INVESTIGATION ON THE SURFACE ROUGHNESS OF THE NIMONIC C-263 ALLOY DURING TURNING UNDER DIFFERENT MACHINING CONDITIONS

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INVESTIGATION ON THE SURFACE ROUGHNESS OF THE NIMONIC C-263 ALLOY DURING TURNING UNDER DIFFERENT MACHINING CONDITIONS

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the bachelor's degree of Manufacturing Engineering (Hons.)

By

TUAN NORLIZA HANIM BINTI TUAN HUSSIN

FACULTY OF MANUFACTURING ENGINEERING

2022

DECLARATION

I hereby, declared this report entitled "Investigation on the Surface Roughness of the Nimonic C-263 Alloy during turning under different machining conditions" is the result of my own researchexcept as cited in the reference.

Signature : ……………………………………

Author's Name : TUAN NORLIZA HANIM BINTI TUAN HUSSIN

Date : 29th June 2022

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.). The members of the supervisory committee are as follow:

………………………………………………………………

(ASSOC. PROFESOR. DR. MOHD AMRI BIN SULAIMAN)

ABSTRAK

Kajian ini dijalankan pada penamat berkelajuan tinggi yang mengubah proses Nimonic C-263 Alloy untuk menilai integriti permukaan mesin dan membuat perbandingan nilai kekasaran permukaan (Ra) untuk keadaan kering dan banjir menggunakan sisipan karbida bersalut PVD. Kajian ini juga dijalankan untuk mencapai dua objektif iaitu untuk menentukan faktor-faktor penting kekasaran permukaan untuk kedua-dua keadaan (kering dan banjir) melalui analisis ANOVA dan terakhir untuk menyiasat nilai kekasaran permukaan Nimonic Alloy C263 di bawah keadaan kering dan banjir. Reka bentuk eksperimen untuk eksperimen ini adalah berdasarkan metodologi permukaan tindak balas (RSM) dalam mengenal pasti prestasi terbaik faktor-faktor penting. Reka bentuk Box-Behnken dipilih untuk mengatur parameter pemesinan. Parameter pemotongan yang telah dipilih dalam kajian ini adalah kelajuan pemotongan (60-120 m / min), kadar suapan (0.05-0.15 mm / rev), dan kedalaman potongan (0.3-0.5 mm). Nilai kekasaran permukaan diukur pada setiap 20mm di sepanjang permukaan mesin menggunakan penguji kekasaran permukaan mudah alih sehingga purata haus sayap, nilai Vb mencapai 0.2mm. Analisis ANOVA digunakan untuk mengenal pasti parameter pemotongan yang ketara ke arah tindak balas. Analisis ANOVA menunjukkan bahawa kadar suapan adalah faktor pemotongan yang paling ketara yang mempengaruhi kekasaran permukaan. Model regrasi telah dibangunkan untuk kekasaran permukaan melalui analisis ANOVA ini. Berdasarkan keputusan yang diperolehi, penggunaan penyejuk banjir menghasilkan kekasaran permukaan yang lebih baik daripada dalam keadaan kering. Di samping itu, hasilnya menunjukkan bahawa parameter optimum untuk kedua-dua keadaan pemesinan adalah kadar suapan.

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ABSTRACT

This study was conducted at the high-speed finish turning the process of Nimonic C-263 Alloy in order to evaluate the surface integrity of the machined surface and make a comparison of the surface roughness (Ra) values for dry and flooded conditions using PVD coated carbide insert. This study was also carried out to achieve three objectives which are to determine the significant factors onto surface roughness for both conditions (dry and flood) through ANOVA analysis and lastly to investigate the surface roughness values of Nimonic Alloy C263 under dry and flood conditions. The experimental design for this experiment was based on the response surface methodology (RSM) in identifying the best performance of significant factors. The box-Behnken design was selected to arrange the machining parameters. The cutting parameters that had been selected in this study are cutting speed (60-120 m/min), feed rate (0.05-0.15 mm/rev), and depth of cut (0.3-0.5 mm). The surface roughness values were measured at every 20mm along the machined surface using a portable surface roughness tester until the flank wear average, Vb value exceeds 0.2mm. ANOVA analysis was used to identify cutting parameters that significantly towards the response. ANOVA analysis showed that the feed rate was the most significant cutting factor affecting the surface roughness. A regression model was developed for surface roughness through this ANOVA analysis. Based on the results obtained, the application of flooded coolants produced better surface roughness rather than in dry conditions. Additionally, the result showed that the optimum parameter for both machining conditions was the feed rate.

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DEDICATION

The name of Allah, the Most Gracious and the Most Merciful

I dedicate this final year project to:

My beloved parents,

Tuan Hussin Bin Tuan Yacob and Rafiah Binti Noor

To my lovely siblings who always support me.

To my supervisor and lecturers who gives the guidance and motivation along my studies in Universiti Teknikal Malaysia Melaka (UTeM)

Thanks to everyone for giving me moral support, money, cooperation, encouragement, and also understanding.

Thank You So Much & Love You All Forever

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Finally, I would like to make an affectionate acknowledgment to all my colleagues and friends who had helped and supported me during my research studies directly or indirectly.

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LIST OF ABBREVIATIONS

PVD	-	Physical Vapor Deposition
CVD	-	Chemical Vapor Deposition
CO2	-	Carbon Dioxide
N2	-	Nitrogen
CNC	-	Computer Numerical Control
Ra	-	Surface Roughness
DOC	-	Depth of cut
HSM	-	High-Speed Machining
Wc	-	Tungsten Carbide
Co	-	Cobalt
TiC	-	Titanium carbide
TiN	-	Titanium nitrate
Al_2O_3	-	Aluminium oxide
TiAlN	-	Titanium aluminium nitrate
CBN	-	Cubic Boron Nitride
PCBN	-	Polycrystalline Cubic Boron Nitride
MRR	-	Material Removal Rate
DOE	-	Design of experiment
RSM	-	Response Surface Methodology
HV	-	Vickers Pyramid Number (Hardness)

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, since nickel-based alloys are extremely famous for their excellent attributes in terms of hardness at elevated hotness and high impervious to corrosion, the application of this type of material has been increasing day by day (Sreenivasa Rao & Venkaiah, 2015).

This study is carried out to investigate the machining conditions in turning the Nimonic C-263 Alloy. According (Ezilarasan et al., 2011b), Nimonic C-263 Alloy is extensively employed in aerospace, power generators, turbine blades as well as heat exchangers. However, as is known, the fabricating method of this material is quite difficult regarding its low thermal conduction and solidification criterion. This material, which is known as heat resistant, consists of alloy that acknowledges the dominant machine-like, ductility, and creep strength at high temperatures, high fatigue strength, and frequently superior corrosion and oxidation resistance at elevated temperatures (Vetri Velmurugan & Venkatesan, 2021).

The Nimonic C-263 alloy is used a lot in heavy industries because of its special properties (Thakur et al., 2014). On the other hand, this alloy is quite challenging to machine. Heat-resistant alloys called superalloys exhibit exceptional mechanical, ductility, and creep strength at high working temperatures, high fatigue strength, and often strong corrosion and oxidation resistance at high temperature (Venkatesan & Thakur, 2018). The experimental study and assessment of the machining requirements for turning the Nimonic C-263 alloy will be explored in more detail.

Turning is a sort of manufacturing process that include machining away excessive element to produce rotatable product parts. The turning process necessitates the use of a turning machine, a workpiece, a fixture, and a cutting tool. The workpiece is a pre-shaped piece of material that is secured to the fixture before being attached to the turning machine and rotated at high speeds. Even though multi-point tools are used in some operations, the cutter used is usually a single point cutting tool that is also fastened in the machine. The cutting tool feeds into the rotating workpiece and cuts material away in the form of small chips to create the desired shape.

The material of the workpiece involved in this study is Nimonic C-263 Alloy which is very suitable to be used in high temperature and high strength applications. According to M. Singh & Gangopadhyay (2017), Nimonic C-263 alloy, one of the age-hard enable nickel-based superalloys, contains a significant quantity of cobalt, chromium, and molybdenum, which improves corrosion and oxidation resistance. This type of material also has high strength, high corrosion resistance, good formability as well as high-temperature ductility.

Besides, the machine used in this study is CNC Lathe Machine and will be a focus on the turning process. The cutting tool that has been used in this study is PVD coated carbide insert. Coated carbide has been applied in a variety of applications because of the superior mechanical features of the material.

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Next, this experiment will be undergone under flood and dry conditions. Lubricant and coolants are other terms for cutting fluid. It is commonly used in the machining process to improve surface integrity by lowering cutting temperature and pressure. It lubricates all tool, chip, and workpiece contact areas, reducing friction between mating surfaces (M. Singh & Gangopadhyay, 2017). Coolants also can prevent adhesion, abrasion, and diffusion wear, as well as heat softening of tool material, extending tool life. Hence, the variables examined by most of the researchers before are the depth of cut, feed rate, and cutting speed. Thus, the impact of various factors and their relationships towards cutting surface roughness has also been investigated in this study.

1.2 Problem Statement

In today's industrial industry, there is a tremendous demand for great accuracy, economical parts. As a result, an ample amount of research has been done on optimization, machining interpretation, surface roughness prognostication, and process optimization. In addition to modeling, the study and investigation of the effect of cutting parameters on the group of cutting force, tool wear, and surface roughness in the turning of aerospace element materials like the Nimonic C-263 alloy is critical to support development control organization actions in the turning of aerospace parts materials.

Because Nimonic C-263 alloys have high-temperature properties, they subject cutting tools to extreme heat, pressure, and abrasion, causing rapid flank wear, crater wear, and tool notching at the tool nose, as well as making them extremely difficult to machine, affecting dimensional accuracy and surface integrity (Sun et al., 2018).

Heat concentration at the cutting tool chip interface is caused by work hardening and limited thermal conductivity, resulting in thermomechanical stress. This, in turn, has an impact on tool life and results insignificant surface degradation (Ezilarasan et al., 2011a).

Even at high temperatures, Nimonic alloys exhibit a great degree of mechanical strength. While this may appear to be a significant benefit, it also means that tool wear is limited, causing excessive stress on the parts. Machining Nimonic alloys, as well as all Nickel-based alloys, is challenging for a variety of reasons (Jangali Satish et al., 2021).

Due to the limited heat conductivity of superalloy, high cutting temperatures are generated in the cutting zone. High tool wear is caused by high-temperature strength, hot hardness, and high cutting temperature, resulting in shorter tool life and poor surface integrity. Increased cutting temperature and pressure at high cutting parameters hurt the tool's condition and the surface quality of the machined component (M. Singh & Gangopadhyay, 2017).

Furthermore, lubricants and coolants that have been used on the machining zone significantly lower the cutting temperature. Various approaches have been used to ensure proper cooling and lubrication. The coolants and lubricants prevent the chip-tool contact from rubbing together and remove the heat created in the cutting zone. Mineral oils and water-based soluble oils are the most common cutting fluids utilized in many manufacturing industries. These oils endanger the environment and jeopardize workplace safety. Cutting fluids are known to be harmful to machinists' health and can occasionally slow down production. Depart of that, one of the main issues on surface finish issue is the surface roughness of the machined surface. Surface roughness might be affected due to the tool characteristic, machining condition, machining parameters and every of each possible reasons are needed to have a deep researched in enhancing the product surface quality.

Moreover, dry machining also gives problems in turning hard material. But, sometimes, although dry turning can be an excellent alternative, the lack of cutting oil caused excessive friction and heating during the machining process. The machined surface is damaged in dry machining due to the creation of Built-up-Edge (BUE) which caused by insert dragging across the surface of the machined component.

1.3 Objectives

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Below are the objectives for this study:

i. To determine the significant factors onto surface roughness for both conditions (dry and flood) through ANOVA analysis.

ii. To investigate the surface roughness values of Nimonic Alloy C263 under dry and flood condition.

1.4 Scopes of the Research

The scope of this study is carried out to analyze the significant factors towards the surface roughness values by aid chart and diagram in differentiate values of Ra between dry and flooded conditions. next, this study also been done in comparing the surface roughness (Ra) values of the machined surface for both conditions. The workpiece that has been used in this study is Nimonic C-263 Alloy. So, this study is focused on that material workpiece to see how it reacts with the use of the cutting tool which is PVD coated carbide insert. The analysis of this study has been referred to by previous research. This study was conducted in high-speed turning machining in flooded and dry conditions as mentioned above. Rearrange the mathematical model of Ra for dry and flood also been studied in this research.

Besides, this study was focused on three cutting parameters which were cutting speed, feed rate and depth of cut. This experiment was conducted in various selected cutting parameters based on the response surface methodology (RSM). This experimental combination arrangement technique is guided by the Box-Behnken technique of RSM. RSM is a statistical method based on the multivariate nonlinear model that entails designing experiments to provide adequate and reliable response measurements, developing a mathematical model that fits the data obtained from the experimental design, and determining the optimal value of the independent variables that produce maximum or minimum response (Sharifi Pajaie & Taghizadeh, 2015).

All the results obtained was analyzed by using Analysis of Variance (ANOVA) analysis. Result obtained also will indicate the mathematical model of Ra for dry and flood conditions. ANOVA analysis was generally used to summarize the experiments that have been performed, also able to identify significant machining parameters and build empirical models for turning of Nimonic C-263 Alloy using PVD coated carbide.

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1.5 Important of Study

In many engineering applications, measuring surface roughness is crucial. The quality of the surface finish can also influence a variety of life characteristics. In the research of surface integrity, surface roughness is thus regarded as one of the most important factors. The shape of the cutting tool and machining parameters are primarily responsible for surface roughness in the turning process. Furthermore, surface roughness is one of the most critical turning process responses since it impacts the machined component's fatigue strength, wear rate, corrosion resistance, and tribological properties.

Besides, surface finish and tool wear are the most important machining parameters to consider when estimating the turning's performance. These characteristics influence fatigue strength, surface integrity, dimensional precision, and corrosion resistance, all of which are essential for important aerospace applications. To obtain enhanced machining performance which is lower surface roughness and lower flank wear for varied combinations of workpiece and inserts, it is critical to optimize machining settings and environmental conditions (Jadhav et al., 2020a).

However, the development of forces and temperatures at the cutting zone, as well as deformation on the flank face and adhesion of the workpiece material, are all thought to be responsible for these surface conditions. Due to the pressure weld between the tool and the chip, which may randomly pluck and scratch the machined surface at a smaller value speed of cutting, hence, the chip may stick to the tool surface. Surface roughness is the mark left on the machined surface by the tool wedge's shape. The angle approach plan, edge of the cutting, nose radius as well as the feed rate all play a crucial role in surface roughness (Ezilarasan et al., 2011a).

Furthermore, through ANOVA analysis, a significant shear factor to the surface roughness can be determined. moreover, through this ANOVA analysis as well, it can develop an empirical model for the machined surface for flooded and dry cooling conditions. Based on these experiments, the obtained machined surface roughness was compiled in the design analysis of historical data to determine the optimal cutting conditions. Next, these optimal parameters are classified through experiments and the percentage of error is determined.

1.6 Organization of the Report/Thesis

Chapter 1: Introduction

This chapter is discussed about the background of the study. Other than that, this chapter also discusses the problem statement that has been identified through the previous research and observation. Next, it is followed by the objectives of this study that need to be achieved throughout this study and it also discusses the scope where it has been narrowed down the study area.

Chapter 2: Literature Review

This chapter is discussed about the fundamental theories concerning the research topic and preceding studies from academic journal and the internet. The current material handling equipment has also been explained in this chapter. The cutting parameters that have been done are also comprised. Lastly, the methods and results of the previous research have also been evaluated and described.

Chapter 3: Methodology

This chapter is discussed about the flow chart process of this experiment that will be carried out. It consists of what type of process will be carried out through this study. Next, this topic also will be finalized what is the cutting parameters that going to be applied in this experiment. Besides, this chapter also will be mentioned what is the method that will be going to use when carrying out this experiment. And lastly, the results of the experiment will be observed and planned for the next action.

Chapter 4: Results and Discussion

This chapter was discussed about the results of surface roughness value of the machined surface for both conditions. All the data and results were recorded. The most significant parameters affecting the surface roughness also been analyzed in this chapter.

Chapter 5: Conclusion and Recommendations

This chapter will conclude for the whole experiment and also some recommendations would be provided for the future studies.

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CHAPTER 2

LITERATURE REVIEW

This chapter clarify the summary of related research on articles, journals, websites, and books that has been done by the researchers before. The theme that is covered in this part is turning, cutting parameter, feed rate, cutting speed, depth of cut, high-speed machining, machining in dry and flood conditions, cutting tool material, cemented carbide tool, coated and uncoated carbide, surface roughness, characteristic of surface roughness, surface topography, surface metallurgy and topology, material removal rate, Nimonic C-263 Alloy, design of experiment and response surface methodology.

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2.1 Turning Process

Turning is a material removal process or a type of machining that is used to shape materials. A turning simple machine or lathe, as well as a workpiece, fixture, and cutting apparatus, are required for the turning process. The work item is fastened to the machine's spinning fixture and allowed to spin at high speeds. To make the required structure, the cutting tool swallows into the spinning workpiece and cut off away material in the form of small-scale chips.

