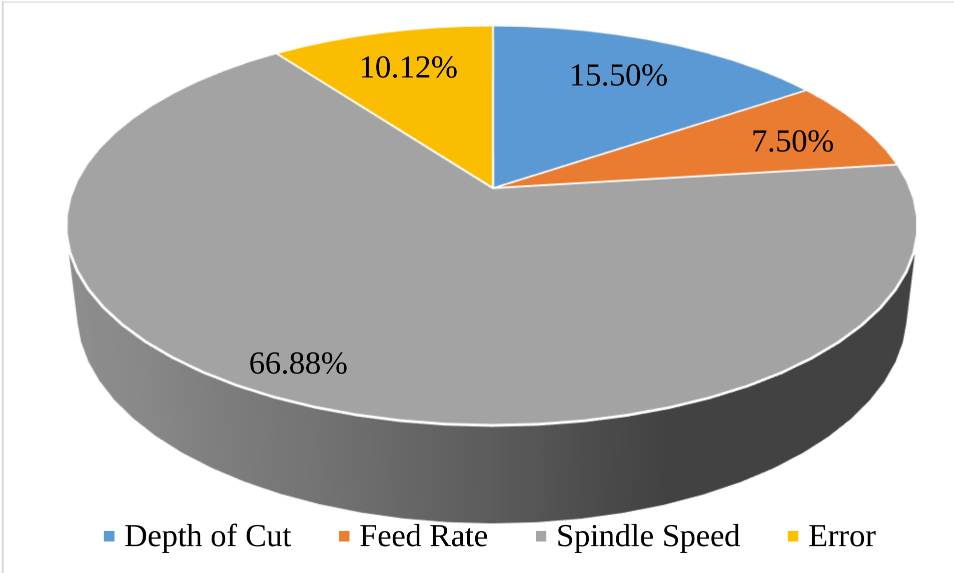


Figure 4.23 Percentage Contribution of Cutting Parameters to Cutting Temperature for Wet Turning

Table 4.17 and Figure 4.23 presents cutting temperature percentage contribution of each factors during wet turning of AISI 1020. It is observed that the depth of cut weight percentage (15.50%) feed rate (7.50%) and spindle speed (66.88%) have significant influence on the cutting temperature. In addition to percentage contribution, F-value and P-value was also given in Table 4.17. The result from the table indicates that spindle speed got the most significant influence on cutting temperature followed by depth of cut at the confidence level of 95% within the specific test range. But feed has almost no significance on the cutting temperature in wet turning condition too. When compared with dry turning the percentage contribution of spindle speed was higher in dry turning than its percentage contribution in wet turning.

4.9 Analysis of Tool Life

Tool life generally indicates the amount of satisfactory performance or service rendered by a fresh tool or a cutting point till it is declared failed. It is the length of cutting time that the tool can be used. Operating the tool until final catastrophic failure is one way of defining tool life. However, in production, it is often a disadvantage to use the tool until this failure occurs because of difficulties in re-sharpening the tool and problems with work surface quality. As an alternative, a level of tool wear can be selected as a criterion of tool life, and the tool is replaced when wear reaches that level. A convenient tool life criterion is a certain flank wear value of 0.5 mm. Tool life is always assessed or expressed by span of machining time (T) in minutes. The tool life for dry turning and wet turning of each experimental run were obtained using Taylor tool life equation (Equation 2.2) i.e. $VT^nf^at^b=C$. Where, *n*, *a*, and *b* are Taylor's tool life exponent and C is constant. The values of 'n' and 'C' depend mainly upon the tool work materials and the value of *'a'* and '*b'* depends on tool-work material and the cutting environment (cutting fluid application). The values of the constants are available in Machining Data Handbooks and can be evaluated from machining tests. In practice typical values for cemented carbide tools for machining steel (low carbon steel) as work piece are given in Table 4.18 (Groover (2013); Rao et al. (2014); Nilesh et al. (2016); Kawthar et al. (2016)).

Table 4.18 Taylor Tool Life Equation Constant Values

Cutting Conditions	Taylor Tool Life Equation Constants			
	C	n	a	b
Dry Turning	500	0.25	0.30	0.15
Wet Turning	500	0.25	0.45	0.2

Tool life for dry and wet turning were calculated for each run of experiment as in Table 4.19. As shown in the table the longer tool life was obtained when all the cutting parameter are at their minimum level both in dry and wet turning conditions. At first experimental run all parameters are in their minimum level (i.e. 0.25mm depth of cut, 60mm/min feed rate, and 500RPM spindle speed) and the maximum tool life 14.22min in dry turning and 43.60min in wet turning were obtained.

Table 4.19 Tool Life Result for Dry and Wet Turning

S/n	Cutting Parameters			Tool Life (min)	
	Depth of Cut (mm)	Feed Rate (mm/min)	Spindle Speed (rpm)	Dry Turning	Wet Turning
1	0.25	60	500	14.22	43.60
2	0.25	80	800	8.09	12.33
3	0.25	100	1100	6.44	7.30
4	0.5	60	800	7.95	10.95
5	0.5	80	1100	6.31	6.73
6	0.5	100	500	9.68	17.01
7	0.75	60	1100	6.40	6.76
8	0.75	80	500	9.76	16.35
9	0.75	100	800	6.68	7.33

4.9.1 Comparison of Tool Life for Dry and Wet Turning

The comparison of tool life for dry and wet turning was shown in Figure 4.24. It was shown on the bar charts that longer tool life were obtained during wet turning due to the role of the coolant in cooling of the cutting area, which help to increase tool life. This agrees with Kawthar et al. (2016) that the life of cutting tools is very long while machining with low cutting parameters. It was also agrees with the conclusion of Isik, (2010) which concluded that the reduction in tool wear increases the tool life and in turn reduces cutting zone temperature with favorable change in chip tool interaction. Maximum tool life was obtained at minimum spindle speed (500 rpm) both for dry and wet turning. As it was explained previously the increase in spindle speed tends to increase cutting temperature which negatively affect the tool life. In experiment run number 1, 6 and 8 the cutting temperature was smaller as shown in Figure 4.18, in opposite manner at this point the value of tool life was higher. In similar manner in Figure 4.18 at experiment run number 3, 5, and 7 at which minimum tool life were resulted as shown in Figure 4.24. The result shows that higher spindle speed tends to increase cutting temperature which affects the tool life negatively.

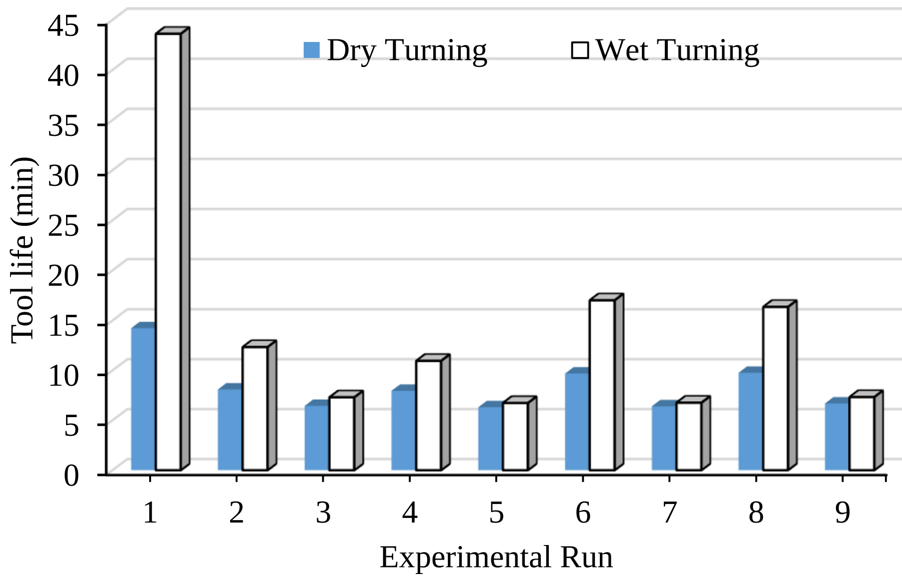


Figure 4.24 Tool Life for each Experimental Run

4.9.2 Analysis of Effect of Cutting Parameters on Tool Life

Table 4.20 gives the means of tool life for tool life during dry turning. It is observed that as all the cutting parameters (depth of cut, feed rate and spindle speed) increased, the life of the cemented carbide tool during dry turning of AISI 1020 steel become reduced. The value of delta indicates that spindle speed was the most significant factor which affect the tool life.