In recent years, turning has shown to be an efficient machining process that has piqued the curiosity of experts looking for a replacement for grinding (Jadhav et al., 2020b). In the machining of hardened steels, hard turning is more effective and efficient than typical grinding procedures (Sivaraman & Prakash, 2017). Jadhav et al., (2019) addressed that one of the oldest and most extensively used methods of metal cutting is turning with a single-point cutting tool. In several instances, it has even replaced grinding, resulting in a faster lead time without affecting surface quality. When turning on a lathe machine, it's critical to understand which machining parameter has the greatest impact on the response factors (Ahmed et al., 2020). A greater nose radius provides more contact area between the tool and the workpiece during the turning process, resulting in a superior surface finish (Shah et al., 2021). Figure 2.1 below indicates the representation figure of the turning process.

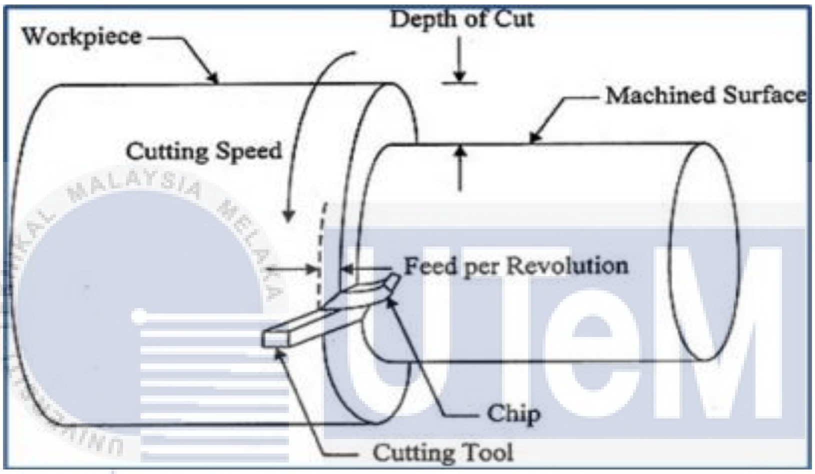

Figure 2.1: Schematic Diagram of Turning Process (Butt et al., 2021)

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2.2 Cutting Parameter

Cutting conditions have an impact on reducing production costs and time as well as determining the end product's quality in metal cutting processes. The setup of cutting parameters in a machining process is one of the crucial aspects that need to be focused on to get good and reliable results for the experiment that carry out. The genetic algorithm has been utilized as an optimal solution finder to determine ideal cutting parameters during a turning operation. While considering technological and material constraints, process optimization must provide the shortest manufacturing time (Ahmed et al., 2020).

When turning on a lathe machine, it's critical to understand which machining parameter has the greatest impact on influencing the response factors. Ezilarasan et al. (2013a) look at how the cutting factors and time of cutting process affect the surface roughness of turning Nimonic C-263. They mentioned that the surface roughness increases up to a speed of 190m/min, whereby it is beyond which the surface roughness is directly proportional to the speed. The lowest Ra value measured was 1.9m. Increased in speed of cutting, it will enhance the temperature of cutting, and the work piece's limited thermal conductivity traps heat at the edge of the cutting device, which causing in tool wear. This is the cause of the extreme of surface roughness value. Figure 2.2 below shows the visualization of the cutting parameter. Figure 2.3 and table 2.1 below indicates the summary of literature review for this experiment.

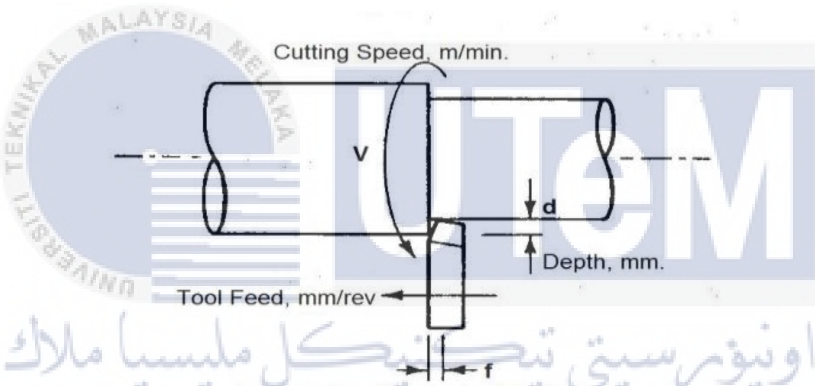

Figure 2.2: Cutting parameter (Rao et al., 2016)

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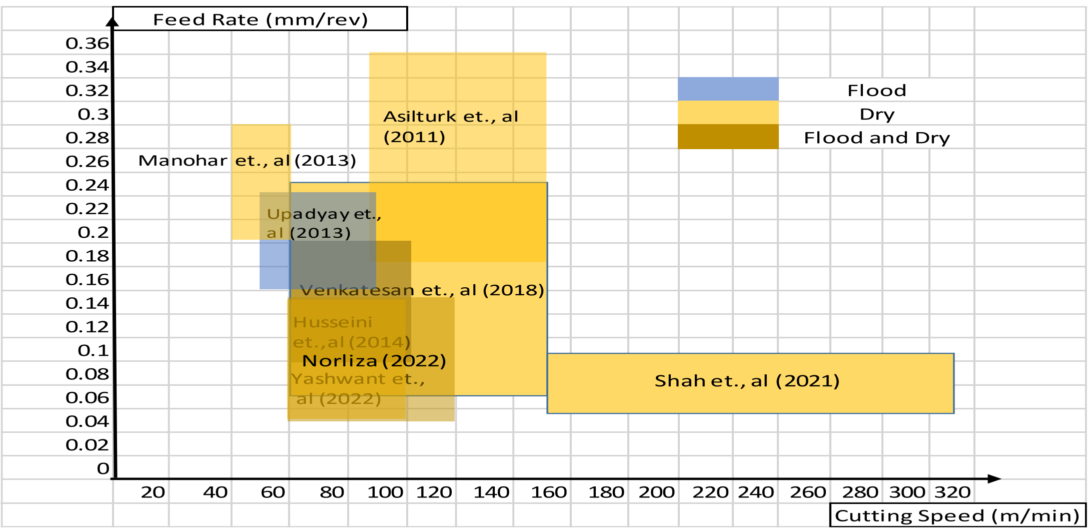

Figure 2.3: Research analysis on turning of Nimonic C-263 Alloy in several cutting parameters

Table 2.1: Summary from literature review in turning Nimonic Alloy under different machining conditions

Title	Author	Types of Coolant	Cutting Tool	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)
Machinability Characteristics in Dry Machining of Nimonic 263 Alloy Using Coated Carbide Inserts	Venkatesan et al. (2018)	Dry	PVD and CVD	60,90,120,150	0.05,0.12,0.18, 0.25	0.4,0.6,0.8,1.0
Effect of cutting parameter and cutting environment on surface integrity during machining of Nimonic C-263a Ni based superalloy	Sigh et.al (2017)	Flood	Uncoated cemented carbide	22,33,54	0.051, 0.102, 0.143	0.50, 0.705, 1.00
Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method	Asiltürk et.al (2011)	Dry	Al2O3 and TiC-coated carbide tools	90, 120, 150	0.18, 0.27, 0.36	0.2, 0.4, 0.6
Investigation of cutting temperature, cutting force and surface roughness using multi-objective optimization for turning of Ti-6Al-4 V (ELI)	Shah et.al (2021)	Dry	coated cemented carbide inserts	140, 224, 315	0.051, 0.071, 0.102	0.5, 0.75, 1

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Application of Box Behnken design to optimize the parameters for turning Inconel 718 using coated carbide tools	M Manohar et.al (2013)	Dry	Coated and uncoated carbide insert	40,50,60	0.20,0.25,0.30	1.0,1.5,2.0
Experimental investigation into tool wear, cutting forces, and resulting surface finish during dry and flood coolant slot milling of Inconel 718	Gueli et.al (2021)	Dry and Flood	Tungsten Carbide	60	0.1,0.2,0.3,0.5	0.25,0.5,0.75,1.0
Effect of cutting speed and feed on surface roughness in dry turning of Inconel X-750	Yashwant et.al (2022)	Dry	PVD TiAlN coated carbide insert	60, 80, 100	0.05,0.10,0.15	0.5
In-process prediction of surface roughness in turning of Ti-6Al-4V alloy using cutting parameters and vibration signals	Upadhyay et.al (2013)	Flood	Uncoated cemented carbide	50,70,90	0.16,0.20,0.24	1,1.5,2.0
Optimization of cutting forces and surface roughness in dry turning of AM magnesium alloy	Kolluru et.al (2020)	Dry	Tungsten Carbide insert	500,600,700	0.1,0.15,0.2	0.5,1.0,1.15

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2.2.1 Feed Rate

Feed rate consists of the most crucial aspects to deal with when utilizing any CNC program. The feed rate refers to how quickly the cutter moves into the task. Feed rate is commonly abbreviated as fn and is expressed in units of length per revolution, such as inches per revolution. To ensure optimal productivity, the fastest feed rate should be selected so that the machine's power can handle while still producing an acceptable surface finish. Commonly, the feed rate is the speed where the cutting tool is engaged with a part and is usually measured in units/minute. The value of the feed rate will be fluctuate varying on the material used, the material of the cutting tool, and another cutting aspect including the relevant machined surface and the uniqueness requirements of the selected CNC machine. Furthermore, the feed rate is very significant as it is straightly linked to practically every factor of NC machining from safety and productivity of surface roughness, quality surface finish, and tool life as well. Feed rate also may commit to wearing on the machine’s components.

According to Ezilarasan et al. (2013), the feed rate was observed to have an effect on the cutting force and surface roughness more considerably than the speed of cutting and depth of cut. Addition to that, they also state that the feed rate and depth of cut were noticed to affect the flank wear more drastically than the speed of cutting. The faster rate of erode edge progression with feed rate followed with the speed of cutting demonstrates the whisker reinforced ceramic insert's higher acceptance of cutting speed. Though machining the Nimonic C-263 alloy with the whisker reinforced ceramic insertion, the input for cutting forces, flank wear, and surface roughness are recognized, and a 95% confidence intensity demonstrates its validity in forecasting the reactions. Figure 2.4 below is the diagram of the feed rate on a workpiece.

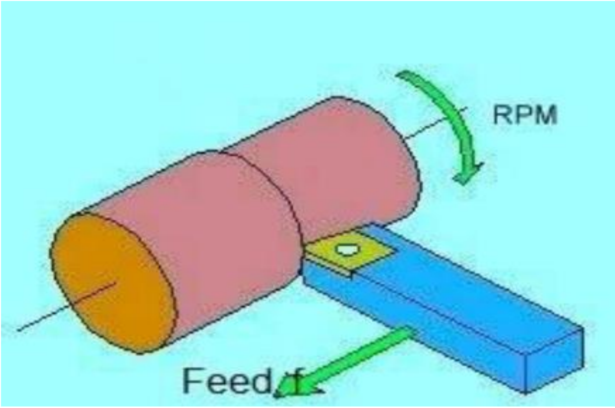

Figure 2.4: Feed rate (Rao et al., 2016)

2.2.2 Cutting Speed

The relative velocity in the middle of the surface of workpiece and the cutting tool is commonly referred to as cutting speed. It is also defined by some experts as the rate at which the workpiece passes past the tool's cutting edge. Cutting speed is a key component in determining other CNC machining characteristics including cutting temperature, power consumption, and tool life, among others. It has a significant effect on these parameters, causing in a large difference in feed rate and cutting speed. To achieve reliable cutting speed, the spindle of the lathe machine must be rapidly regulated for workplaces of small diameter and moderate for workplaces of large diameter. Figure 2.5 depicts below is the visualization of the cutting speed of the workpiece.

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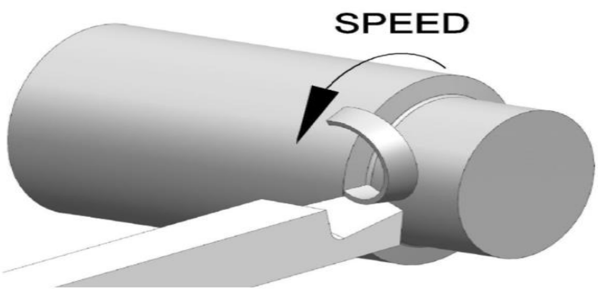

Figure 2.5: Cutting Speed

2.2.3 Depth of cut

The depth of cut deal with to how much the cutting tool engages the job radially. The value of the depth of cut is half the difference in diameter between the uncut and cut cylindrical surfaces. The abbreviation DOC or ap stands for depth of cut. Depth of cut is referred to the length of the cutting side of the cutting area or how far the tool bit penetrates the work. Ezilarasan et al. (2011) addressed that the amount of depth of cut is desired for machining the C-263 alloy. Tool life can be extended by increasing the depth of cut and figure 2.6 below is the diagram depth of cut of the workpiece.

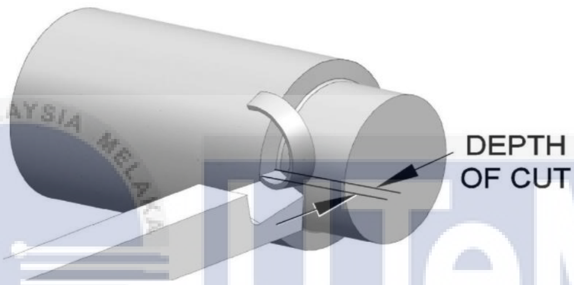

Figure 2.6: Depth of cut

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2.3 High-Speed Machining

Jain & Bajpai (2020) has regarded that high-speed machining (HSM) is an innovative and growing machining technique that is used to create complicated parts with high productivity, increased quality, long-term durability, and low cost. Despite that, high-speed machining is now widely acknowledged as one of the most important manufacturing technologies for increasing productivity and throughput (Pasko et al., 2017). For many years, high-speed machining, or more especially high-speed cutting, has piqued the curiosity of manufacturing scientists and engineers. HSM has been created as a leading technology in the field of quick tooling and production (Kaçal & Yildirim, 2013). HSM also may reduce production time and enhance the precision of machined products. Pasko et al., (2017) regard that increasing the cutting speed to HSM values has various advantages, including increasing the removal rate and enhancing the end surface.

According to Z. Wang & Rahman, (2014), HSM can produce high-quality surfaces, burr-free edges, and almost stress-free components after machining, in addition to higher productivity. It may also be used to manufacture thin-wall workpieces because the cutting pressures involved under HSM circumstances are in a low range. Another key benefit of high-speed machining is that temperature impacts on the machined parts are minimized whereby cutting chips absorb the majority of the cutting temperature, decreasing current damaging and extending the lifetime of the cutting tool. Because of these benefits, Da Silva et al. (2019) believe that high-speed machining is commonly used in the automotive, precision engineering, aerospace industries. However, according to Iqbal et al., (2016) in their study, there are various drawbacks to HSM, one of which is that the duration lifetime of the tool become reduced to half of what it is in traditional mode. This is owing to the unusually high heat output caused by the rapid rate of deformation. As a result, depending on tool damage such as adhesion wear, heat increases the temperature mode.

2.4 Cutting Tool Material

Cutting tool qualities such as high hot hardness, toughness, and chemical stability are all required in recent industries. As a result, numerous cutting tools available on the market today can meet the need. Some cutting tool materials have been manufactured for specific tasks and have different qualities. According to Chen et al., (2018) even though the generated compressive stress found higher and lower roughness, it is discovered that round tools with reformed cutting edges disclose lower rake face temperatures than square and rhomboid tools. On the other hand, the reducing in environmental hazards of the conventional cutting fluids and improving the efficiency of the machining process in terms of surface roughness, cutting forces as well as the tool life really influence by the sustainable of the cutting environment when the process is carried out.

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2.4.1 Cemented Carbide Tool

Cemented carbide is a tough material that's utilized in a variety of industrial applications, including cutting tools (Ahmed et al., 2020). Strano et al. (2015) in their study regards that the microhardness of the carbide implants increased by 7–11%. Hatt et al. (2018) addressed that the usage of cemented carbide Wc-Co is very command and cutting process by this tool insert always been recommended by researchers in machining industry nowadays. It is recommended due to its excellent mechanical properties.

Nayak (2014) has covered that the flow manufacturing process of this cemented carbide cutting tool is consists of mixing, compacting as well as sintering. The sintering process of this cutting tool is carried out largely with the use of tungsten carbide and cobalt powder. Besides, cobalt grain performs as a binder for tungsten carbide (WC) due to the solid metallic quality of the carbide which can influence excellent electrical and thermal conductivity. Cemented carbides were first offered to the European market in the 1920s and 1930s as materials with a good combination of hardness, feasible fracture toughness, and wear resistance. Cemented carbides have become the material of choice for cutting and drilling tools, mining bits, and wear-resistant components in several industry field applications due to their relevant properties.

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2.4.2 Coated and Uncoated Carbide Tool

Coated carbide is a robust fibrous structure with a special toughness that improves wear and fracture resistance. It consists of a wide range of applications and reduces the number of tools consumed. Compared to uncoated carbide, it consists of a carbide insert that does not cover with a coating of a particular substance. The base material for carbide is tungsten carbide (WC) and cobalt (Co). Titanium carbide (TiC), Aluminum oxide (Al_2O_3), and Titanium nitrate (TiN) are the most frequent material used for coating layers. Both coated and uncoated carbide inserts are widely used in industrial applications.

Apart from that, Safari et al. (2014) have conducted a study on milling of Ti-6Al-4 V alloy by using coated and uncoated inserts in a cryogenic cooling environment and found that cutting intensity and severity of the surface was better performing in coated inserts instead of in untreated inserts.

Olovsjö and Nyborg (2012) also have investigated grain size in wasp alloy using the same cutting equipment. The tool wear was found to be highly reliant on the notch wear when cutting at a pace of 30 meters per minute. Material adhesion was also discovered, although it caused no serious harm because it formed a protective layer.

According to Nayak (2014) for high-speed machining of Nimonic C-263 alloy, the implementation of coated carbide tools, ceramic, and CBN/PCBN tools are commonly utilized, whereas uncoated carbide tools are employed for low-speed machining. Thus, the effective machining can be accomplished by depending on the use of various kind of cutting tool material during handling the process.

Physical vapor deposition (PVD) is a well-known process that is frequently utilized for the deposition of thin films for a wide range of applications, including tribological behavior enhancement (Baptista et al., 2018). Venkatesan & Thakur (2018) has regarded in comparison of machinability characteristic of machining Nimonic in a dry condition using coated carbide and found that in the case of Physical Vapor Deposition (PVD) and Chemical Vapor Deposition (CVD) inserts machining, the roughness is decreased at higher speeds. PVD coated inserts also perform better than CVD coated inserts throughout a moderate range of feed levels. Besides, throughout the turning process, Veerappan et al. (2018) discover that a CVD carbide insert was employed. An internal cooling system with a cooling fluid is coupled to the tool holder. This coolant circulates within the tool holder, removing heat from the tool and preventing red hardening.

Ezilarasan & Senthil Kumar (2012) have observed that machining of the Nimonic C-263 alloy with PVD coated carbide provides a significant improvement owing to its increased endurance to typical wear structures. Other than that, when it came to the amount of material removed and tool life, the CVD-coated tools outperformed the PVD-coated (A. Ginting et al., 2018).

During the machining of the Nimonic C-263 alloy, Sivaraman & Prakash (2017) evaluated the execution of multilayer TiN/TiC/TiN and TiAlN PVD coated carbide tools in conditions of tool life expectancy, surface texture, and cutting forces. The multilayer-coated carbide insert had an extended tool life than the single-layer coated carbide inserts, according to the study. During high speed and depth of cut conditions, single layer PVD inserted tool provides superior surface finish than multilayer PVD inserted tool. (M. Singh, 2016) regards that due to superior antifriction properties and less material adherence on the tool surface, surfaces machined with PVD coated tools show less tearing and grain refinement.

2.5 Cutting Fluid

Cutting fluids are liquids or gases that are used to increase cutting performance in machining operations (Namb & Paulo, 2011). Various types of cutting fluids have been utilized in machining processes to improve turning efficiency (R. Singh, 2020). According to Grzesik & Grzesik (2017) cutting fluid is delivered to the chip machining zone gravitationally or under pressure to increase the performance of the cutting through lubricant and coolant effects. Predominantly, all these impacts are dependent on the quantity of heat created, with lubrication being more essential at low cutting speeds and cooling being the most critical response to the higher cutting speeds because of the more intensive heat generation take part. Table 2.2 below shows the advantages and disadvantages of cutting fluids towards the machining product.

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Table 2.2: Advantages and disadvantages of cutting fluids (Benedicto et al., 2017)

Advantages	Disadvantages
Improve tool life	Costs for purchasing, storing, maintaining, and removing used fluids
Less cutting power and force needed	Due to poor maintenance, workpieces and machine tools may become damaged over time.

Greater feed rates and cutting speeds	Impact of environment
Lessen the need of post-process heat treatments	Employee health risks
Superior surface conditions	

2.5.1 Flood Coolant

Traditionally, industries have employed flood machining to achieve an excellent surface finish and dimensional precision by reducing the workpiece's thermal expansion. Flooded condition is a familiar technique of reducing the high temperature produced in the cutting region to expand tool life and enhance surface condition. Cooling method has numerous benefits, including better tool life, advanced chip segmentation, and economical cooling and lubrication, as well as low down the usage of power. In this experiment, the coolant used was Ecocool 700 NBF (M) with net volume of 20 litres. Conventional cutting fluids, on the other hand, affect health and environmental problems as well as elevated manufacturing costs. As a result, an alternative to the heavy use of cutting fluid during machining is necessary Kumar et al., (2017). However, it is unable to reduce tool wear, particularly for difficult-to-machine items. Also, the sustainability of flood machining is poor due to the following aspects:

i. Worker's health risk may influence due to the bacterial that occur during cutting fluid performance.
ii. The recyclability procedure is required for oil particles to stick to the chip.
iii. The breakdown of oil particles into hazardous gases at a greater temperature causes air pollution to spread.
iv. The cutting fluid requires a lot of space and energy to circulate, recycle, and store.

Despite of the negative impact due to the poor machining, flood coolant also has its own outstanding performances. According to Zishanur Rahman et al., (2020), flood coolant improves the quality of the machined surface and machining precision by ensuring good cooling effects and smoother machining performance. Flood coolant also mostly utilized in industries as a cutting fluid to lubricate and cool down the machining process (Microelectrodes, 2019). Flood coolant has better ideal conditions for completing the scenario. Cryogenic coolant, on the other hand, produced improved surface quality (16%) and lower cutting forces (60%) resulting in lower cutting temperatures and, as a result, decreased tool wear (Hegab et al., 2021). The lowest possible of Ra value reported in flood machining system could be present attributable towards the reduced tool wear caused by uninterrupted emulsion surface make contact at the tool-chip in addition to tool-workpiece boundaries. Flood and cryogenic machining produced decreased surface roughness as it should be to express make contact with cutting fluid in the middle of the tool-chip and tool-workpiece boundaries, as associated to MQL and dry machining method in rising order (Khanna et al., 2020a).

2.6 Dry Machining

Due to the lack of lubricants and coolants, dry machining is considered a more environmentally friendly method than machining with cutting fluid. Dry turning of super alloys requires less cutting force and produces a better surface quality than wet machining (Thomas 2016). Dry machining, minimal quantity lubrication (MQL), machining with coated cutting tools, solid lubricant aided machining, cryogenic machining, and hybrid machining have all been investigated as alternatives to machining with traditional cutting fluids by various researchers (J & N, 2020). According to Paturi et al., (2022), to encourage sustainable manufacturing, dry or near-dry machining is the preferred method. In dry machining, heat generated and friction in the cutting zone are key issues that affect surface quality and tool life (Nimel Sworna Ross & Manimaran, 2019).

Dry machining offers a variety of benefits, including more flexibility, increased productivity, shorter cycle times, and lower machine tool costs (Thomas et al. (2016). According to (V.BALAJI, 2015), machining in a dry environment does not pollute the atmosphere or water, lowering the risk of illness, skin irritation, and respiratory problems.

The workpiece and chips have no fluid remains, according to (Benedicto et al., 2017). There is a expense and energy lessening because the maintenance and excess fluid treatment processes are no longer required.

Dry machining was used by Thomas et al., (2016) to show the restriction. Dry machining produces high temperatures, a high rate of wear, and short tool life. Despite being the cleanest machining technology, dry machining is unsuccessful due to low surface quality and significant tool wear, according to (Khanna et al., 2020b). Because the cutting tool and workpiece aren't lubricated, the temperature rises, limiting the process parameter and output.

2.7 Surface Roughness

Nowadays, surface roughness plays a crucial part in the manufacturing industry, in assessing and determining the quality surface of the fabricated products. Surface roughness extremely influences the practical description of products like friction, fatigue, lubricants, a reflection of light, coating as well as wear resistance. Surface roughness is not only an element in quality but is also the last phase in managing achievement and the processing charge.

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Surface roughness is still one of the most essential factors that characterize surface topography. Because it directly monitors surface acts such as friction, wear, lubricant retention, and load-carrying capability. It is used to estimate the surface integrity of machined components. It also enhances fatigue strength, corrosion resistance, and creep life, all of which are essential for aircraft components. Surface roughness is a big deal in a lot of places, and it's a big deal when it comes to machining precision.

According to Gara & Tsoumarev (2016), surface roughness is a factor that has a significant impact on dimensional accuracy and workpiece conformance. As a result, research has been conducted to define appropriate tool design and cutting conditions (cutting speed and feed per tooth) that provide the surface roughness required in the definition drawing while causing the least amount of damage to the workpiece (delamination) and the cutting tool (longer service life). In many engineering applications, measuring surface roughness is crucial. The quality of the surface finish can influence a variety of life characteristics. In the research of surface integrity, surface roughness is thus regarded as one of the most important factors. The shape of the cutting tool and machining settings are primarily responsible for surface roughness in the turning process (Ezilarasan et al., 2013b).

Many factors have an effect on surface roughness. The factors are machining parameters, tool geometry, the material of the workpiece, coolants as well as cutting tools. It is always fascinated to come out with a correct and solid mathematical model which capable to predict the surface roughness together with the quality of a product. The surface roughness is shown to diminish as the cutting speed was raised. It was also discovered that increasing the feed rate gradually increases the surface roughness (Srithar et al., 2014). Figure 2.7 depicts below is the graph variation of surface roughness with feed rate whereby it results that surface roughness is directly proportional to feed rate.

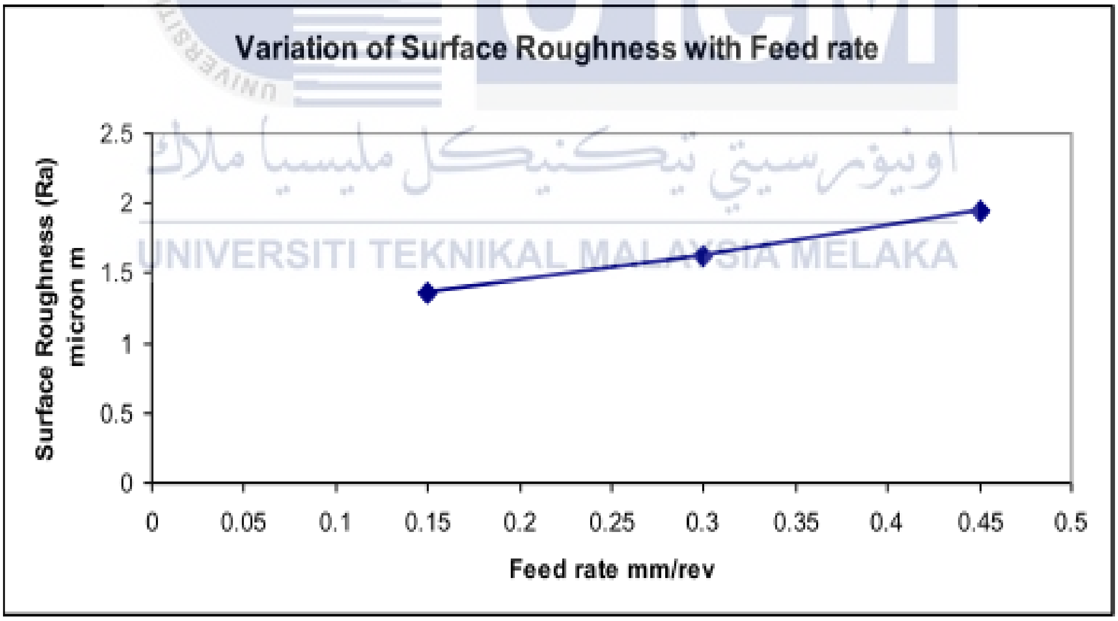

Figure 2.7: Variation of feed rate on surface roughness (Rao et al., 2016)

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2.7.1 Characteristic of Surface Roughness

Rough surfaces are more tendency to get erode and shred. Compared to the condition of the surface whether it is smooth or rough, the value of friction is different whereby the friction value is higher on rough surfaces instead of the smooth surface, and variations in the smoothness of a surface tend to form nucleation sites. Breaks and corrosion at these locations could cause the material to wear out quickly. Gara & Tsoumarev (2016) explored the influence of tool geometry on surface intensity and discovered that it had a significant impact. An excellent surface finish is desired to increase the product's tribological characteristics and fatigue strength (Krishna Madhavi et al., 2017). Surface quality is also critical for the proper function of precision micro parts, and it varies depending on work material qualities.

2.7.2 Surface Topography

Özel & Arisoy, (2014) had mentioned in their research that surface topography related to the textures, waviness, and surface roughness of the machined surface. Related machining procedures can all have a substantial impact on completed item surface integrity which was residual stresses and hardness. Apart from that, tool surface topography was found to have a significant impact on the tribology during machining process. Houchuan et al., (2015) and Liang & Liu, (2018) discovered that the new tools' surfaces predicted better topographical amplitude than the worn tools' surfaces.

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Surface roughness and product quality are related. The connection between surface roughness and usability needs to be addressed in the manufacturing industry. Due to its effect on product performance and life cycle, as well as residual stresses and the presence of surface and subsurface micro-ruptures, surface finish is a crucial feature of machinability that is actively researched (Dutra Xavier et al., 2011). On the other hand, surface roughness is the method that is most frequently used to measure surface integrity properly and is thought to be the main sign of how well a surface has been machined (Yazid et al., 2011).

As a result, when it comes to metal cutting, estimations on preliminary design surface roughness have become a major research area (Upadhyay et al., 2013). As the cutting speed increased, the surface roughness reduced. A lower value of surface roughness indicates a better workpiece surface.

2.7.3 Surface Metallurgy and Topology

Surface metallurgy is the study of the surface layer that lies just below the machined surface. Both the machined surface and the sub-surface layer have undergone metallurgical modifications. During machining, the surface of nickel-based super alloys was subjected to intense mechanical forces, including high stress, high strain, exceptional thermal temperature, as well as the quenching of loads. These forces can cause changes in the surface's microstructure and metallurgy (Kortabarria et al., 2011). Surface integrity is a crucial component of machining niobium alloys, particularly in the fabrication of medical equipment, heavy machinery, and aerospace applications. For Nimonic alloy machining, surface integrity is an important element especially in aerospace applications, heavy power industry and medical equipment manufacturing.

This is due to the fact that in an industry where high levels of reliability are necessary, surface integrity is one of the most important factors in determining how well-machined a surface is (Ulutan & Ozel, 2011). The microstructure of the changed layers below the surface is then described by metalworking in relation to the base or matrix material. In addition, surface metallurgy is an examination of the surface layer that is present beneath the machined surface as a result of the machining process, as opposed to surface tribology, which focused on the hardness of the machined surface. The layer beneath the machined surface is illustrated in the SEM image in Figure 2.8 below.

This is because in the industry requires a high level of reliability, surface integrity is one of the most relevant parameters in assessing the quality of machined surfaces. Metallurgy, then, characterizes the microstructure of the modified layers below the surface in relation to the base or matrix material. Furthermore, according to Armansyah Ginting et al., (2010), in contrast to surface tribology, which concentrated on the hardness of the machined surface, surface metallurgy is an investigation of the surface layer that is present beneath the machined surface as a result of the machining process. Figure 2.7 depicted below shows the SEM image of the layer below the surface that has been machined.

i. During both cold and hot machining, plastic deformation takes place.

ii. Errors brought on by built-up edges

iii. The top layer's surface hardness varies

iv. Phase conversion

Surface metallurgical change, on the other hand, is concentrated on plastic deformation and variations in hardness. The high temperature during machining, debris undergoing plastic deformation, and chemical reactivity between the workpiece and the machining tools were all factors in the surface alterations.

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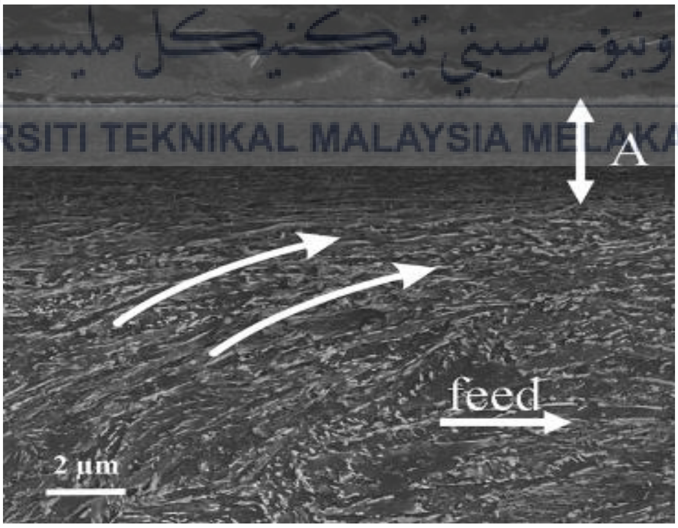

Figure 2.8: SEM image of the layer below the surface that has been machined.

2.8 Material Removal Rate (MRR)

The amount of material removed from the workpiece per unit time is known as the material removal rate. The amount of material removed or the weight difference before and after machining can be used to compute the material removal rate.

Leo Kumar (2019) has investigated the measurement and uncertainty analysis of surface roughness and material removal rate and found that for a particular spindle speed, MRR is found to be dependent on feed rate and depth of cut factors. MRR grows proportionally as feed rate and cut depth increase. It's because feed rate controls the amount of material removed per unit time for a given spindle speed and depth of cut parameter.

Verma et al. (2019) has evaluated the optimization of material removal rate and surface roughness in turning of 316 steel and it is obvious that as the cutting speed is increased, the MRR increases as well. The rise in MRR with cutting speed is greater when the feed rate is increased than when the depth of cut is increased. The greatest MRR was attained using a maximum feed rate of 0.11 mm/rev and a cutting speed of 88 m/min, as well as a moderate (0.5mm) depth of cut. The rate of material removal and the roughness of the surface are directly proportional to the feed rate and the depth of cut. In addition to that, the overall conclusion from the study is the rate of material removal increases as cutting velocity increases, whereas cutting velocity does not affect surface roughness. As a result, cutting speed is a critical input parameter for MRR.