Table 4.20 Means of Tool Life for dry turning

Level	Cutting Parameters		
	Depth of Cut	Feed Rate	Spindle Speed
1	9.583	9.522	11.221
2	7.980	8.053	7.573
3	7.613	7.602	6.382
Delta	1.970	1.920	4.839
Rank	2	3	1

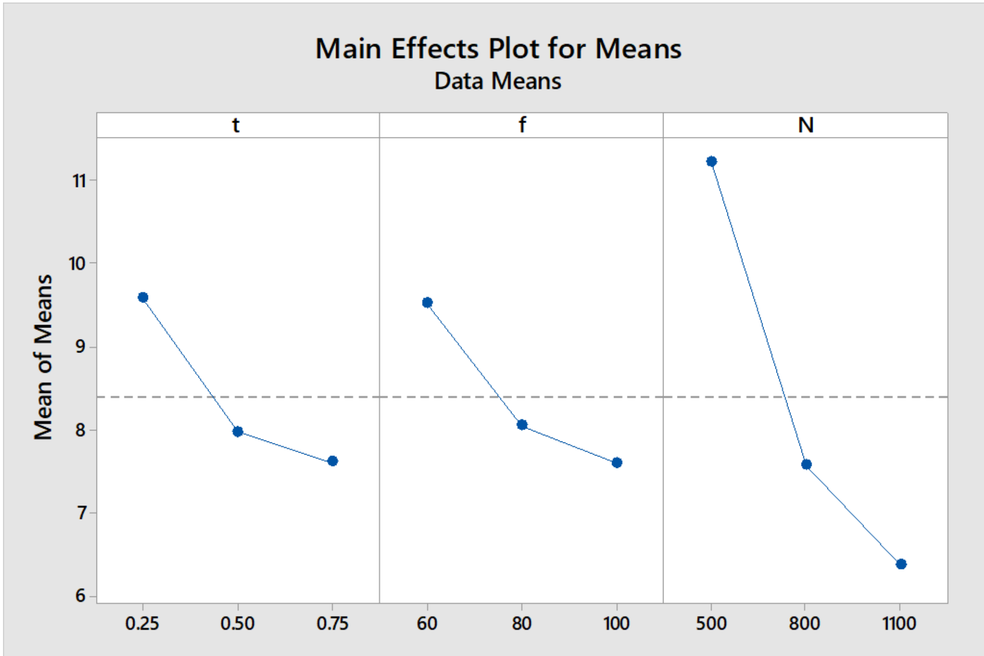


Figure 4.25 Main Effects Plot for Means of Tool Life for Dry Turning

Figure 4.25 shows that the main effect plot for means of tool life during dry turning. As it is observed from the graph, the slope of all the graph are negative, which indicates that the life of the tool were reducing with increasing the value of all cutting parameters.

Mean effect response of each parameters at each levels were given in Table 4.21 for wet turning. The delta value indicates that spindle speed is the most predominant factor in tool life followed by depth of cut and the feed rate as in dry turning (spindle speed is at 1st rank with delta value 4839, depth of cut is at 2nd rank with 1.970 delta value and feed rate is at 3rd rank with delta value 1.920). The result shows that tool life reduced as the level of each cutting parameters were increasing as indicated in Figure 4.25.

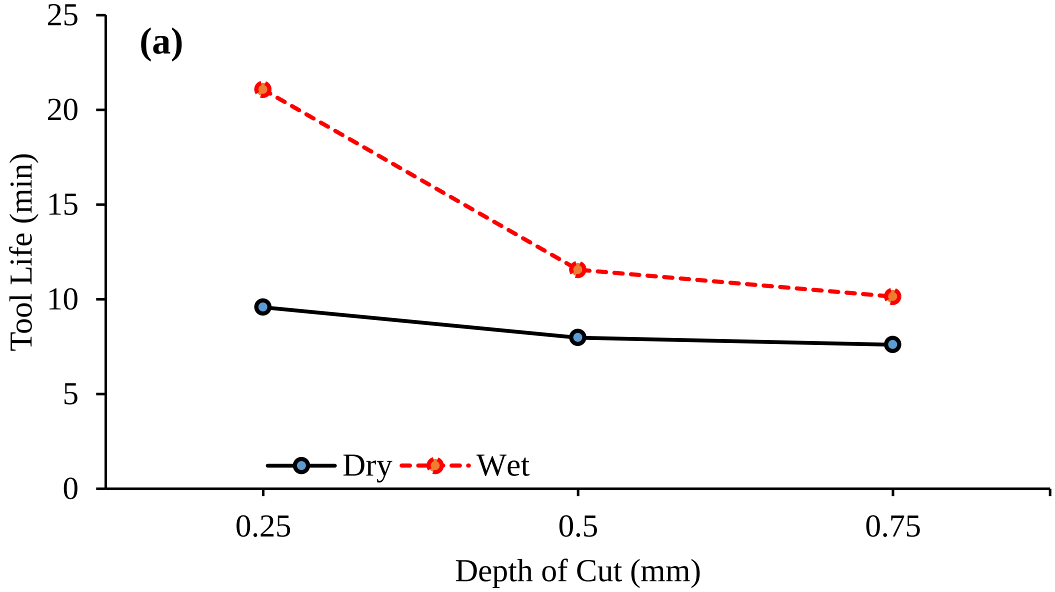
Table 4.21 Means of Tool Life for Wet Turning

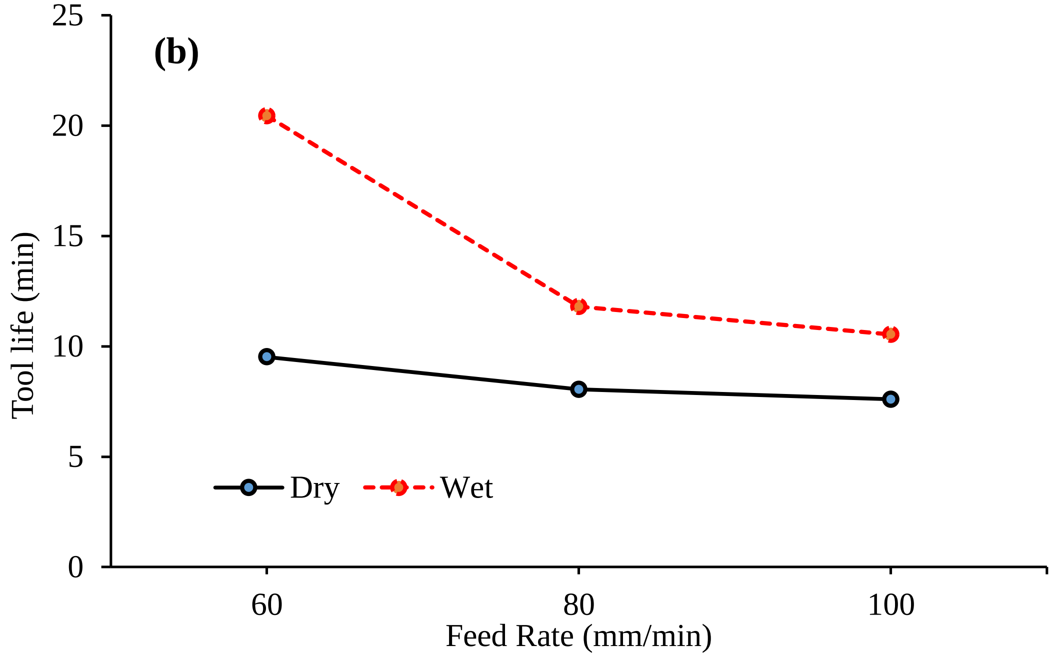
Level	Cutting Parameters		
	Depth of Cut	Feed Rate	Spindle Speed
1	21.078	20.438	25.655
2	11.561	11.803	10.202
3	10.147	10.547	6.929
Delta	10.931	9.891	18.726
Rank	2	3	1

Figure 4.26 Main Effects Plot for Means of Tool Life for Wet Turning

Figure 4.26 shows the main effect plot for means of tool life for wet turning. As it can be observed from the plot, the life of the tool became decreasing with increasing all the cutting parameters. The longest tool life is obtained at the minimum level of all the cutting parameters while the shortest tool life is obtained at the maximum level of all the cutting parameters at it is shown in the plot.

Figure 4.24 (a), (b), and (c) shows the comparison of mean effect of each cutting parameters on tool life for dry and wet turning operation.





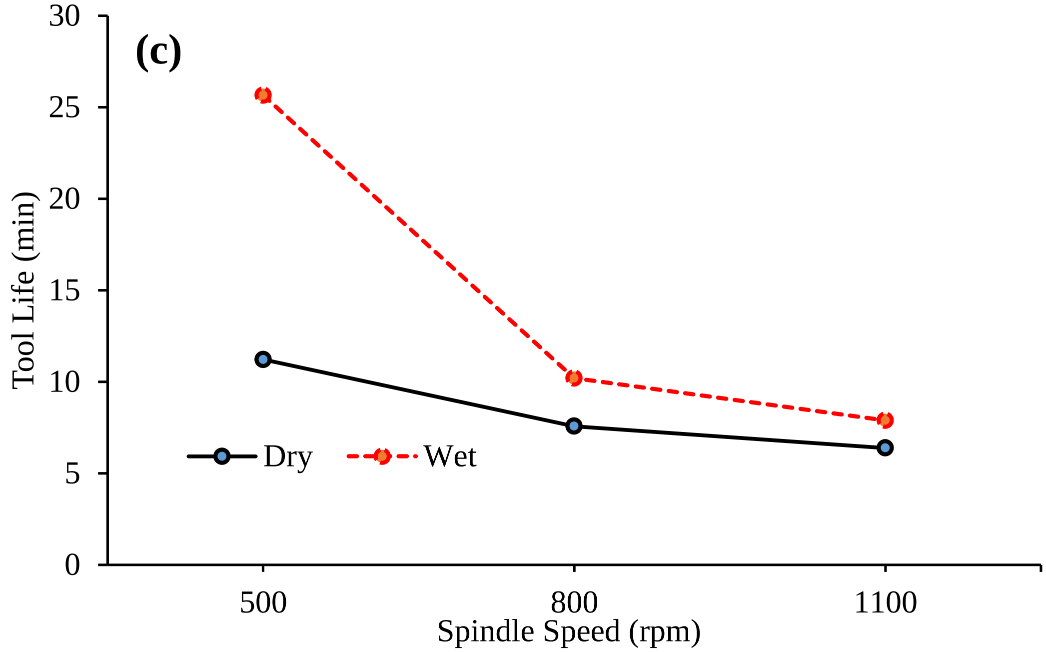


Figure 4.27 Mean Effect of (a). Depth of Cut, (b).Feed Rate, and (c) Spindle Speed on Tool Life

As it was presented in Figure 4.27(a), (b) and (c) above, as all cutting parameters increases the mean tool life become decreased both for dry and wet turning. The graph shows mean tool life for wet turning was greater than that of dry turning at the same cutting parameters. This is due to presence of cutting fluid during wet turning reduce heat and friction generated at tool chip interface.

4.9.3 Analysis of Variance for Tool Life

Table 4.22 and Table 4.23 gives the analysis of variance of tool life for dry turning and wet turning respectively. Percentage contribution of each factors (cutting parameters) in tool life were presented in each table. It is observed that the depth of cut weight percentage (12.47%), feed rate (11.45%) and spindle speed (72.19%) have significant influence on tool life for dry turning while in wet turning depth of cut weight percentage (19.33%), feed rate (15.86%) and spindle speed (54.70%) have significant influence. Therefore, from Table 4.22 and Table 4.23 it can be seen that spindle speed has got the most significant influence on tool life followed by depth of cut at the confidence level of 95%. But feed has least significance on the tool life both in dry and wet turning condition.

Table 4.22 Analysis of Variance of Tool Life for Dry Turning

Source	DoF	SS	MSS	F-Value	P-Value	Percentage Contribution
Depth of Cut	2	6.586	3.293	3.20	0.238	12.47%
Feed Rate	2	6.049	3.024	2.94	0.254	11.45%
Spindle Speed	2	38.137	19.068	18.54	0.051	72.19%
Error	2	2.057	1.028			3.89%
Total	8	52.828				100%

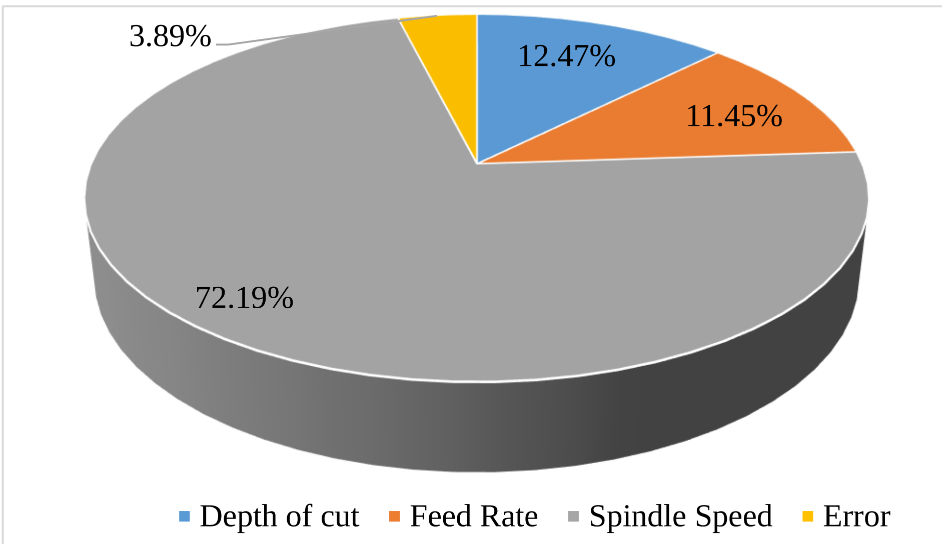


Figure 4.28 Percentage Contribution of Cutting Parameters to Tool Life for Dry Turning

Table 4.23 Analysis of Variance of Tool Life for Wet Turning

Source	DoF	SS	MSS	F-Value	P-Value	Percentage Contribution
Depth of Cut	2	212.1	106.03	1.91	0.344	19.33%
Feed Rate	2	174.0	86.99	1.57	0.389	15.86%
Spindle Speed	2	600.2	300.08	5.41	0.156	54.70%
Error	2	111.0	55.49			10.12%
Total	8	1097.2				100%

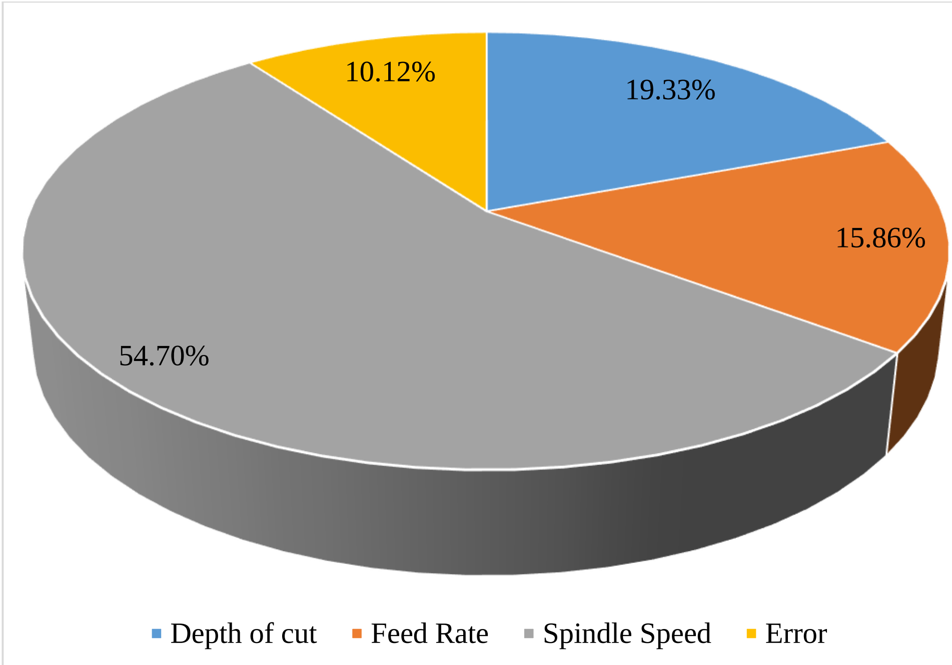


Figure 4.29 Percentage Contribution of Cutting Parameters to Tool Life for Wet Turning

4.10 Analysis of Machining Cost

Machining cost of dry and wet turning of AISI 1020 steel were analyzed and presented in this section. The analysis of the total cost from the beginning to the end of the machining process is essential for achieving economic machining process. Cost is one of the main factor that should be considered in machining. The effect of presence and absence of cutting fluid on machining cost was analyzed in this section. As it was explained in section 2.7 total machining cost (C_T) comprises of energy (electricity) consumption cost (C_e), overhead cost (C_o), cutting to cost (C_t), and coolant cost (C_c). Those cost associated with machining has been analyzed one by one for each experimental run for dry and wet turning environment.

4.10.1 Energy consumption Cost, C_e ($)

The electricity consumption cost by the machine tool is dependent upon machining time for which machine tool is used, spindle motor power and unit energy cost. Machining time was calculated using Equation (2.6) and the result is shown in Table 4.24. The length of cut was 30mm for each specimen with 1mm allowance. Spindle motor power for DMTG CNC lathe machine with CKE 6150 model is 7KW, coolant pump power is 240W and standby power is 2KW which is constant. The world average price for electric energy consumption is 0.139$/KWh for household users and 0.126$/KWh for business users (Gupta et al. (2021)). The

DMTG CNC lathe machine have 85% efficiency. The energy consumption cost was obtained both for dry and wet turning using Equation (2.4) and summarized as in Table 4.24.