2.9 Nickel-based superalloy

The application of nickel-based superalloys in the engineering industry is very commanded nowadays including in the application of gas turbine components, submarines rocket engines, aerospace vehicles together with the petrochemical apparatus. This type of material is very famous in that applications because this material is very high in toughness, outstanding creep, tensile strength, and corrosion strength although long exposure at a high temperature of 650 °C above. According to (Ulutan & Ozel, 2011), nickel alloys are commonly utilized in the hot sections of mission essential components and are available in wrought, forged, cast, and sintered (powder metallurgy) forms.

Nickel-based alloys are consist of the most extensively utilized materials in aerospace, defense, and nuclear management because this alloy has functioned effectively under extreme stress and temperatures (Jadhav et al., 2019). In the periodic table, superalloys belong to Group VIII B elements which consist of various combinations of Fe, Ni, Co, and Cr, as well as lesser amounts of W, Mo, Ta, Nb, Ti, and Al. There are three major classes of superalloys. The three classes are nickel, iron, and cobalt-based alloys. Among three of these classes, the development of the nickel-based superalloy has endorsed a huge number of extensive programs worldwide.

Besides, superalloys have excellent mechanical strength and creep resistance at very high temperatures. This material also has good surface stability, phase stability along with high oxidation and good corrosion resistance. Furthermore, the combinations of added elements to this superalloy are depended on the application area.

2.9.1 Nimonic C-263 alloy

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Nimonic refers to a group of nickel-based superalloys that can withstand long temperatures while also exhibiting low creep. Typically, they are made up of 50% of Nickel together with 20% of Chromium (Cr), combined with a smaller fraction of Cobalt (Co), Titanium (Ti), and Aluminum (Al). The presence of Cr causes the material to have unique features in terms of mechanical qualities and corrosion resistance at high temperatures. The usage of Molybdenum is to strengthen solid solutions. It's a material that's employed in aerospace application. The high solidification rate and piercing resistance of this superalloy are two of the most difficult aspects of machining it.

For the duration of machining the Nimonic C-263 alloy, the tool that been used is dominated to excessive heat, pressure, and abnormality, which is resulted in tool wear, flank wear, and variations in dimensional efficiency and surface finish. Furthermore, most of the alloys feature substantial abrasive inter-metallic inclusions in the microstructure, such as carbides, and have a strong tendency to work hardening as well as a high chemical affinity to a variety of cutting tools. These also cause problems with machining processes (Chen et al., 2018). Figure 2.9 below shows the microstructure of Nimonic C-263 Alloy. As for the table 2.3 and 2.4, both tables indicate the mechanical properties and chemical composition of Nimonic C-263 alloy that will be used for this experiment.

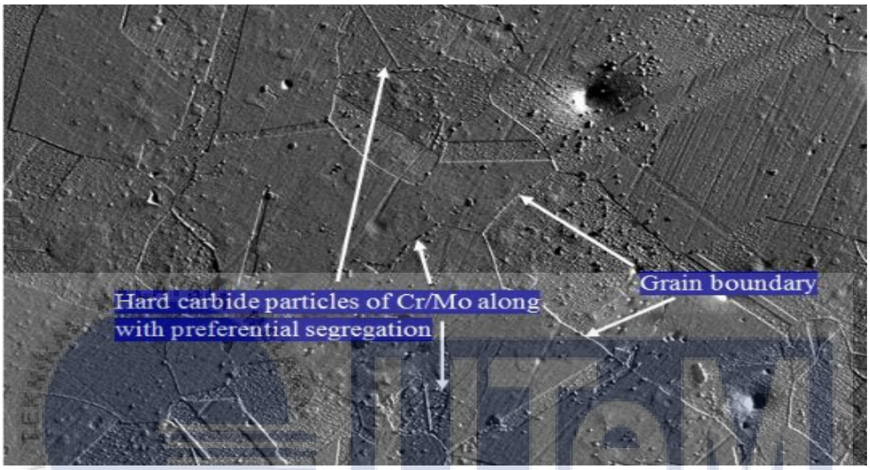

Figure 2.9: Microstructure of Nimonic C-263 Alloy (Ezilarasan et al., 2013b)

Table 2.3: Mechanical properties of Nimonic C-263 Alloy (Koyilada et al., 2016)

Material	**Tensile strength (MPa)**	**Yield strength (MPa)**	**Creep strength (MPa)**	**Hardness HV**
Nimonic C-263	540	400	120	300

Table 2.4: Chemical composition of Nimonic C-263 alloys (Giridhar Reddy et al., 2020)

Elements	**Composition (valves in weight %)**
Co	21
Cr	19
Mo	5.86
Ti	1.56

Mn	0.43
Ni	Rest

Nowadays, there are many different types of nickel-based superalloys in the industry, especially in the engineering field. Nimonic C-263 Alloy is one of the types of these superalloys. Typically, the nominal chemical utilization of nickel-based alloys ranges from 38 to 76 wt.% nickel, up to 27 wt.% chromium (Cr), and 20 wt.% cobalt (Co). There are various types of Nimonic alloys, which are Nimonic 75, 80A, 86, 90, 105, 115, and 263. Table 2.5 below is the list of Nimonic alloy and its applications and characteristics.

Table 2.5: Types of Nimonic Alloy with its composition and characteristics

Types of Nimonic Alloy	Composition	Characteristics
Nimonic 75	Ni: 76.0 Cr: 20.0 Fe: 4.0	This Nimonic alloy is good in mechanical properties and resistance of oxidation at high temperatures.
Nimonic 80A	Ni: 76.0 Cr: 19.5 Ti: 2.4 Al: 1.4	This alloy is also very good in mechanical properties. It is also very good in oxidation and corrosion resistance as well as consisting of the large tensile and creep-rupture points at high temperatures. It also more hardened due to the addition of aluminum and titanium
Nimonic 86	Ni: 65.0 Cr: 25.0 Mo: 10.0 Cerium: 0.03	This nickel-chromium-molybdenum alloy is very good in formability and weldability
Nimonic 90	Ni: 60.0 Cr: 19.5 Co: 16.0 Ti: 2.5	This Nickel-chromium-cobalt has high-stress rupture strength and high creep resistance at elevated temperatures (920 °C). It also good in corrosion resistance and oxidation.

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	Al: 1.5	
Nimonic 105	Ni: 54.0 Co: 20.0 Cr: 15.0 Mo: 5.0 Al: 4.7 Ti: 1.3	This Nickel-chromium-cobalt with the addition of molybdenum has good for solid solution strengthening. It is very hardened and has a huge amount of aluminum which can increase the strength and oxidation resistance.
Nimonic 115	Ni:60.0 Cr: 14.2 Co: 13.2 Al: 4.9 Ti: 3.8 Mo: 3.2	The properties are quite like Nimonic alloy 105 but have a high amount of titanium and aluminum compared to Nimonic alloy 105 for improving the strengthening.
Nimonic C-263	Ni: 51.0 Cr: 20.0 Co: 20.0 Mo: 5.8 Ti: 2.2 Al: 0.5	This alloy is very hardened with an additional high amount of molybdenum for a solid strengthening solution. It is also very high in corrosion resistance and oxidation at elevated temperature which is up until 850°C.

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2.9.2 Characteristics of Nimonic C-263 Alloy

Superalloys are designed to withstand corrosion resistance and oxidation due to the creation of a protective oxide layer, mechanical and thermal fatigue, creep, impact load, and mechanical deterioration for long periods at high temperatures while maintaining properties such as a high strength-to-weight ratio that ensures low fuel consumption.

Because of their benefits, nickel-based alloys are particularly popular in the industry. The following are some of the benefits of nickel-based alloys. There is heat resistance, maintaining strong mechanical and chemical qualities at high temperatures, high melting temperatures, high corrosion resistance, and resistance to thermal fatigue, thermal shock, creep, and erosion (Ulutan & Ozel, 2011).

At high temperatures, excellent mechanical properties such as high hardness, tensile strength, corrosion resistance, and oxidation have influenced this alloy to be engaged in other fields (Thakur & Gangopadhyay, 2016).

During the machining process, the creation of component forces is one of the distinguishing aspects of a nickel-based superalloy. Cutting force generation must be measured because it affects the part design machined, design of the tool, power utilization, fluctuation, the precision of part designed, and other factors. It is quite difficult to manufacture and machine intricately shaped parts at a reliable cost due to some of the following reasons:

i. Deformation in the cutting tool may occur during high strength machining due to the hardened material of Nimonic alloy
ii. Tool wear easily at the line of the depth of cut as Nimonic alloy has austenite matrix that will influence accelerated work hardening.
iii. Notching of the cutting tool will happen when there is shear stress and abrasive saw tooth formation occur due to the high dynamic shear strength.
iv. Abrasive tool failure in the Nimonic alloy’s microstructure occurs due to the hard abrasive of the carbide insert.
v. Elevated gradient temperature of the tool chip happened due to the low thermal conductivity.

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2.9.3 Machining of Nimonic C-263 Alloy

Machining of difficult-to-cut materials at high speeds is possible with the right tool coating, machining technique, and cooling technology (Shokrani et al., 2012) and (Thakur & Gangopadhyay, 2016). Koyilada et al. (2016) addressed that machining Nimonic C-263, has always been a difficult process because of its high hot strength, limited thermal conductivity, the trend to work harden as well as closeness for material’s tool. Choosing the right coated tool with the right deposition procedure is very critical although this type of cutting tool has usually been used to solve several issues.

Previous research on the effect of machining settings on the Nimonic C-263 alloy demonstrated that a slower cutting speed and a greater feed rate resulted in a poor surface finish. The feed rate and depth of cut were also found to have a significant impact on the surface finish and surface damage (Ulutan & Ozel, 2011). According to Chetan, Behera, et al. (2016) machining of Ni-based alloys can result in the production of a diffusion wear mechanism, which can be said to speed up tool cutting edge fracture. Lower costs will be obtained throughout the aerospace manufacturing supply chain for alloys that can deliver greater machinability and ductility without losing high strength and fracture toughness (Hatt et al., 2018). Machinability refers to the process of removing material from the workpiece to the desired surface finish. Many factors have been considered in the machining performance of each material. Factors that have been influenced is:

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i. Mechanical properties of the material
ii. Chemical properties of the material
iii. Physical properties
iv. Size and shape of the workpiece
v. Cutting parameter
   a. Feed rate
   b. Cutting speed
   c. Depth of cut

The observed criteria to determine the machinability is:

i. Tool wear
ii. Chip characteristic
iii. Cutting forces
iv. Cutting temperature
v. Surface roughness

Different usage cutting tools can increase machinability like the use of coated and uncoated carbide insert tools which will provide slightly higher machinability.

2.10 Design of Experiment (DOE)

Design of Experiments (DOEs) is an organized, planned strategy for determining the relationship between various elements that affect an experiment and the various experiment outcomes. Other than that, the design of experiments (DOE) is also classified as a systematic, proper method to engineering problem-solving that uses concepts and procedures to ensure the creation of authentic, logical, and supportable engineering findings throughout the data gathering stage. Mukkamala & Gunji (2020) has mentioned the Design of Experiment (DOE) method has been successfully applied in a variety of industrial applications as well as in optimizing production processes.

Furthermore, all of this is done with the utmost efficiency in terms of engineering runs, time, and cost. Comparative, screening or characterizing, modeling as well as optimizing are the four general engineering field issues that may be applied to this DOE. Krishna Madhavi et al. (2017) addressed that by laying out the investigative trials objectively, DOE can be very useful in optimizing manufactured goods and design of process, studying the consequences of numerous aspects on performance, and solving production issues. The DOE can meet the demands of problem-solving and invention of product or process design optimization strategies on a budget using the Taguchi method.

Technologists, researchers, and academics can considerably shorten the period necessary for experimental examinations by understanding and utilizing this technique. On the other hand, the use of DOE necessitates meticulous planning, careful arrangement of the experiment, and skilled interpretation of the data.

2.10.1 Response Surface Methodology

Response surface methodology (RSM) is a set of mathematical and statistical tools for modeling and analyzing problems in which a response of interest is influenced by several variables, and the goal is to maximize the response (Ezilarasan et al., 2011b). Qiu et al. (2014) addressed that this method is frequently used in conjunction with factorial design methods like Box–Behnken and central-composite designs.

According to Ezilarasan et al. (2013) RSM (response surface methodology) is an approach for analyzing, modeling, and optimizing processes that combine statistical and mathematical tools. This strategy is used to figure out the new relationship between the input variables and the response of the process. According to Kant & Sangwan (2014) combining the grey relation method with the RSM, technique yields gives better outcomes in terms of decreased power usage and improved surface smoothness. M Manohar & Jomy Joseph (2013) regards that the link between the controlled input parameters and the resulting response surfaces is also quantified using RSM. RSM follows the following design procedure.

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i. Designing a set of experiments to ensure that the response of interest is accurately and consistently measured.
ii. Creating a mathematical model of the second-order response surface that has the best match
iii. Identifying the best set of experimental parameters for achieving a maximum or minimum response value.

iv. Using two and three-dimensional charts to represent the direct and interactive effects of process factors.

2.10.2 Box Behnken

Box-Behnken consists of an independent quadratic design. The Box–Behnken designs of experiments implement the design of the response surface. These methods do not consist either in full or fractional factorial designs (Amir et al., 2020).

Pasma et al. (2013) have covered in their study that the Box-Behnken design enables response computation at intermediate levels that have not been experimentally examined. When compared to typical factorial design methods, Box–Behnken designs can drastically reduce the number of experimental sets while maintaining the quality of the optimization (Qiu et al., 2014). Figure 2.10 shows the illustration of three factors of Box Behnken.

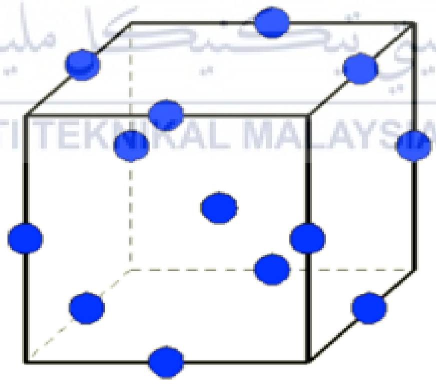

Figure 2.10: Illustration Box Behnken Design of three factors (Amir et al., 2020)

According to (Qiu et al., 2014), in general, there are four basic steps to implementing a Box–Behnken design with RSM.

i. Based on the given conditions, an experimental plan is produced.

ii. Experiments using a statistical design are carried out.
iii. The mathematical model's coefficients are estimated, and the model's accuracy is verified.
iv. Response analysis is performed to predict the optimal conditions, and these predictions are confirmed experimentally.

2.11 Summary of Literature Review

Table 2.6 attached below was the summary from literature review which related to this experiment.

Table 2.6: Summary of past analysis

AUTHORS/YEAR	TITLE	FINDINGS
Venkatesan et.al (2018)	A Comparative Study on Machinability Characteristics in Dry Machining of Nimonic 263 Alloy Using Coated Carbide Inserts	Depth of cut of 0.4mm and feed rate of 0.05mm/rev are found to be the most optimal value for all response
Ezilarasan et.al (2011)	Assessment of factors influencing tool wear on the machining of Nimonic C-263 Alloy with PVD coated carbide inserts	Cutting speed, followed by feed rate and depth of cut, was found to be the most important parameter.
Asiltürk et.al (2011)	Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method	According to the ANOVA analysis, the feed rate influences Ra and Rz at a reliability level of 95%. Any difference (variance) was not observed for the cutting speed and the depth of cut at the reliability level of 95%.
Shah et.al (2021)	Investigation of cutting temperature, cutting force, and surface roughness using multi-objective optimization for turning of Ti-6Al-4 V (ELI)	The experimental values and values predicted by nonlinear regression models are showing close correlation, as the percentage error between them is found to be less than 10%
Sivaraman et.al (2012)	The effect of cutting parameters on cutting force during turning	Feed rate and depth of cut are the significant parameters that influence

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	multiphase micro-alloyed steel	the cutting force than the cutting speed
Kolluru et.al (2020)	Optimization of cutting forces and surface roughness in dry turning of AM magnesium alloy using the Taguchi method	Feed rate has a more impact on the Surface roughness followed by speed. Thus, by this, we can say that the feed and speed directly impact the surface roughness.
Davoodi et.al (2014)	Experimental investigation and optimization of cutting parameters in dry and wet machining of aluminum alloy 5083 in order to remove cutting fluid	In dry and wet machining with high cutting speeds and the least undeformed chip thickness, it is possible to achieve the least cutting and feed forces and the least tool tip temperatures.
Yashwant et.al (2022)	Effect of cutting speed and feed on surface roughness in dry turning of Inconel X-750	The feed rate and cutting speed in turning were found to be important parameters while studying the surface roughness. However, it is observed that the feed rate has a greater impact on the surface integrity as compared to cutting speed.
Emmanuel et.al (2013)	An Experimental Study of the Effect of Control Parameters on the Surface Roughness in Turning Operation of EN 353 Steel	Machining with a high cutting speed decreases the surface roughness with all types of cutting fluids, and with dry cutting, too.