Table 4.24 Energy Consumption Cost

S/n	Cutting Parameters			Machining Time	Energy Consumption Cost	
	t (mm)	f (mm/min)	N (RPM)	t_m (min)	Dry, C_e ($)	Wet, C_e ($)
1	0.25	60	500	0.5167	0.0115	0.0118
2	0.25	80	800	0.3875	0.0086	0.0088
3	0.25	100	1100	0.31	0.0069	0.0071
4	0.5	60	800	0.5167	0.0115	0.0118
5	0.5	80	1100	0.3875	0.0086	0.0088
6	0.5	100	500	0.31	0.0069	0.0071
7	0.75	60	1100	0.5167	0.0115	0.0118
8	0.75	80	500	0.3875	0.0086	0.0088
9	0.75	100	800	0.31	0.0069	0.0071

As it was clearly shown in Figure 4.30 the energy consumption cost for wet turning environment was greater than that of dry turning environment, because wet turning need additional power for delivering cutting fluids by coolant pump. At experimental run number 1, 4 and 7 the energy consumption cost was high. This is due to low value of feed rate which cause high machining time which result is high consumption of electric power.

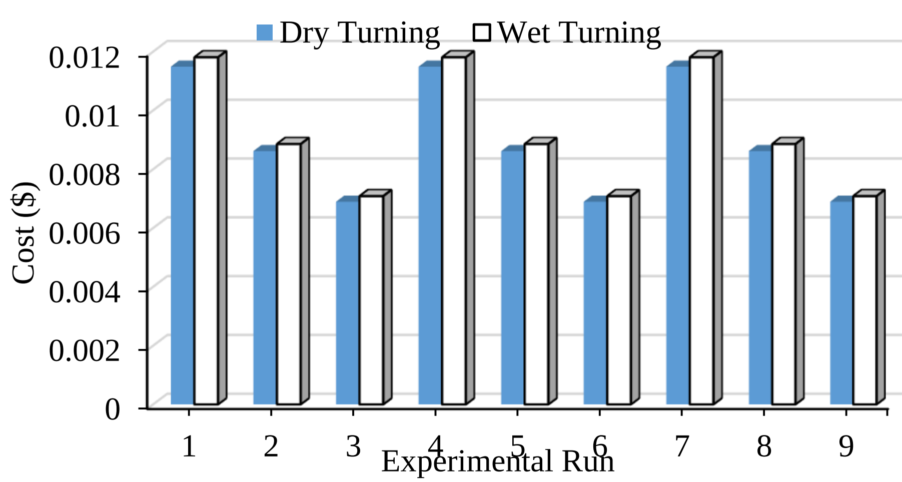


Figure 4.30 Energy Consumption Cost

4.10.2 Overhead Cost, C_o ($)

The overhead cost consisted of operator cost (C_{op}), cost of lighting and HVAC (C_L), and machine depreciation cost (C_m). Operator cost was calculated by using Equation 2.6 and operator labor rate 6.57$/hr and 1 operator (Guptat al. (2021)). Cost of lighting and HVAC was also calculated using Equation 2.7. The machine cost was calculated by using initial cost of DMTG CNC lathe machine of CKE 6150 model 20,000$, depreciation value of 1200$/year, 270 annual working days and the service life of the machine was 5 years. The result of each overhead cost was calculated and summarized as in Table 4.25.

Table 4.25 Overhead Cost

s/n	t_m (min)	Operator Cost ($)	Lighting and HVAC cost ($)	Machine Depreciation Cost ($)	Total Overhead Cost ($)
1	0.5167	0.1315	0.0246	0.0048	0.1610
2	0.3875	0.0986	0.0185	0.0036	0.1207
3	0.31	0.0789	0.0148	0.0029	0.0966
4	0.5167	0.1315	0.0246	0.0048	0.1610
5	0.3875	0.0986	0.0185	0.0036	0.1207
6	0.31	0.0789	0.0148	0.0029	0.0966
7	0.5167	0.1315	0.0246	0.0048	0.1610
8	0.3875	0.0986	0.0185	0.0036	0.1207
9	0.31	0.0789	0.0148	0.0029	0.0966

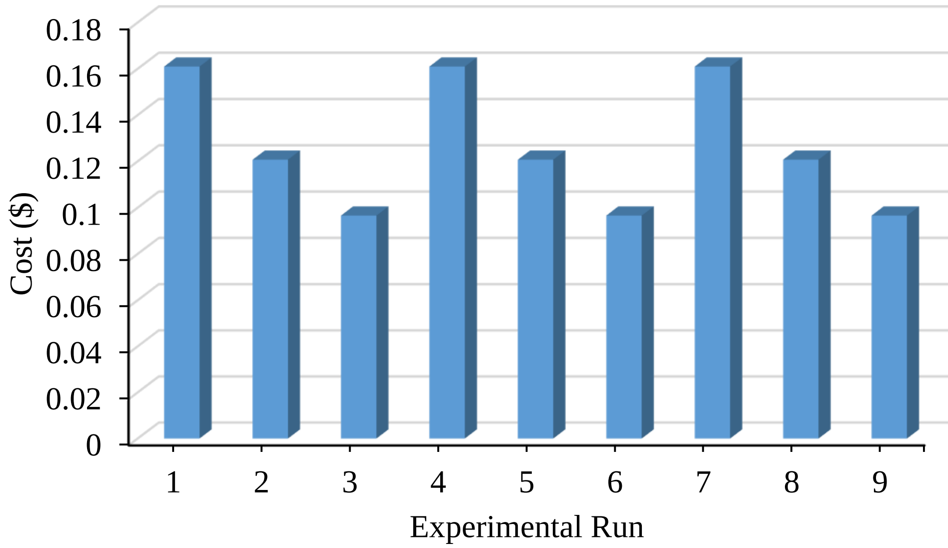


Figure 4.31 Total Overhead Cost

As it were shown in Table 4.25 and Figure 4.31 the total overhead cost for dry and wet turning was equal. Accordingly, it can be deduced from Figure 4.35 the share of the overhead cost, with a sum of above mentioned components such as operator cost, cost of lighting and HVAC and machine depreciation cost, in the total cost per unit part is 13.47% and 6.00% for dry and wet turning respectively.

4.10.3 Tool Cost, C_t ($)

Tool cost depends on initial insert price, resale price after its wear and life of the tool. Unit insert for cemented carbide insert price is 14$ and its resale price is 6$ (Guptat al. (2021)). Tool life for dry and wet turning was taken from Table 4.19. The result of tool cost was calculated using Equation (2.11) and summarized as in Table 4.25. From the result obtained in Table 4.26 the value of tool cost in dry turning was greater than that of wet turning. This is due to the shorter tool life in dry turning. As explained previously in Figure 4.24 tool life was shorter at experiment run number 3, 5 and 7. This result in high tool cost as shown in Figure 4.32. Figure 4.35 illustrates the proportion of tool cost to total cost. According to this, cutting tool costs account for 81.33% and 27.60% of total cost in machining under dry and wet turning condition respectively. As can be seen, tool cost has the second largest share after coolant cost in wet turning and it has the largest cost in dry turning condition.

Table 4.26 Tool Cost

s/n	t_m (min)	Dry turning Tool Life (min)	Wet turning Tool Life (min)	Dry Turning Tool Cost ($)	Wet Turning Tool Cost ($)
1	0.5167	14.2176	43.6038	0.2907	0.0948
2	0.3875	8.0901	12.3311	0.3832	0.2514
3	0.31	6.4411	7.2995	0.3850	0.3397
4	0.5167	7.9497	10.9466	0.5199	0.3776
5	0.3875	6.3073	6.7262	0.4915	0.4609
6	0.31	9.6843	17.0112	0.2561	0.1458
7	0.5167	6.3979	6.7626	0.6460	0.6112
8	0.3875	9.7604	16.3503	0.31761	0.1896
9	0.31	6.6793	7.3291	0.3713	0.3384