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CHAPTER 3

METHODOLOGY

This chapter discussed the experimental procedure, workpiece material, cutting tool, and tool holder that have been utilized in the investigation. The experiment was carried out on Nimonic-C263 Alloy by turning in high-speed machining using various cutting speeds, feed rates, as well as the depth of cut.

3.1 Process Flowchart

Figure 3.1 below shows the flowchart for the overall experiment's operations. The procedure was scheduled to start with machining Nimonic C-263 Alloy using a PVD coated carbide tool. It was consisted of turning with high-speed machining. The response surface methodology (RSM) was used to carry out the turning operation. The flow chart for the experiment's overall operations is depicted in Figure 3.1. In conjunction with the Box-Behnken approach, the response surface methodology (RSM) was used to carry out the turning process. The main purpose of using this method was to decide the optimal cutting parameters towards surface roughness during turning of Nimonic C-263.

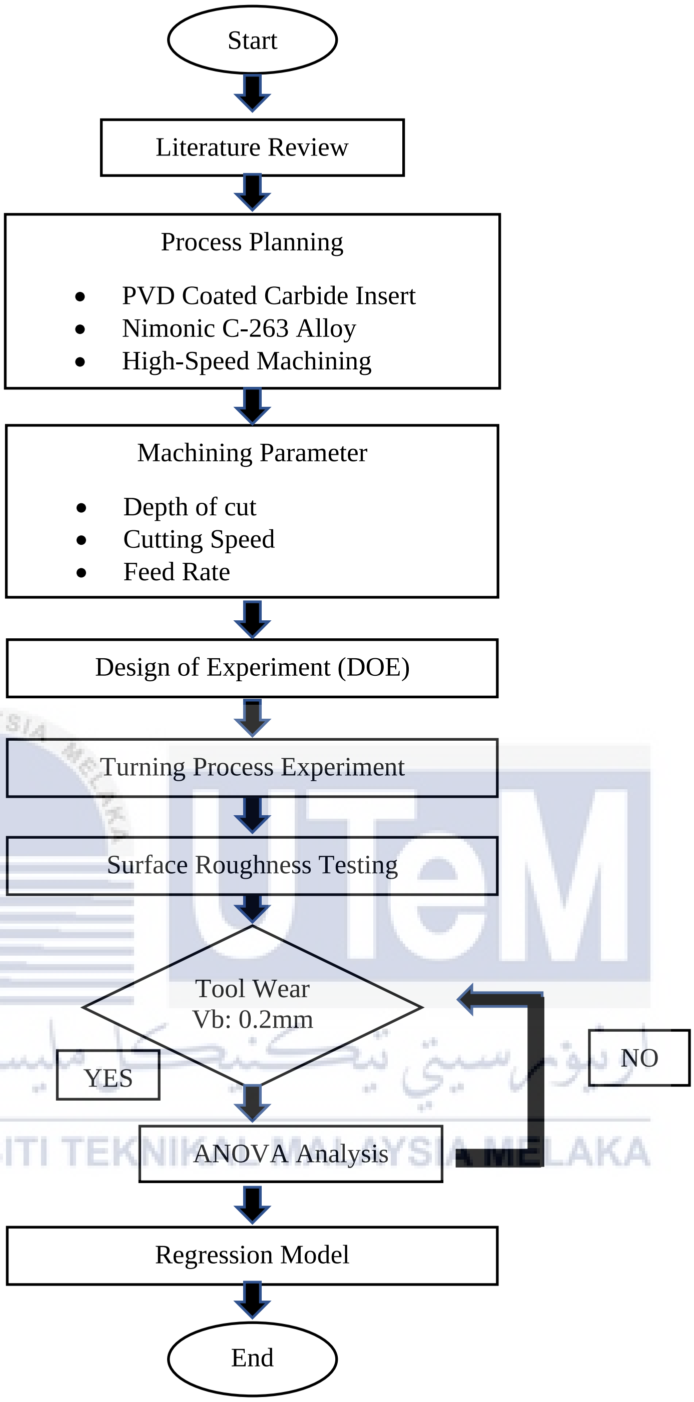

Figure 3.1: Flowchart Process of experiment

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3.2 Experimental Equipment

This subtopic will describe the procedure that was used in evaluating surface roughness during high-speed turning of Nimonic C-263 alloy by using PVD coated carbide. This experiment will undergo under flooded and dry conditions.

3.2.1 CNC Lathe Haas ST-20

For this experiment, CNC Lathe Haas ST-20 as shown in figure 3.2 below was used to machine the Nimonic C-263 Alloy. This lathe machine was usually applied to machine cylindrical parting a suitable cutting tool. The details and specifications of this machine that would be set up during the experiment was depicted in Table 3.1 below.

Figure 3.2: Haas ST-20 CNC Lathe Machine

Table 3.1: Lathe machine specifications and capabilities

CNC Machine’s Qualification	Requirement of CNC machine
Size of front over apron	806mm
Over cross slide size	527mm
Size of over tailstock	584mm
Size of chuck	210mm
Diameter of cutting (maximum)	381mm
Length of cutting (maximum)	533mm

Capacity of bar	51mm
X-Axis	236mm
Z-Axis	533mm
Rapids on X axis	24.0mm
Rapids on Z axis	24.0mm
Thrust X (maximum)	18238 N
Trust Z (maximum)	22686 N
Rating value (maximum)	14.9Kw
Maximum of speed	4000 rpm
Maximum of torque	203 Nm @ 500 rpm
Nose value of spindle	A2-6
Bore’s spindle	Ø 88.9mm
Tools’ number	12 stations
Air capacity	113L/min, 6.9 bar
Capacity of coolant/lubricant	208 L

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3.2.2 Portable Surface Roughness

According to Basil (2015), surface roughness is one of the most critical factors in determining product quality. Surface roughness is formed through a dynamic, intricate, and process-dependent mechanism. In this experiment, the measurement of the surface roughness is the crucial part of producing a good quality workpiece. Therefore, a proper technique was needed in getting a higher surface finish whereby could help in maintaining the quality of the part produced. Mitutoyo (SJ 301) model equipment of portable surface roughness was used in this experiment as depicted in Figure 3.3 below. This equipment comes with a diamond stylus tip whereby it been used to give accurate value measurement of surface roughness. In addition, this portable surface roughness tester has huge LCD panel which allow an easy reading of the roughness value and automatically generate the graph for the surface roughness via the fast thermal profile speed printer which able to print out the result faster and clearly. Figure 3.4 below shows the receipt of the calibration of the portable tester. Based on the figure, the part that has been highlighted in the result receipt is the value motion of the stylus tip onto the machined surface whereby it consistently move at 0.8mm for five times throughout the desired location. As for figure 3.5, it shows the precision roughness specimen where it been used in calibrating this portable surface roughness tester.

Figure 3.3: Portable Surface Roughness (Mitutoyo (SJ 301)

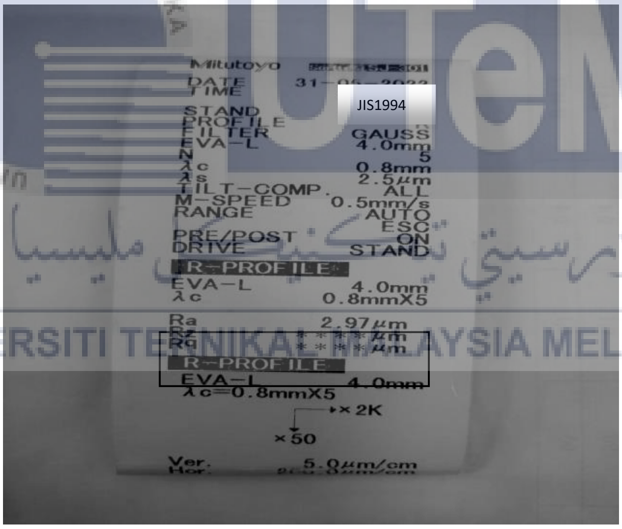

Figure 3.4: Receipt of calibration

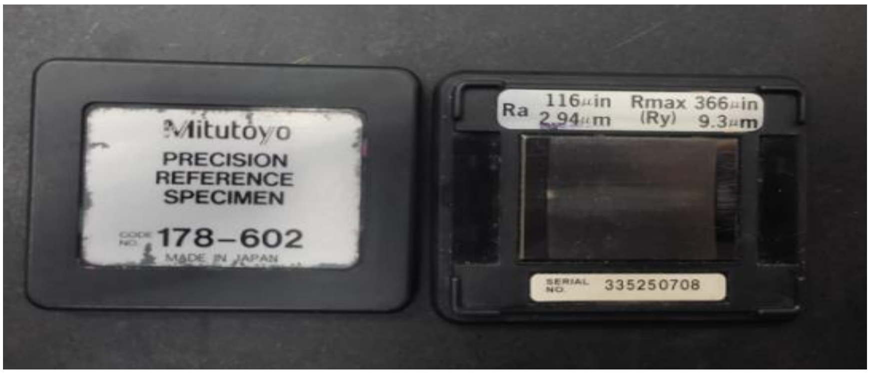

Figure 3.5: Precision Roughness Specimen of Mitutoyo SJ 310

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3.2.3 Procedure operation for Portable Surface Roughness Tester

i. Power been supply to the display unit by connecting the AC adaptor to the display unit from the plug. All the connection must be in good condition.
ii. Detector and the drive unit is connected to each other. Avoid from touching the stylus on the detector in order to prevent any error.
iii. Then, make sure the drive unit is connected to the display unit using the cable provided.
iv. After that, turn on the Power button which located at the right bottom of the display unit to make sure the profilometer has been energized.

3.2.4 Procedure for calibration of profilometer

i. Attained the precision of the roughness specimen.

ii. The precision roughness specimen has then been removed from the cover and placed it onto the work surface.

iii. Gently placed the drive unit/detector onto the indent of the precision roughness specimen to allow the detector stay still on the specimen.

iv. Level is used to make sure that the location detector/drive unit is parallel to the workpiece surface. Adjust the support foot to level up the detector/unit drive if necessary.

v. Press the "CAL" button on the touch screen of the display unit.

vi. Turn on the "Start/Stop" button of the touch screen display unit.

vii. Allow the detector to read the specimen and return to the original position.

viii. When the calibration of the resulting measurement on the specimen label is within 3% tolerance, push the "enter" button on the touch screen to accept the calibration.

3.3 Workpiece Material

Nimonic C-263 Alloy was chosen as the workpiece material for this machining operation. The diameter of the workpiece material that would be used in this experiment was 90mm and 150mm in length and come in a cylindrical shape. Figure 3.6 below showed the workpiece material for this experiment. Before installing the workpiece to the chuck, a center drill was applied to the workpiece's base. This was to reduce the vibration of the hole that was held by the tailstock.

Figure 3.6: Nimonic C-263 Alloy (cylinder bar)

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3.4 Cutting Tool

Because the material, which is a Nimonic alloy, whereby has been recognized for being difficult to cut, the cutting tool material chosen should be suited for high-speed machining in cryogenic CO_2 cooling treatment. The investigations will be conducted with a coated carbide insert with the ISO number CNGG 120408-SGF 1105. This cutting tool was provided by the Sandvick Company. PVD titanium aluminium nitride was used to coat this cutting tool (TiAlN). This cutting tool was chosen because it has sufficient hot hardness to resist high temperatures during machining of Nimonic C-263. Furthermore, this coated carbide is frequently employed in the machining sector. Effective machining of the workpiece can be done depending on the type of cutting tool material utilized during machining. Despite that, the cutting insert for the turning operation was depicted in figure 3.7 below. As for the geometry of the CNGG 120408-SGF 1105 coated carbide insert, it was shown in figure 3.8 while table 3.2 showed its geometry dimension.

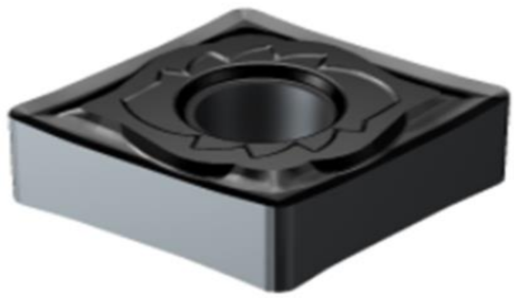

Figure 3.7: PVD coated carbide insert (Source: Sandvik Coromant)

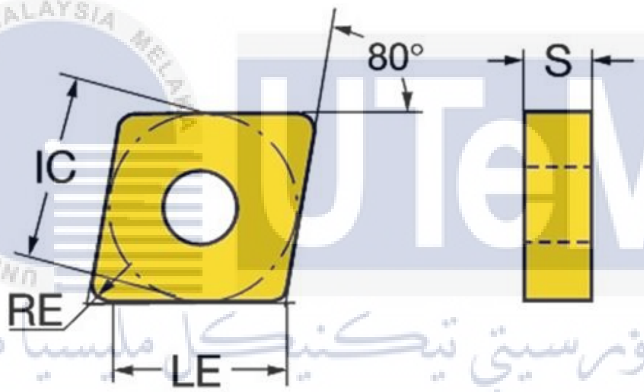

Figure 3.8: Illustrative configuration of PVD coated carbide (Source: Sandvik Coromant)

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Table 3.2: Measurement configuration of PVD coated carbide

Symbol	Character	Measurement (mm)
IC	Inscribed circle (diameter)	12.7
S	Insert thickness	4.7625
RE	Corner radius	0.7983
LE	Effective length of cutting edge	8.5

3.5 Tool Holder

The sort of holder employed for the experimental work was shown in Figure 3.10. The tool holder will be attached the PVD coated insert on it. Figure 3.9 depicts the illustrative picture for tool holder of model DCLNR 2525M 12 while the lists of the dimensions of the tool holder in detail was depicted in table 3.3 below. The tool holder was chosen with a negative rake angle (6°) since this value of rake angle may eager the longer life of the tool and allow it to produce a high-quality machined surface. It's also useful for cutting hard materials. Negative rake angles are also preferable over positive rake angles because they produce better edge security and are very suitable for this experiment.

Figure 3.9: Tool holder

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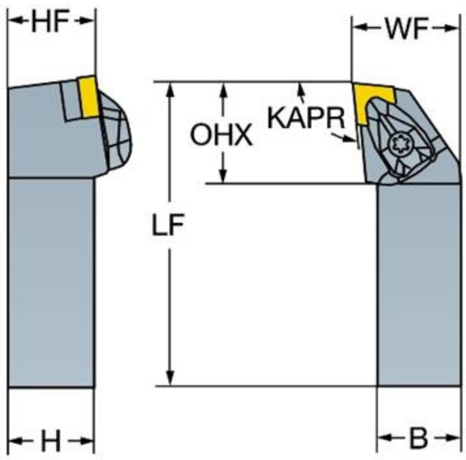

Figure 3.10: Illustrative picture of tool holder

Table 3.3: Measurement of tool holder

Dimension	Measurement
Rake angle	-6°
Functional length, LF	150mm
Tool cutting edge angle, KAPR	95°
Maximum overhang, OHK	32mm
Functional width, WF	32mm
Shank width, B	25mm
Functional height, HF	25mm
Shank height, H	25mm

3.6 Experimental Procedure

This section explains a few of the steps that must be undertaken before the experiments may be carried out. An initial preparation step, a cutting parameter experimentation phase, a working process phase, and a surface roughness measurement phase make up the technique.

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3.6.1 Initial Preparation

For initial preparations, the equipment and material used in this experiment were prepared. The equipment used for this machining process was the cutting tool, tool holder, and the material which was Nimonic C-263 Alloy. The equipment and machines like CNC Lathe and the scanning electron microscope were being tested before conduction the turning process. In addition to that, the coding for this CNC turning process and the recording of tool wear will be tabulated in a data and cutting time were set up.

3.6.2 Cutting Parameter

In selecting cutting parameter, the response surface methodology (RSM) method was established to organize the cutting conditions combinations. Box-Behnken was used in RSM to organize the seventeen runs of experiments. When the flank wear (Vb) exceeds 0.2mm, the turning operations were examined and suspended. The Ra value was then determined using a portable surface roughness sensor. The Ra value was taken thrice times for every twenty millimeters along the machine's surface until Vb = 0.2 millimeters. Table 3.5 below was the list of the parameters in turning the Nimonic C-263 Alloy. Table 3.6 below shows the result for the design of experiments using Box-Behnken. It shows that there would be 17 runs for these experiments.

Table 3.4: The level of parameters for turning Nimonic C-263

Parameters	**Level 1**	**Level 2**	**Level 3**
	-1	0	1
Feed Rate, f (mm/rev)	0.05	0.1	0.15
Cutting Speed, v (m/min)	60	90	120
Depth of cut, d (mm)	0.3	0.4	0.5

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Table 3.5: Design matrix of Box-Behnken

Run	Factor 1 Cutting Speed (m/min)	Factor 2 Feed Rate (mm/rev)	Factor 3 Depth of cut (mm)
1	1	-1	0
2	1	0	1
3	0	-1	1
4	0	0	0
5	0	-1	-1
6	1	0	-1
7	1	1	0
8	0	0	0
9	0	1	1
10	0	0	0
11	0	0	0
12	-1	1	0
13	-1	-1	0
14	0	0	0
15	-1	0	-1
16	-1	0	1
17	0	1	-1

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3.6.3 Experiment Procedure

Firstly, for the workpiece, the Nimonic alloy bar was cut to 90 mm x 150 mm cut using a wire cut machine. Center drilling was produced in the workpiece's core section before the workpiece was inserted into the machine's chuck. The technique of the chuck holding of the workpiece at the back while the tailstock was kept in the front was simplified by this approach. During machining, the proper location of the workpiece would reduce the influence of vibration or wobble on the workpiece. The experiment was set up as shown in figure 3.13 below.