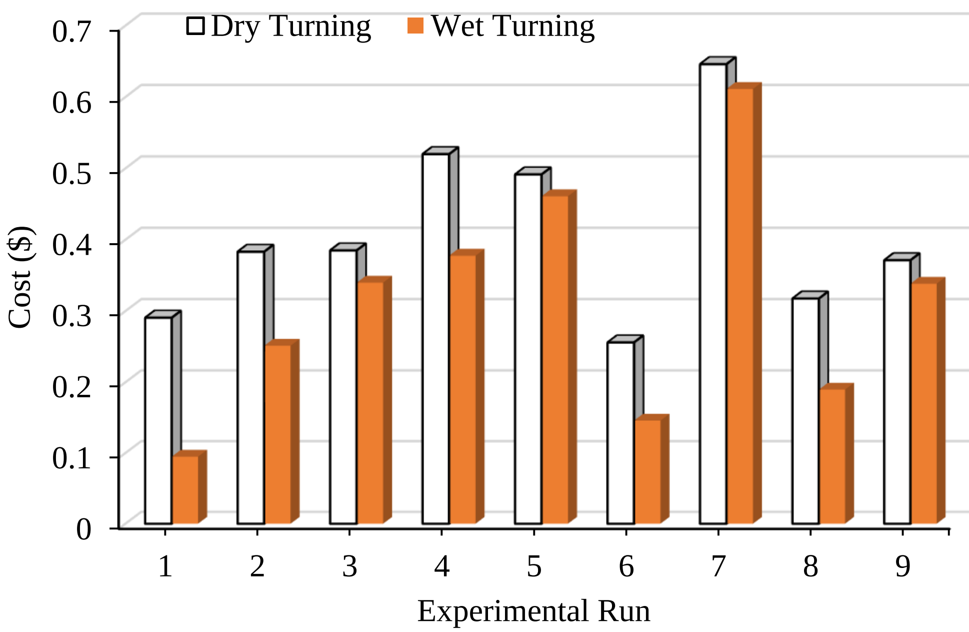


Figure 4.32 Tool Cost

4.10.4 Coolant Cost, C_c ($)

In addition to energy consumption cost, overhead cost and cutting tool cost wet turning has coolant cost. It is the cost of specific volume of coolant or cutting fluid. Water soluble vegetable based oil which used in wet turning has proportion of 1:20 oil to water ratio (Avila and Abaro (2001)). The flow rate of the coolant was 3.52L/min. the cost of water soluble oil was 10$/L (Onuohe et al. (2016); Gupta et al. (2021). In this study cost of cutting fluid was obtained by using equation (2.12) and result was shown as in Table 4.27. Figure 4.35 exhibits that the cooling cost has a share of 0% and 70.00% within the total cost for dry turning and wet turning, respectively. In an operation using coolant in wet turning is the reason for the higher share of coolant costs in the total cost and it is undoubtedly due to its higher consumption per unit time.

Table 4.27 The result of Coolant Cost

s/n	Machining Time	Coolant Cost ($)	
	t_m (min)	Dry	Wet
1	0.5167	0	0.9093
2	0.3875	0	0.682
3	0.31	0	0.5456
4	0.5167	0	0.9093
5	0.3875	0	0.682
6	0.31	0	0.5456
7	0.5167	0	0.9093
8	0.3875	0	0.682
9	0.31	0	0.5456

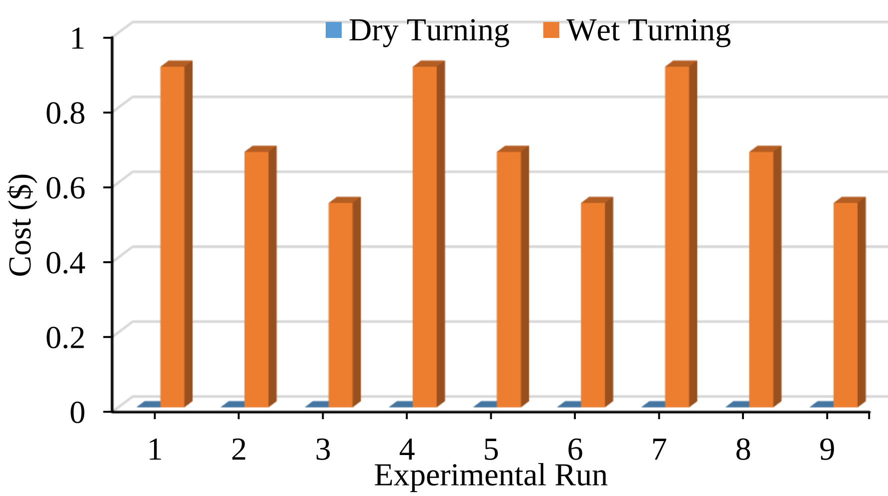


Figure 4.33 Coolant Cost

4.10.5 Total Machining Cost

Total machining cost is the sum of energy consumption cost, overhead cot, tool cost and coolant cost. The total machining cost for dry and wet turning was shown in Table 4.28;

Table 4.28 The Total Cost for Dry and Wet Turning

s/n	Cost ($)								
	Energy		Overhead	Tool		Coolant		Total	
	Dry	Wet	Dry=Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	0.0332	0.0497	0.0860	0.291	0.0948	0	0.9093	0.4100	1.1399
2	0.0249	0.0373	0.0645	0.3832	0.2514	0	0.682	0.4726	1.0352
3	0.0199	0.0298	0.0516	0.3850	0.3397	0	0.546	0.4565	0.9668
4	0.0332	0.0497	0.0860	0.5199	0.377	0	0.9093	0.6391	1.4227
5	0.0249	0.0373	0.0645	0.4915	0.4608	0	0.682	0.5809	1.2447
6	0.0199	0.0298	0.0516	0.2561	0.1458	0	0.546	0.3276	0.7728
7	0.0332	0.0497	0.0860	0.6460	0.6112	0	0.9093	0.7652	1.6563
8	0.0249	0.0373	0.0645	0.318	0.1896	0	0.682	0.4070	0.9734
9	0.0199	0.0298	0.0516	0.3713	0.3384	0	0.5456	0.4428	0.9654

4.10.6 Comparison of Total Machining Cost for Dry and Wet Turning

Figure 4.34 demonstrates the total machining cost for each experimental runs for different machining environments i.e. dry turning and wet turning. The total machining cost is lower for dry turning as it has been observed in all experimental run. Taking total average sum of all costs for all experimental run, the cost of wet turning was about 56% greater than cost of dry turning. Cost of coolant in wet turning is 42.88% greater than cost of cutting tool. This is because as it was explained that the cost of cutting fluid is greater than that of cost of cutting tool which is not present in dry turning.

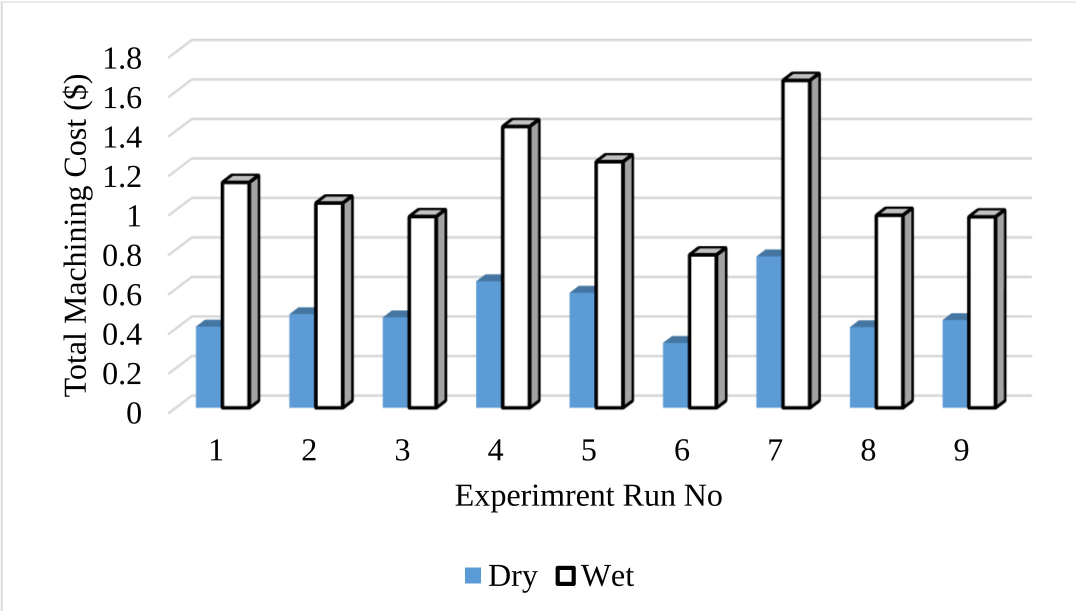
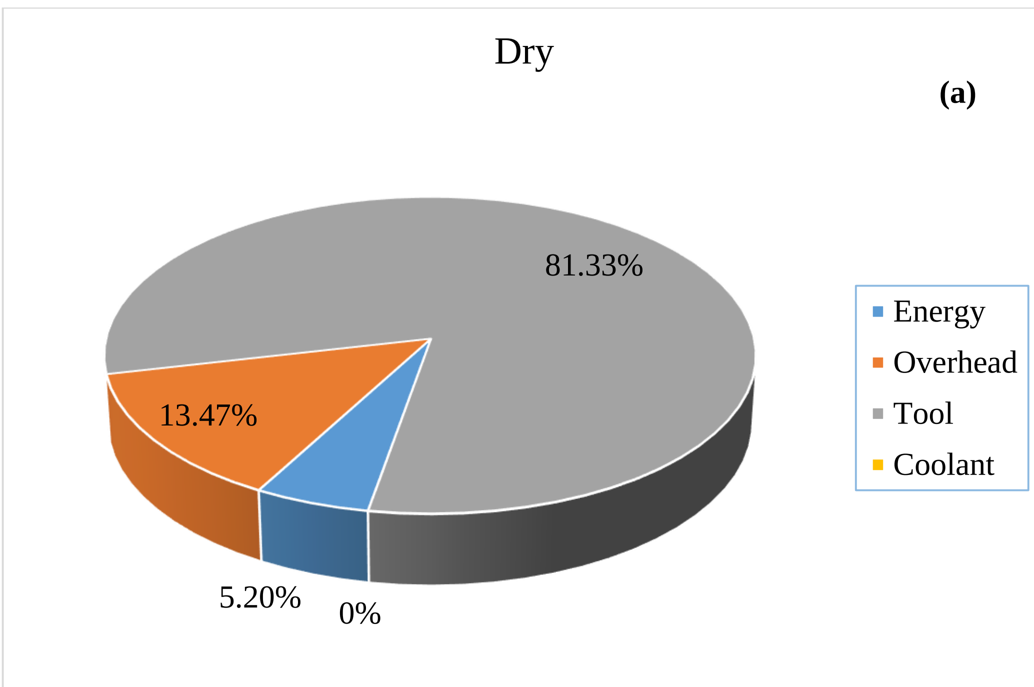