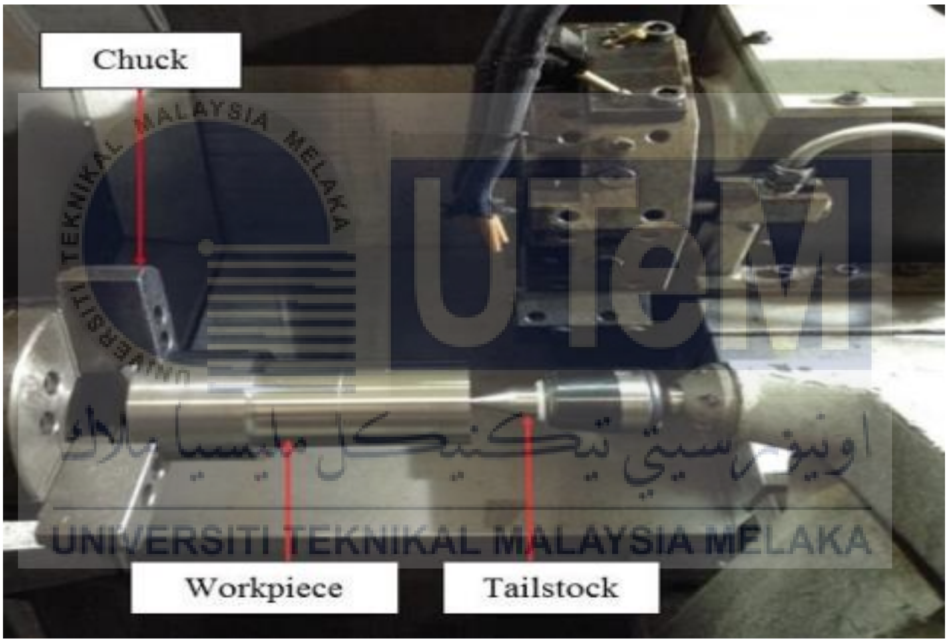

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Figure 3.11: Setting of the workpiece on lathe machine

Then, the outer layer of the Nimonic C-263 bar will be removed in extracting of any surface flaws or wobbling that could affect the machining result. Then, the experiment was repeated with a different cutting tool and a different cutting parameter. The tests were designed using the Box-Behnken method. By using a toolmaker microscope, the insert was withdrawn from the tool holder at 20 mm intervals and assessed tool wear on the flank face. On the insert, the value of flank wear was determined and noted. As for the life of the cutting tool, it was computed using Microsoft Excel and checked with a stopwatch. The experiment was then repeated until the wear value reaches 0.2 mm using the same tools. For the other parameters, the procedure was repeated. Figure 3.13 below depicted the overall experiment flow chart.

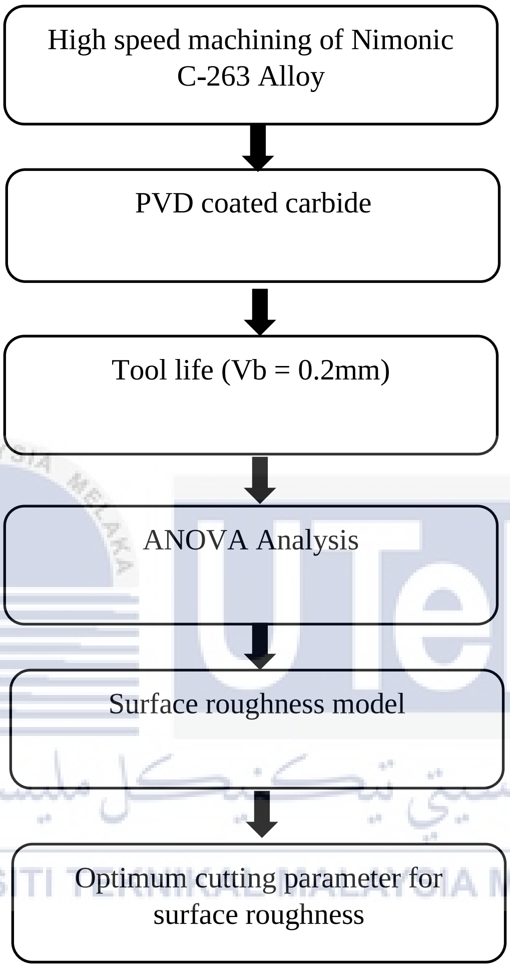

Figure 3.12: Flowchart of the experiment

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will briefly exhibit the result that has been executed from the experiment and data that has been gained will be discussed. The graph has been plotted in order to represent the result of the experiment in addition to showing the relationship between the cutting speed, feed rate, and the depth of cut.

4.2 Surface Roughness

Surface roughness plays a crucial part in the manufacturing industry, in assessing and determining the quality surface of the fabricated products. Surface roughness extremely influences the practical description of products like friction, fatigue, lubricants, a reflection of light, coating as well as wear resistance. Surface roughness is not only an element in quality but is also the last phase in managing achievement and the processing charge. Microstructure, hardness, surface roughness, and residual stresses, among other surface qualities of machined items, are among the most essential elements determining a product's stability and usefulness (Rotella et al., 2014). In this experiment, surface roughness was measured for five times at the numerous locations alongside the machined surface.

Upadhyay et al., (2013) in their study regarded that generally the surface roughness was measured through machinability after machining process was completed. However, this kind of technique may cause extra cost due to improvement work on the quality of the part product. Surface finish is important for component service life and assures the high dependability of sensitive aircraft components. As a result, process parameters must be optimized for the optimum surface finish (Ramana & Aditya, 2017). Table 4.1 and 4.2 depicted below shown the results of 17 experimental runs for each coolants method. Results obtained was the surface roughness (Ra) values of turning Nimonic C-263 Alloy using PVD coated carbide in dry and flooded conditions. The impact of surface roughness on each experimental run was investigated utilizing a Mitutoyo SJ 301 Portable Surface Roughness Tester. For each parameter, surface roughness value was measured five times, and the average surface roughness was determined as the output response for this research.

For each parameter, the surface roughness findings were calculated based on the average of the data with constant measurement trends. According to the most findings, the surface roughness value for machined part does not follow a consistent pattern during the machining process. This is because the machining parameters, such as feed rate, cutting speed, and depth of cut, have an impact on the surface roughness value. However, the pattern of surface roughness value is influenced by cutting tool wear. The surface roughness limits are taken from ANSI/ASME B46.1–2009 class N7, which indicates that the allowable range of Ra values for aerospace and aeronautical applications is 0.8 to 1.6 µm. As a result, only surface roughness (Ra) values of up to 1.6µm are acceptable.

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4.2.1 Flooded Machining Condition

At low and medium cutting parameters, a flood cutting environment provides proper lubrication between tool chips, which decreases force and harmful built-up edge creation, resulting in low surface roughness. Another rationale for minimizing surface roughness is the reduction of built-up edge development at high speeds.

Moreover, in flood coolant, it was discovered that the Ra value was quite high at the start of the cutting speed, but steadily decreased as the tool's life progressed. The new tool's edge has a sharp tapered surface and a short contact area with the machined surface, which caused that scenario. Furthermore, these sharp edges scrape the machined area's surface, resulting in a rough surface quality. When a cutting tool becomes blunt, the contact surface increases and the surface roughness value decreases. Furthermore, when machining at high speeds, the cutting zone temperature rises, it will soften the material and lowering the average surface roughness value (Kumar et al., 2017).

Figure 4.1 below is constructed the average of surface roughness (Ra) for flood condition. For every run have different parameter. There are three level of the machining parameter. The highest value of cutting speed is 120 m/min, followed by 90 m/min and the lowest is 60 m/min. As for the feed rate, the highest value is 0.15 mm/rev followed by 0.1 mm/rev and lastly 0.05 mm/rev. The highest value for the depth of cut is 0.5mm, followed by 0.4mm and the smallest is 0.3mm. Surface roughness value is the desired response to be obtained in this experiment. The smallest value of Ra in flood condition was 0.2563µm with the machining parameter 90m/min of cutting speed, 0.05mm/rev of feed rate and 0.5mm depth of cut. While the largest value of Ra for flood condition was 1.309µm with the cutting parameter of 120m/min cutting speed, 0.15mm/rev feed rate, and 0.4mm depth of cut.

The smallest the value of surface roughness, the best surface finish will be produced which lead to the superior quality of product. In the context of surface roughness, the technique applied was “the smaller, the better.” The smallest surface roughness value is the desired value for this experiment. When flooded coolant was used instead of dry cutting, the amount of attached material was significantly reduced, this showed that the Ra value in flood condition is smaller than in dry cutting.

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Table 4.1: Result of Surface Roughness Value in Flood Condition

Run	Factor 1 A: Cutting Speed (m/min)	Factor 2 B: Feed rate (mm/rev)	Factor 3 C: Depth of Cut (mm)	Average Surface Roughness (µm)
1	60	0.1	0.3	0.5499
2	120	0.1	0.3	0.8993
3	90	0.15	0.3	0.9096
4	90	0.1	0.4	0.5587
5	90	0.15	0.5	0.9867
6	60	0.1	0.5	0.5469
7	90	0.1	0.4	0.6071
8	90	0.1	0.4	0.4196
9	90	0.05	0.5	0.2563
10	120	0.1	0.5	0.6004
11	60	0.15	0.4	0.8423
12	60	0.05	0.4	0.5116
13	90	0.1	0.4	0.4639
14	90	0.1	0.4	0.5289
15	120	0.15	0.4	1.309
16	120	0.05	0.4	0.3993
17	90	0.05	0.3	0.434

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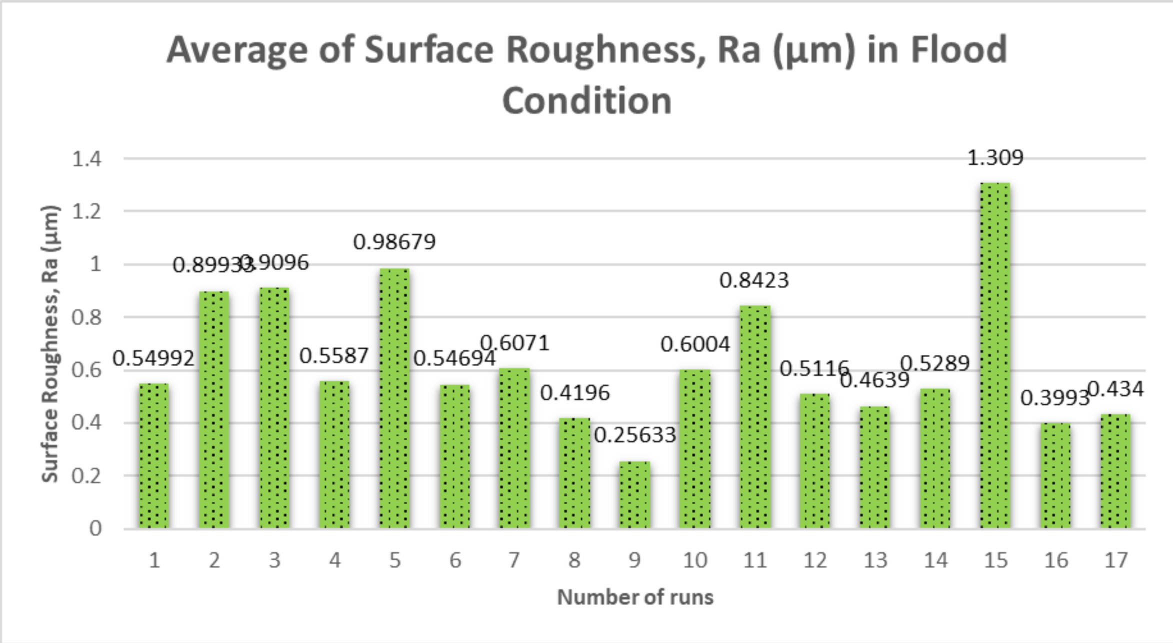

Figure 4.1: Average of Surface Roughness in Flood Condition

4.2.2 Dry Machining Condition

Table 4.2 depicted below is the average of surface roughness (Ra) for dry condition. The best value of average surface roughness for dry condition was 0.414µm with the machining parameter of 120m/min cutting speed, 0.15mm/rev feed rate, 0.4mm depth of cut while the highest value of surface roughness for dry condition was 1.199µm at cutting parameter of 90m/min cutting speed, 0.05mm/rev feed rate and 0.3mm depth of cut. Based on the result obtained, the Ra value in dry conditions, it can be concluded that the surface roughness value for machined surface does not follow a consistent pattern during the machining process. This is due to the fact that the Ra value is influenced by the machining parameters.

The machining parameter used in this experiment is same as in the flood condition. Meanwhile, based on the result of surface roughness in figure 4.2, it was found that the surface roughness value in dry condition quite greater rather in flood coolant for the whole result. This is because high temperatures in the machining zone of dry machining can result from higher order friction between the tool and the workpiece, as well as between the tool and the chip. This high temperature in the machining zone will eventually result in

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workpiece dimensional errors and tool wear issues. During dry cutting, the maximum rate of adherence of the work material to the tool was observed. When the machining speed was increased from 60 to 120 m/min, the material adherence was seen all over the tool surfaces such as flank, rake, and clearing surfaces.

Table 4.2: Result of Surface Roughness Value in Dry Condition

Run	**Factor 1 A: Cutting Speed (m/min)**	**Factor 2 B: Feed rate (mm/rev)**	**Factor 3 C: Depth of Cut (mm)**	**Average Surface Roughness (µm)**
1	60	0.1	0.3	0.512
2	120	0.1	0.3	0.7038
3	90	0.15	0.3	0.7821
4	90	0.1	0.4	0.4874
5	90	0.15	0.5	1.1969
6	60	0.1	0.5	0.7563
7	90	0.1	0.4	0.5098
8	90	0.1	0.4	0.5767
9	90	0.05	0.5	0.555
10	120	0.1	0.5	0.7248
11	60	0.15	0.4	0.91
12	60	0.05	0.4	0.605
13	90	0.1	0.4	0.4768
14	90	0.1	0.4	0.5804
15	120	0.15	0.4	1.199
16	120	0.05	0.4	0.4885
17	90	0.05	0.3	0.414

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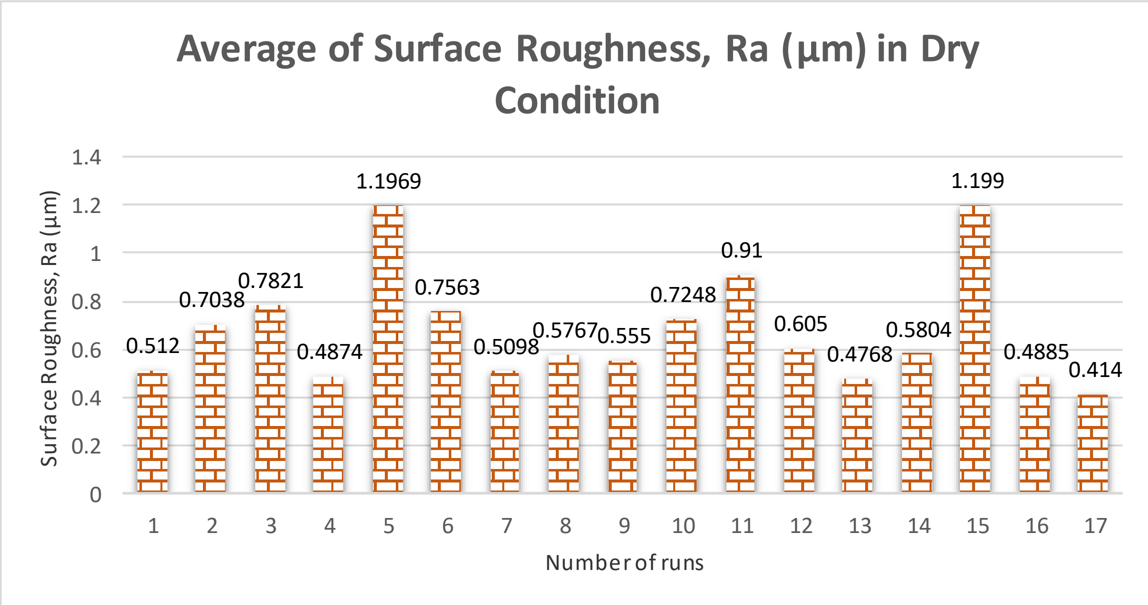

Figure 4.2: Average of Surface Roughness in Dry Condition

4.2.3 Comparison of Surface Roughness under Flooded and Dry Conditions

In most situations, increasing cutting speed improved average surface roughness values because dry machining generates elevated temperatures in the cutting zone, a result, microchip material adheres to the tool insert's cutting edge, resulting in a built-up edge that compromises the surface integrity even more. The inherent trend of turning is that increasing the feed rate degrades the surface roughness because greater feed results in increased cross section and volume deformation. During the research of surface roughness, the feed rate and cutting speed in turning were discovered to be critical characteristics. However, compared to cutting speed, the feed rate appears to have a bigger impact on surface integrity.