Figure 4.34 Total Machining Cost Values under Dry and Wet Turning



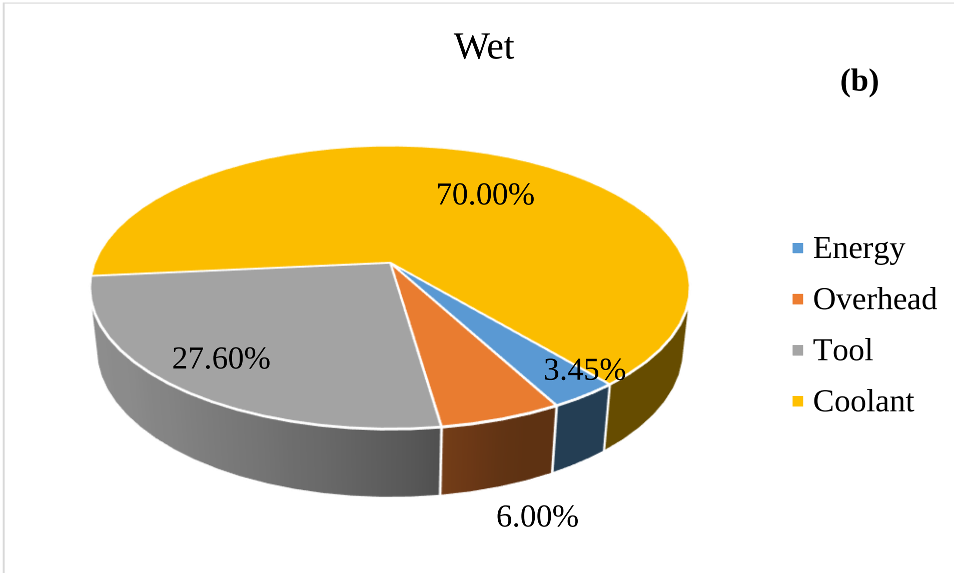
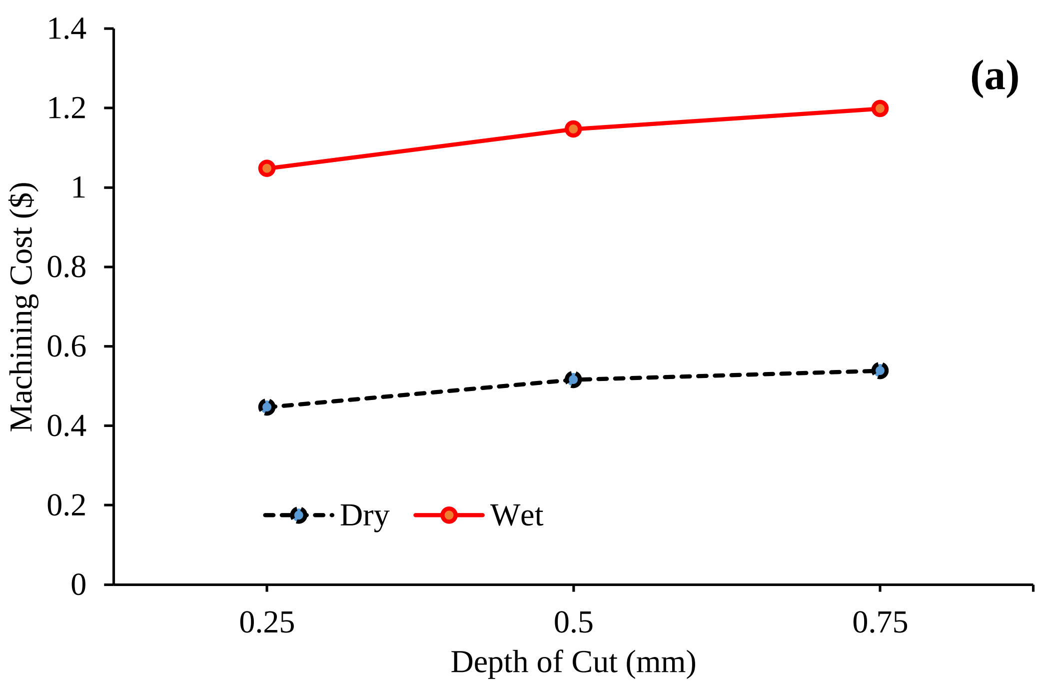
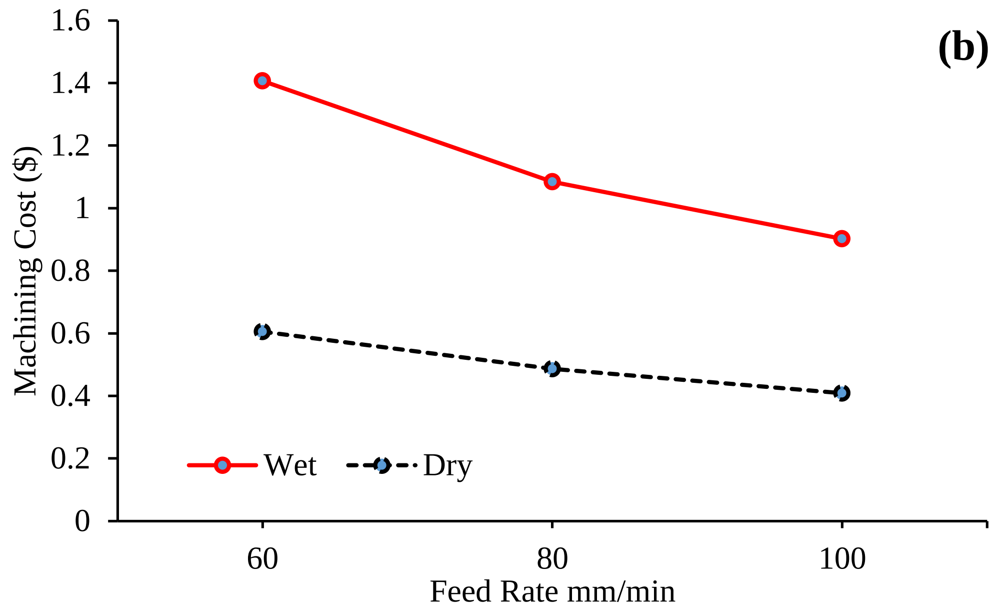


Figure 4.35 Cost Sharing under (a). Dry and (b). Wet turning

Figure 4.35 (a) and (b) shows the percentage cost sharing of the machining cost for dry and wet turning. As clearly shown the chart the highest cost was shared by tool cost, which was 81.33% of the total cost, for dry turning. While 70.00% of total cost was shared by coolant cost for wet turning.

4.10.7 Effect of Cutting Parameters on Machining Cost





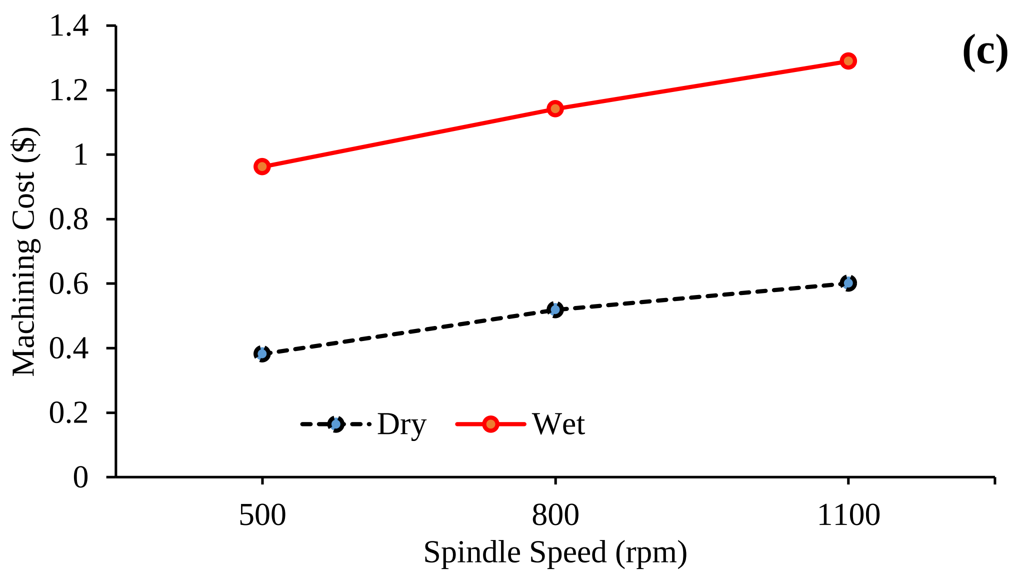


Figure 4.36 Mean Effect of a). Depth of Cut, b). Feed Rate, and c). Spindle Speed on Machining Cost

As shown in Figure 4.36 (a), (b), and (c) machining cost increase with increasing depth of cut and spindle speed and it decreases with increasing feed rate. As it was explained previously spindle speed and depth of cut highly affects the cutting tool life. This implies that as depth of cut and spindle speed increases, tool cost become increased which result in higher machining cost. Increasing feed rate means minimizing machining time and therefore, machining cost become decreased.

4.10.8 Analysis of Variance for Total Machining Cost

Contribution of each cutting parameters to machining cost was given as in Table 4.29 and 4.30. The result total machining cost was highly affected by spindle speed in dry turning and by feed rate in wet turning. This is due to high spindle speed result in high cutting temperature, which cause shorter tool life in dry turning. As it was shown previously in Figure 4.35 (a) cutting tool cost is the highest cost in dry machining. Feed rate decide the machining time which decide the amount of coolant consumed during cutting. The highest cost in wet turning was coolant cost as it was shown in previous Figure 4.35 (b).

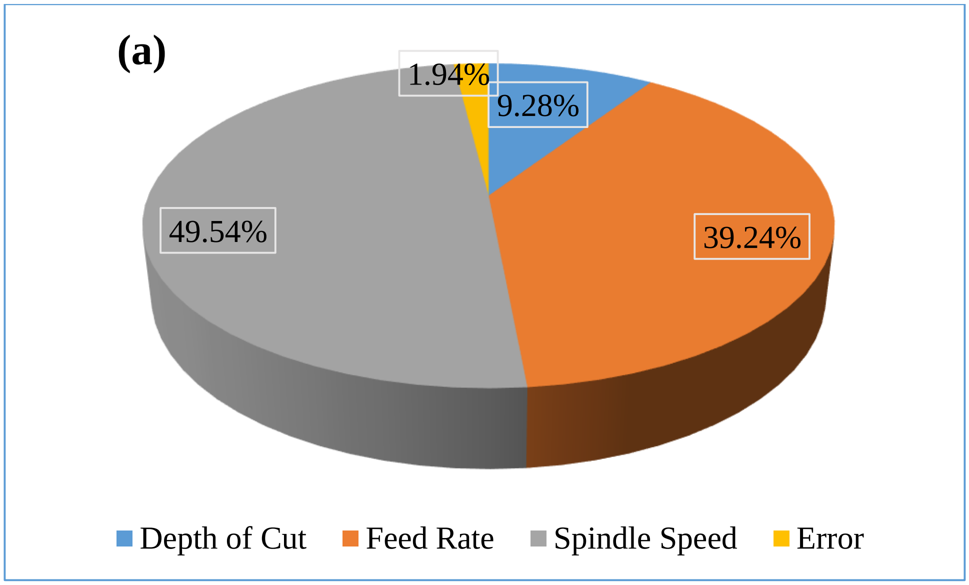
Table 4.29 Analysis of Variance of Machining Cost for Dry Turning

Source	DoF	SS	MSS	F-Value	P-Value	Percentage Contribution (%)	Significance (α=0.05)
t	2	0.0138	0.0069	4.77	0.173	9.28	Less Significant
f	2	0.0583	0.0292	20.16	0.047	39.24	Significant
N	2	0.0736	0.03681	25.45	0.038	49.54	Highly Significant
Error	2	0.0029	0.0015			1.94	
Total	8	0.1486				100	

Table 4.30 Analysis of Variance of Machining Cost for Wet Turning

Source	DoF	SS	MSS	F-Value	P-Value	Percentage Contribution (%)	Significance (α=0.05)
t	2	0.0354	0.0177	13.54	0.069	5.99	Less Significant
f	2	0.3917	0.1958	149.91	0.007	66.30	Highly Significant
N	2	0.1611	0.0806	61.66	0.016	27.27	Significant
Error	2	0.0026	0.0013			0.44	
Total	8	0.5907				100	

The percentage contribution of each cutting parameters were shown by pie chart as in Figure 4.37 below.



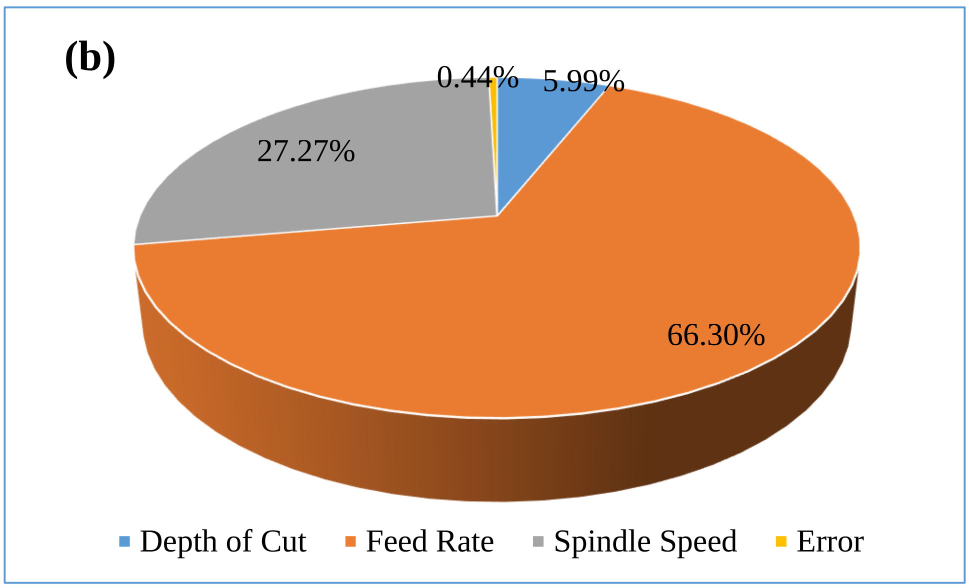


Figure 4.37 Percentage contribution of Cutting Parameters to Total Machining Cost (a). Dry Turning and (b). Wet Turning

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The current study was focused on the comparison of effect of cutting parameters during dry and wet turning of AISI 1020 steel on CNC lathe machine using cemented carbide cutting tool. The main cutting parameters in this study were depth of cut, feed rate, and spindle speed. The effect of these cutting parameters on surface roughness, cutting temperature, tool life and machining cost were studied using L9 Taguchi orthogonal array design. Selection of cutting parameters was done based on knowledge found in the literature, recommendations of tool manufacturer, current industrial practice and experience. The role of each factor was identified by the analysis of variance (ANOVA) for each responses. Based on the results, the following conclusions were drawn;

- Surface roughness decreases at higher spindle speeds, and it increases by the increase of the feed rate and depth of cut both for dry and wet turning.
- The minimum surface roughness was obtained at depth of cut of 0.25mm, feed rate of 60mm/min and spindle speed of 1100RPM, which was 1.13 µm in the dry turning, while it was improved to be 0.81 µm in the wet turning, which was 28.32% improvement.
- Analysis of variance (ANOVA) shows that spindle speed was the most significant parameter for surface roughness followed by feed rate and depth of cut, affecting by 50.51%, 35.58% and 12.35% respectively for dry turning and 57.34%, 36.51%, and 4.31% for wet turning.
- Increasing in cutting parameters (depth of cut, feed rate and spindle speed) was result in increase in cutting temperature and reduce tool life in dry turning. But application of coolant highly minimize the cutting temperature and increase tool life.
- Spindle speed got the most significant influence on cutting temperature and tool life followed by depth of cut. Its percentage contribution in cutting temperature was 88.82% and 66.88% for dry and wet turning respectively. For tool life it contributed 72.19% in dry turning and 54.70% in wet turning.
- The total machining cost was lower for dry turning than wet turning due to higher cost of coolant. Tool cost was the highest, which was 81.33% of total machining cost, in dry

turning, while coolant cost was the highest, which was 70.00% of total machining cost, in wet turning. Total average sum of all costs for all experimental run, the cost of wet turning was about 56% greater than cost of dry turning. Total machining cost was highly affected by spindle speed for dry turning and by feed rate for wet turning.