In addition, Yashwant Bhise & Jogi, (2022) in their study stated that in dry cutting, the surface roughness rises when the feed rate is increased while the spindle speed remains constant. The study also discovered that when flood coolant used, the Ra value is lower than when cutting in dry. This means that the cutting fluid has a high thermal conductivity and is good in reducing heat created during the process. Additionally, during machining at high speeds, the cutting zone temperature rises, softening the material and lowering the average surface roughness value. Figure 4.3 below revealed that the comparison of surface roughness value in dry and flood conditions.

Based on the result, it showed that the surface roughness values (Ra) of the machined surface in dry condition is much higher than in flooded condition for most runs. This result can be attributed to the life performance of cutting tool used, where a rapidly worn cutting tool will result in a poor machined surface. This was happened due to the deformation on the flank surface as well as the adhesion of the workpiece material to the cutting tool have contributed to the roughness of the machined surface. Ra values are lower under flooded conditions than in dry cuttings. This suggested that the cutting speed has a high thermal conductivity and specific heat effectiveness in terms of minimizing heat created during the machining process. Additionally, in dry cutting, it has been discovered that as the feed rate is increased at a constant spindle speed, the surface roughness increases. Ra begins to develop at the same rate, eventually reaching its highest level, and so on for the other spindle speeds. However, as the spindle speed increases, the surface roughness decreases. At the same time, the feed rate (Ra) begins to drop, eventually reaching its lowest value (Jodia, 2018).

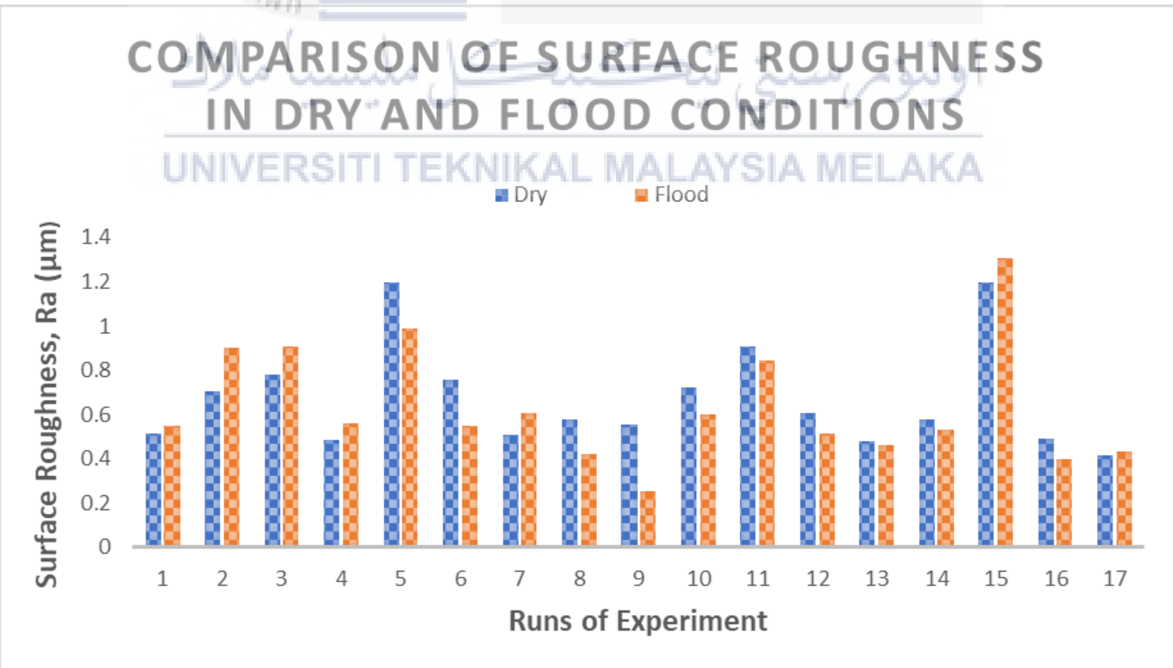

Figure 4.3: Comparison of Surface Roughness in dry and flood conditions

4.2.4 Comparison of Surface Roughness between cutting parameters

In machining this Nimonic C-263 Alloy, the surface roughness value will definitely influence by the cutting parameters which are cutting speed, feed rate and depth of cut. Figure 4.4, 4.5 and 4.6 attached below show the changes in machining parameters on surface roughness of turning Nimonic C-263 Alloy in both flood and dry conditions. Figure 4.4 revealed the surface roughness value at constant cutting speed of 120 m/min, depth of cut (0.4 mm) with the various cutting parameter of feed rate. The cutting speed was kept constant in comparing the effect of feed rate on the surface roughness of the machined surface. From this figure, it can be analyzed that the surface roughness value for dry condition is increased from 0.4885 µm to 1.199 µm. As for the surface roughness value in flood condition, the value is also increased from 0.3993 µm to 1.309 µm. Result depicted below shows that the surface roughness is directly proportional to feed rate which also been supported by (Hosseini Tazehkandi et al., 2014)

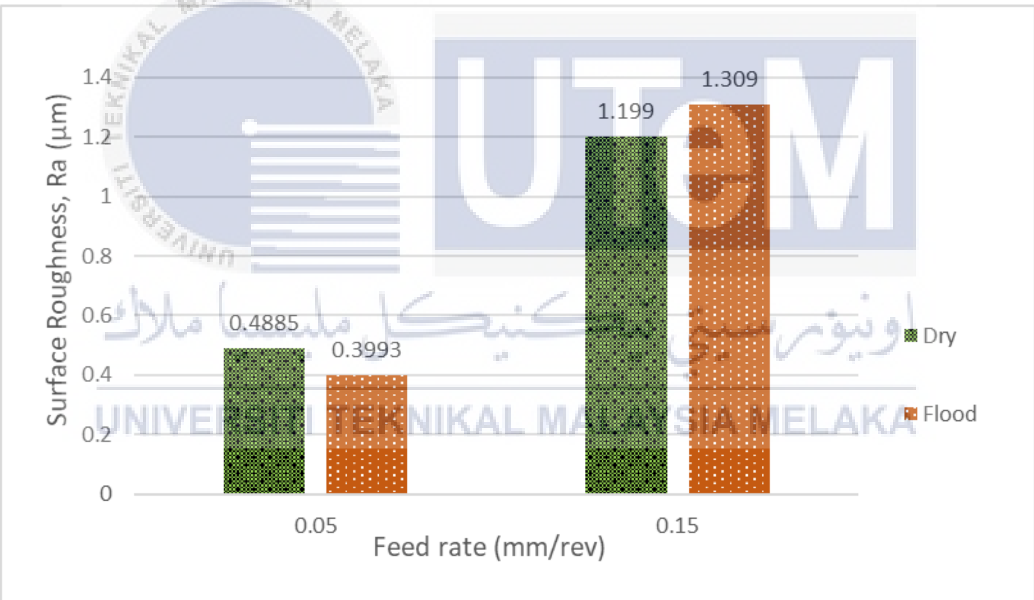

Figure 4.4: The surface roughness value at constant cutting speed (120 m/min), depth of cut (0.4 mm) and various feed rate

Figure 4.5 obtained below shows the effect of various cutting speed towards the surface roughness value in both dry and flood conditions. Based on the figure, the surface roughness value in dry condition is decreased from 0.605 µm to 0.4885 µm when the cutting speed increased from 60 m/min to 120 m/min. Furthermore, for the flood condition, the surface roughness value is decreasing from 0.5116 µm to 0.3993 µm. This proved that cutting speed is inversely proportional to the surface roughness

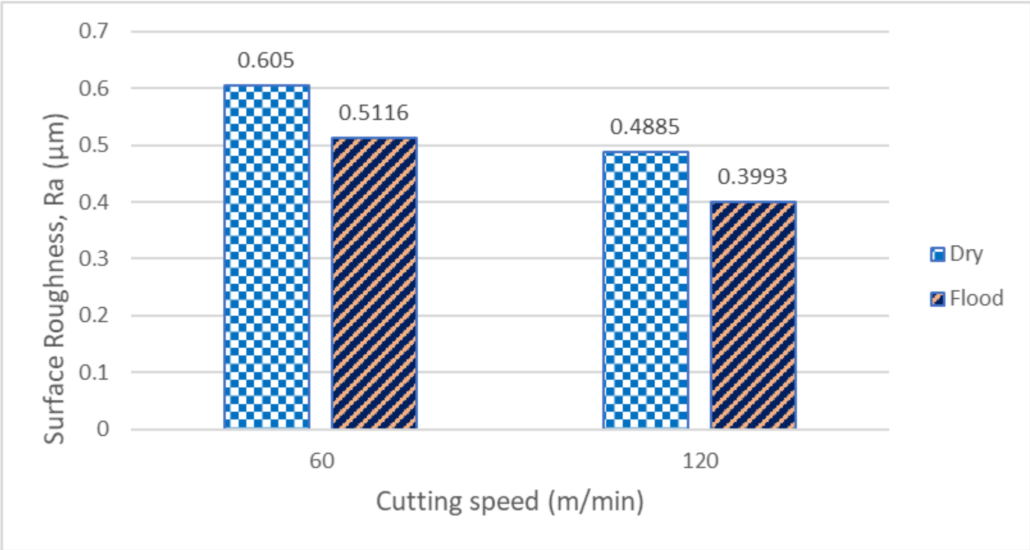

Figure 4.5: The surface roughness value at constant feed rate (0.05 mm/rev), depth of cut (0.4 mm) and various of cutting speed

Figure 4.6 attached below show the bar graph of surface roughness versus the depth of cut in both flood and dry conditions. The surface roughness value in dry conditions, is drastically increased from 0.7821 µm to 1.1969 µm at 0.3 mm and 0.5 mm depth of cut. Meanwhile, in flood coolants, the surface roughness value being decreased from 0.9096 µm to 0.9867 µm at the same value depth of cut as in dry condition. Both result show that the depth of cut is also inversely proportional to the surface roughness.

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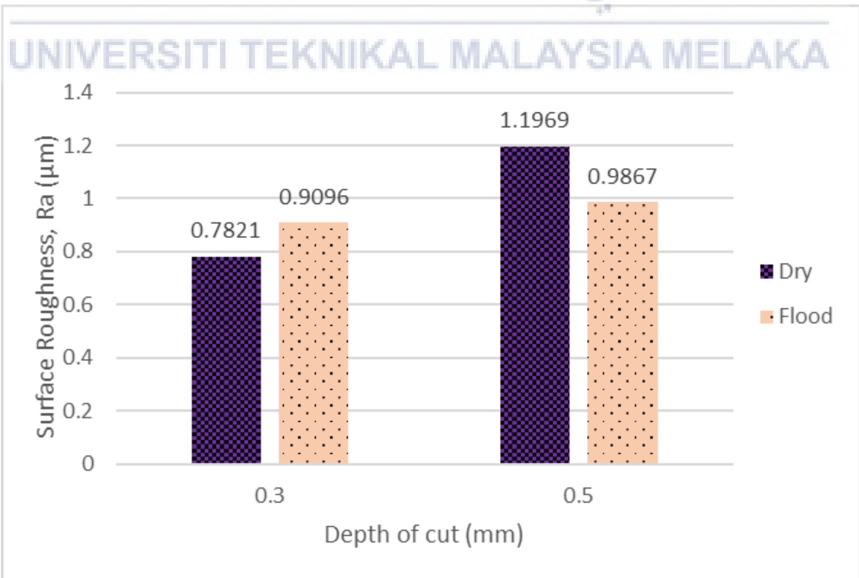

Figure 4.6: The surface roughness value at constant cutting speed (90 m/min), feed rate (0.15 mm/rev) and various depth of cut

4.2.5 Effect of Machining Parameters on Surface Roughness in Flood Condition

This surface roughness value is quite high at the start of cutting, then steadily lowers as the cutting duration approaches the tool point's mid-life stage. This is due to the sharp tapered surface of the new tool’s surface edge and the little contact area it has with the workpiece surface. Furthermore, this sharp edge will scrape the machined surface, resulting in a poor machined surface quality. When the sharp edge of this tool begins to dull, the area of contact increases and the surface roughness value steadily falls. However, as cutting progresses, the value of this surface roughness rises until it approaches the average wear value, Vb=0.2mm at the end of the tool’s life. This is caused by the workpiece material adhering to the edges, rib surface, and tool used.

When machining Nimonic alloy in a dry environment, cutting parameters such as cutting speed, feed rate, and depth of cut will definitely affect the surface roughness. Figures 4.4, 4.6, and 4.8 depicted below shows the effects of changing the cutting parameter on surface roughness in the dry machining. Figure 4.7 illustrates the surface roughness value at 120 m/min cutting speed, 0.4 mm depth of cut and various of feed rate. The Ra value raised up from 0.3999 µm to 1.309 µm. Surface roughness value increased when feed rate also arising from 0.05 mm/rev to 0.15 mm/rev. A study of surface roughness found that when feed rate rose, roughness increased in a general upward trend. All in all, the feed rate was shown to be the most important factor in achieving lower surface roughness, followed by cutting speed and the depth of cut. Result obtained shows that when the feed rate is increased, the surface roughness also being increased and also been supported by Ezilarasan et al., (2011a). This could be due to the presence of a hard carbide component in the workpiece.

Meanwhile, as the feed rate is increased, the surface roughness value also being increases. The gradient line of the graph of Ra against the feed rate is large in the following figure 4.8, indicating that the feed rate is particularly important to the surface roughness value. The feed rate factor has a greater influence on the value of surface roughness than the cutting speed factor and the depth of cut factor in most recent research. When the feed rate is reduced, the machined surface quality improves. This is due to the fact that increased friction between the workpiece and the tool’s face interface raises the temperature in the cutting zone indirectly. This high cutting temperature weakens the microstructure of the machined surface while increasing the roughness as well. This high temperature also promotes the formation of a built-in layer (BUL) on the rib surface, which might cause the tool tip to deviate from its initial route, resulting in machined surface roughness.

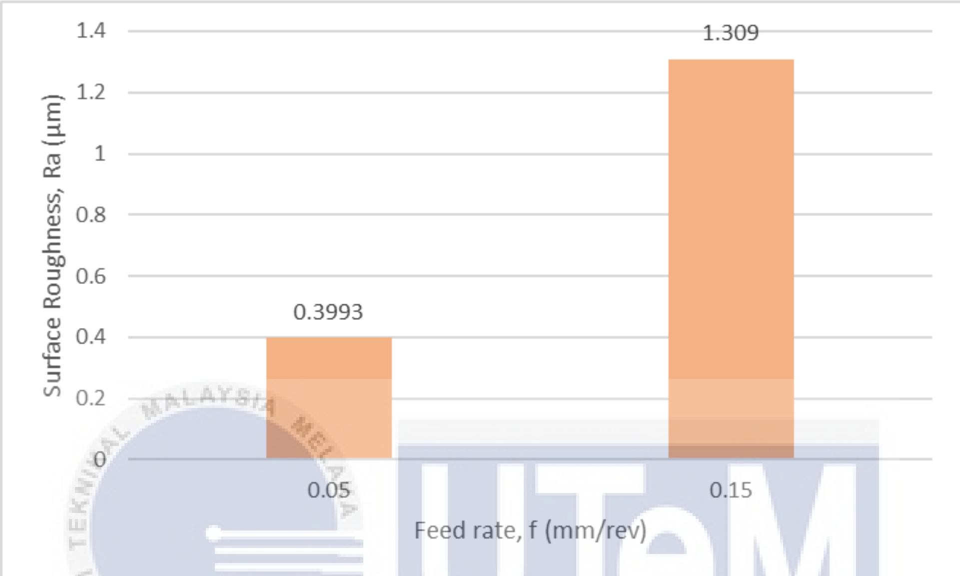

Figure 4.7: The surface roughness at 120 m/min cutting speed, 0.4 mm depth of cut and various feed rate (Flood Condition)

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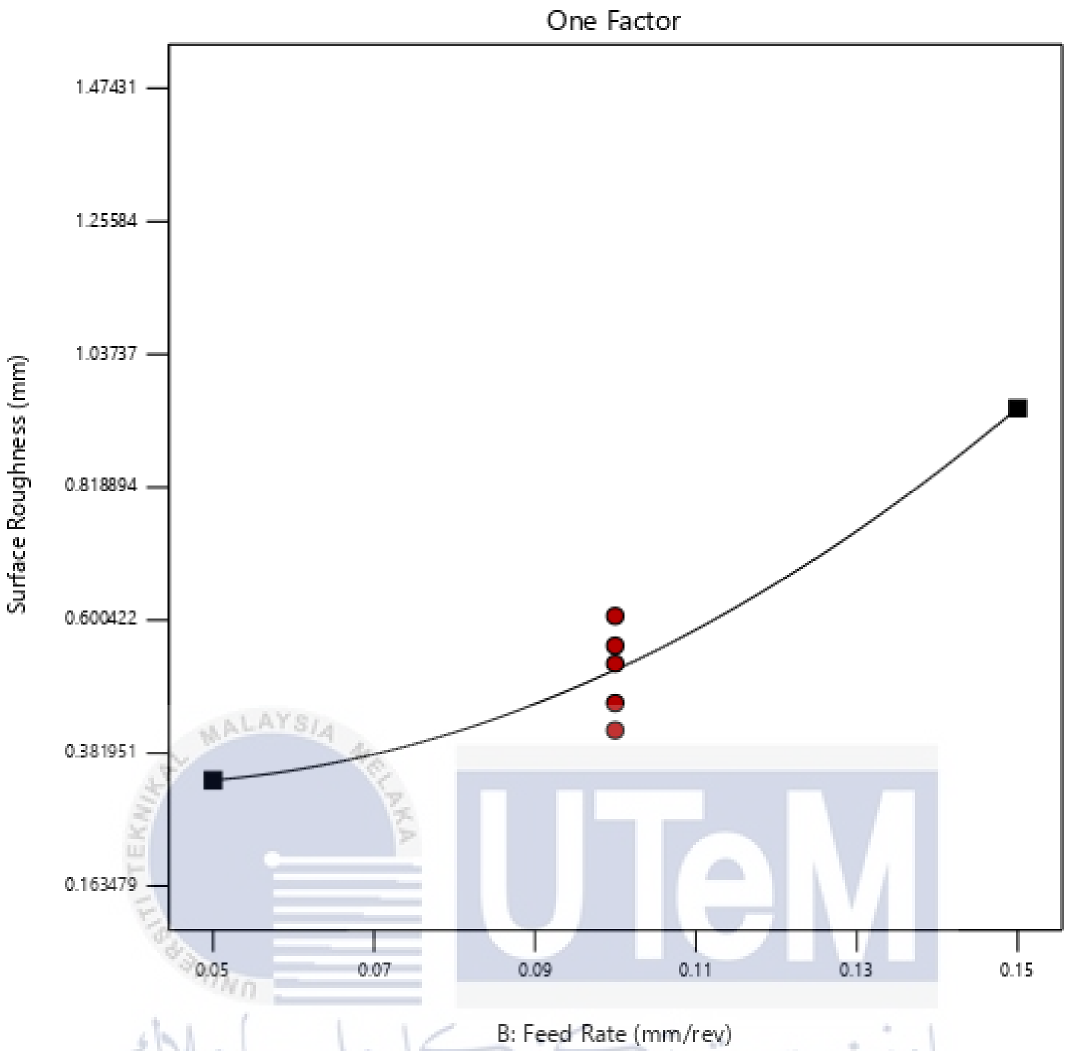

Figure 4.8: Variation in feed rate and surface roughness behavior (Flood Condition)

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Result obtained in the figure 4.9 below discovered that the surface roughness was progressively decreased from 0.5116 µm to 0.3999 µm at feed rate of 0.05 mm/rev and 0.4 mm depth of cut. The surface roughness value shown to be gradually decreasing when the cutting speed was increased. Therefore, this result illustrated that the cutting speed gave a comparable result. An increase in cutting speed had a huge impact on the surface roughness that resulted (Yashwant Bhise & Jogi, 2022).