5.2 Recommendations

Based on the results and conclusions found from this study, the researcher forwards the following recommendations;

- The metal fabrication, automotive and spare part manufacturing industries can use the optimized turning parameters for dry and wet turning of AISI 1020 steel to achieve the product with minimum surface roughness.
- The study can be extended by using double tool turning to improve productivity.
- In this study AISI 1020 steel has been used. This can be further extended to other material types to study the effect of cutting parameters on the surface roughness, cutting temperature, tool life, and machining costs under dry and wet turning for the same level of cutting parameters.
- The study can be extended by various parameters and their interactions

5.3 Scope for Future Work

As a future research work, the following will be carried out by any interested person:

- Analyses of the effect of cutting parameters on force and tool wear rate
- Study the effects of tool geometry like Nose radius and Rake angle on the surface roughness, cutting temperature and tool life.
- Study the effect of different cutting tools with similar cutting parameters.
- Future research work may also be directed towards applying minimum quantity lubrication technique for further study the effect of cutting parameters and to compare it with dry and wet turning.

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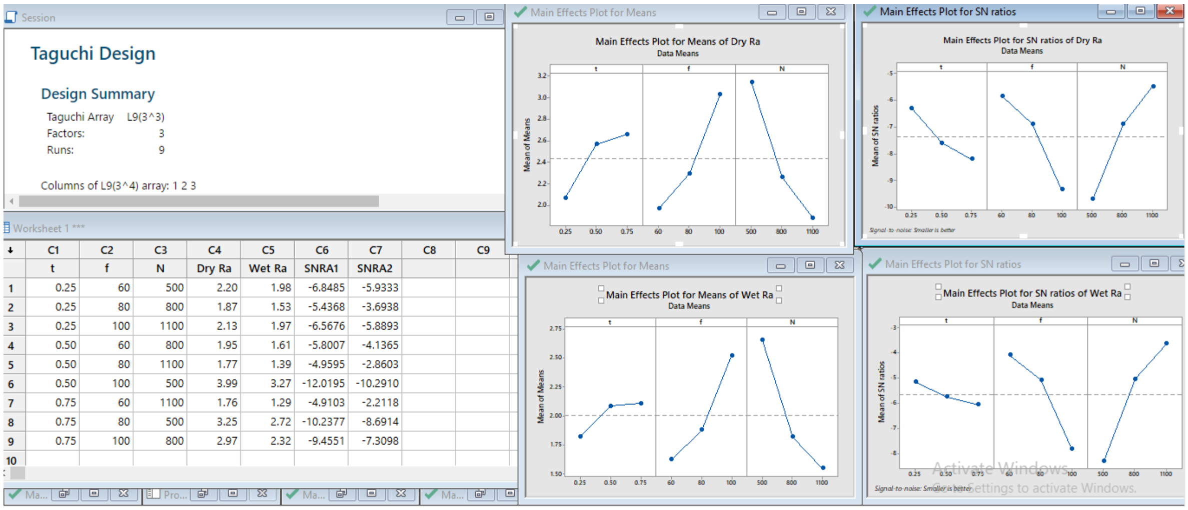
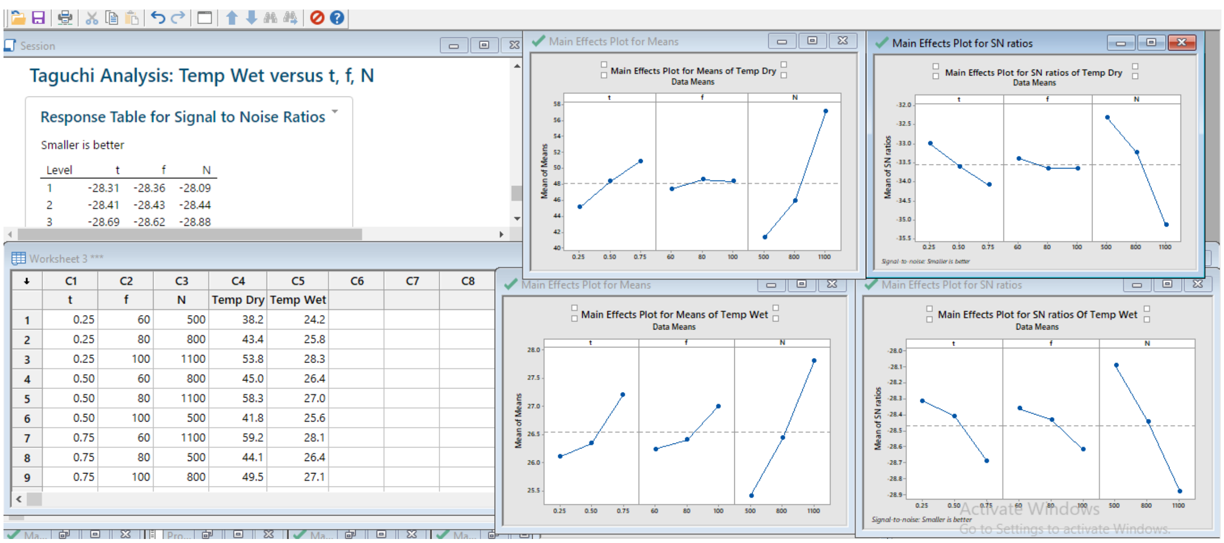
Appendices

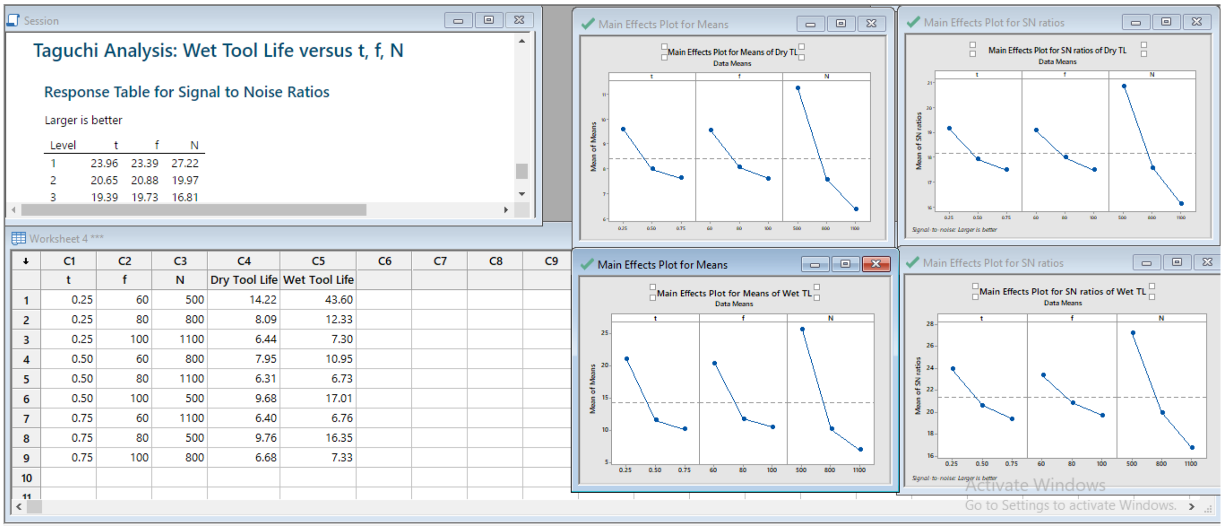
Analysis of Mean and SN Ratio by Minitab for Ra during Dry and Wet Turning



Analysis of Mean and SN Ratio by Minitab for Cutting Temperature during Dry and Wet Turning



Analysis of Mean and SN Ratio by Minitab for Tool Life during Dry and Wet Turning



Percentage of the F distribution: F$_{0.05,\ v1,\ v2}$

(*v1* = numerator of DoF *and v2* = denominator of DoF)

$v_1 \backslash v_2$	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	161.5	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	241.9
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08
50	4.03	3.18	2.79	2.56	2.40	2.29	2.20	2.13	2.07	2.03
100	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.97	1.93

Value of *n* and *C* in Taylor tool Life Equations

TABLE 23.2 Representative values of *n* and *C* in the Taylor tool life equation, Eq. (23.1), for selected tool materials.

Tool Material	*n*	*C* Nonsteel Cutting m/min	(ft/min)	Steel Cutting m/min	ft/min
Plain carbon tool steel	0.1	70	(200)	20	60
High-speed steel	0.125	120	(350)	70	200
Cemented carbide	0.25	900	(2700)	500	1500
Cermet	0.25			600	2000
Coated carbide	0.25			700	2200
Ceramic	0.6			3000	10,000