High machined surface roughness values were found at low cutting speeds in a graph of machined surface roughness. However, as the cutting speed is increased, the machine's surface roughness value reduces, resulting in a smooth surface, as shown in figure 4.10 below, which depicts the connection between the surface roughness value and the cutting speed factor. Clearly, as the cutting speed increases, the surface roughness lowers, indicating that the quality of the machined surface improves. This is because high-speed machining has a high material loss rate, low cutting force, and better precision and quality of the finished surface, among other benefits. In terms of smoothness and level of surface roughness, machined surface outcomes at various cutting speeds are quite variable. When speed machining is used, the machined surface has a low roughness because there are fewer imperfections on the surface. As stated on the one factor plot graft, the surface roughness value was decreased from cutting speed of 60 m/min to 90 m/min. Meanwhile, when the cutting speed start to increase to 120 m/min, the surface roughness value pattern turned out to be in increasing trend. This is due to the varying speeds which influence the thermal softening of the machined surface and this scenario also been supported by (D'Addona et al., 2017). Despite of that, the surface roughness value in flood condition is showing a good range at medium value cutting speed which is 90 m/min.

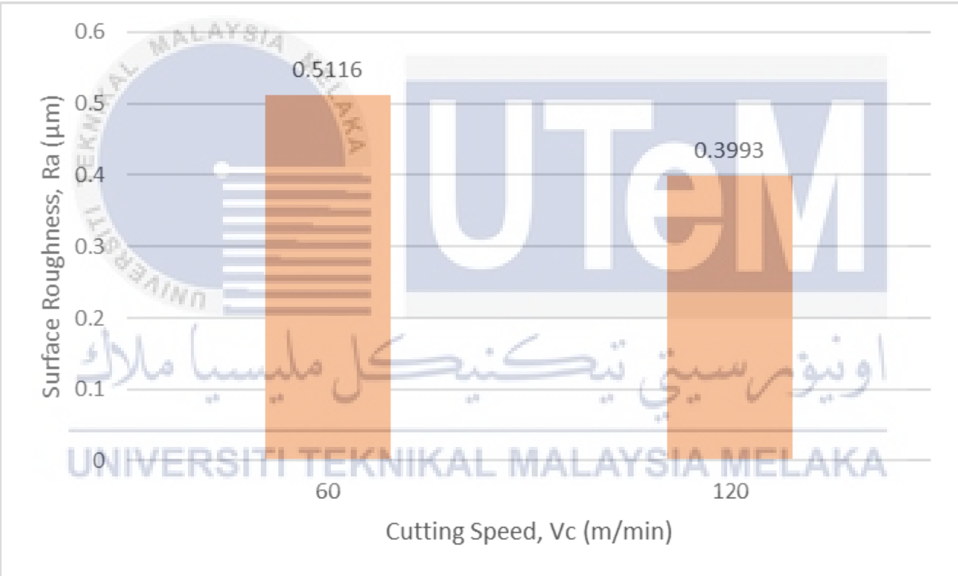

Figure 4.9: The surface roughness at feed rate of 0.05 mm/rev, 0.4 mm depth of cut and various cutting speed (Flood Condition)

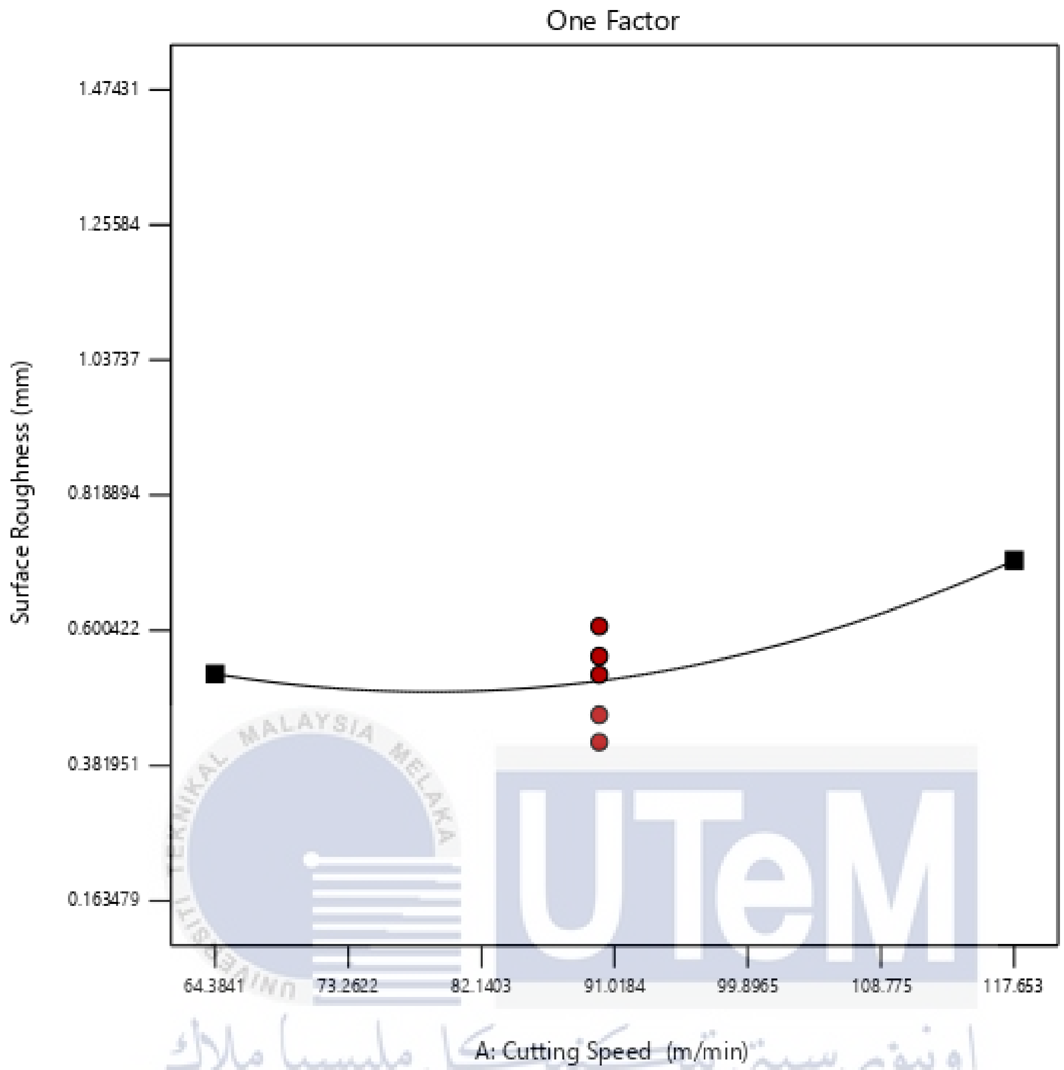

Figure 4.10: Variation in cutting speed and surface roughness behavior (Flood Condition)

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Depicted below is figure 4.11 showed the value of surface roughness at constant 120 m/min cutting speed, 0.1 mm/rev feed rate and various depth of cut. From figure 4.8, the result observed that the surface roughness value increases from 0.9096 µm to 0.9867 µm with the increasing of the depth of cut from 0.3mm to 0.5mm. High cutting depths will result in a poor surface finish, as demonstrated by this experiment. Furthermore, the shear angle and heat impacted zone were determined by the depth of the cut. When the cutting depth raises the shear angle and heat affected zone, deposition on the rake face of a tool would be happened. If the depth of cut value generated are large, it will produce a larger contact surface area between the workpiece and the tool used whereby it will influence the cutting force of the machining process.

Apart from that, it can be seen that increasing the depth of cut resulted in a much worse surface finish and obtained in figure 4.12. This is happened due to the fact that the depth of cut is connected to the cutting force operating on the workpiece and cutting tool during the machining process, which causes deformation in the workpiece and tool, as well as pressure and deflection on the machined structure, resulting in poor surface quality. Surface roughness increased as the feed rate was increased at all cutting depths (Kannan et al., 2019). This could be due to the presence of a hard carbide component of the workpiece. Once the depth of cut is arising from 0.3 to 0.5 mm, the surface roughness rose as well. The deeper the cut, the larger the contact zone among the tool and the work material, and therefore the cutting force. Similar findings and viewpoints are reinforced by (Sivaiah & Chakradhar, 2019), who found that the value of surface roughness increases as the depth of cut increases.

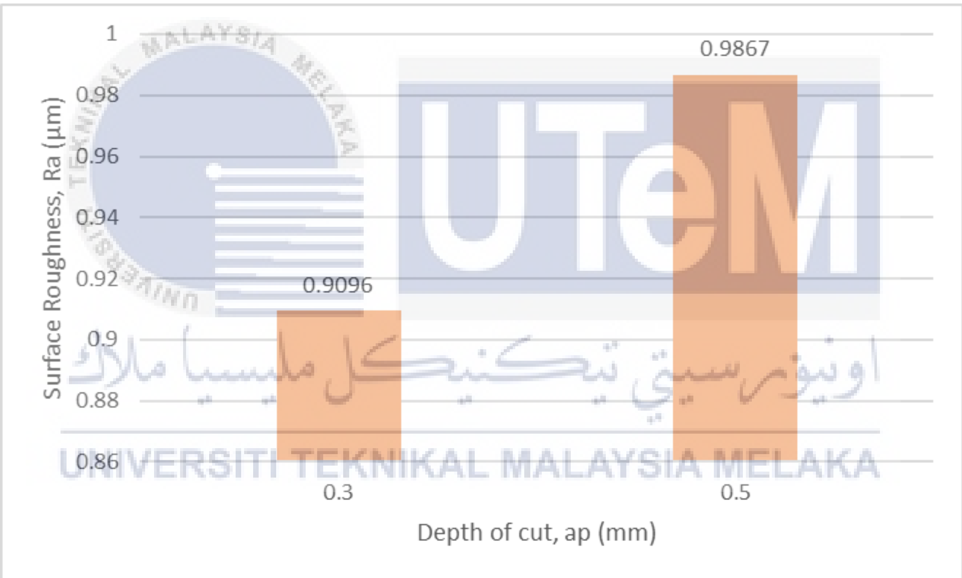

Figure 4.11: The surface roughness at 120 m/min cutting speed, feed rate of 0.1 mm/rev and various of depth of cut (Flood Condition)

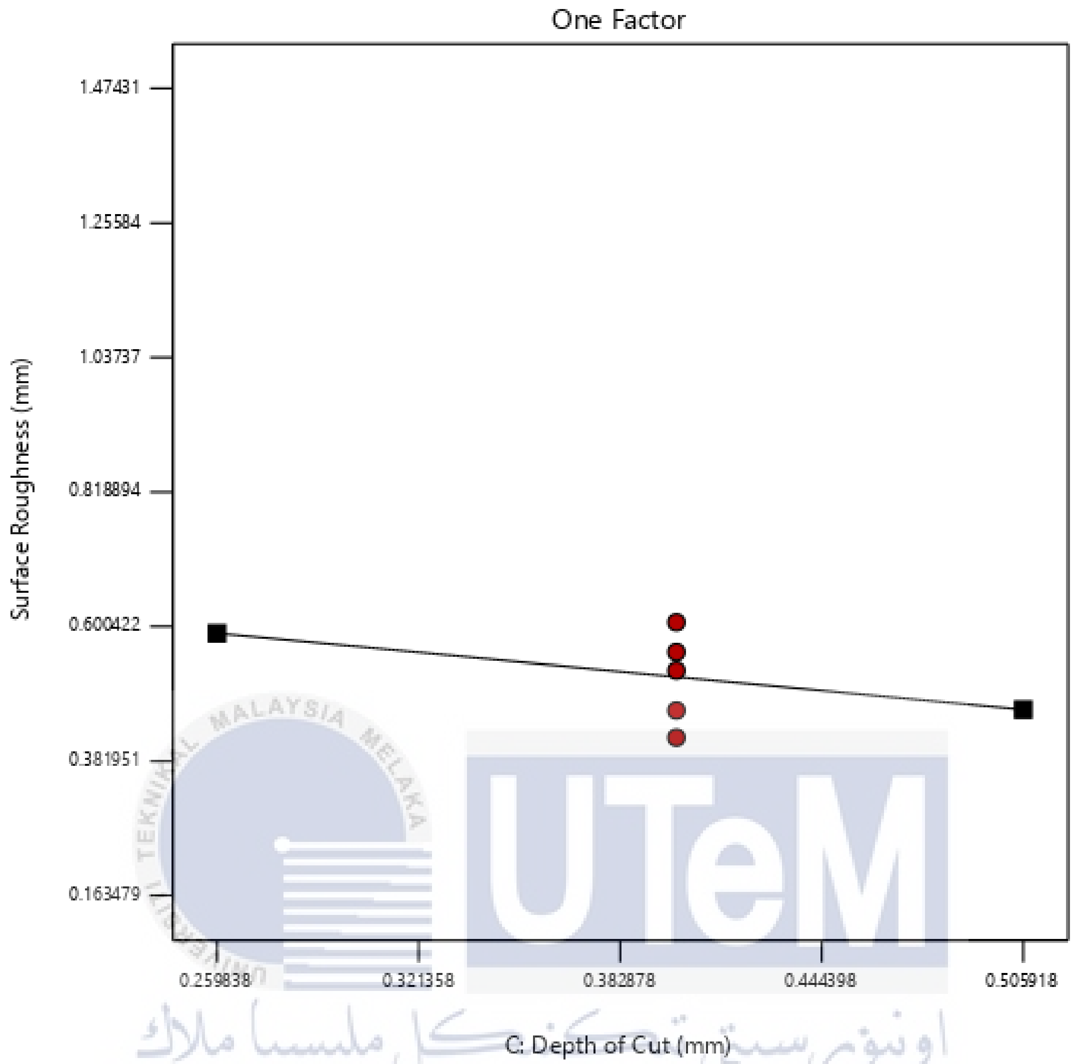

Figure 4.12: Variation in depth of cut and surface roughness behavior (Flood Condition)

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4.2.6 Effect of Machining Parameters on Surface Roughness in Dry Condition

Figure 4.13 depicted below revealed that the trend of surface roughness measurement drastically increased from 0.605 µm to 0.91 µm once the feed rate arising from 0.05 mm/rev to 0.15 mm/rev. These results observed at the cutting speed of 60 m/min and depth of cut of 0.4 mm. According to these observed results, feed rate changes have a significant impact on surface roughness. In terms of smoothness and level of surface roughness, machined surface outcomes at various cutting speeds are quite variable. When speed machining is used, the machined surface has a low roughness because there are fewer imperfections on the surface. The relationship between surface roughness and feed rate, f, is depicted in figure 4.14. It is obvious that as feed rate increases, surface roughness also increase, indicating improved machined surface quality. This showed that when the feed rate was increased, the surface roughness value also increased, furthermore, value of feed rate was directly proportional to the surface roughness value. Meanwhile, the surface roughness value obtained at a low feed rate was the smallest. This occurred as a result of increased friction between the workpiece and the cutting tool, which increased the temperature at the cutting zone, causing damage to the microstructure of the machined surface structure (Sun et al., 2018).

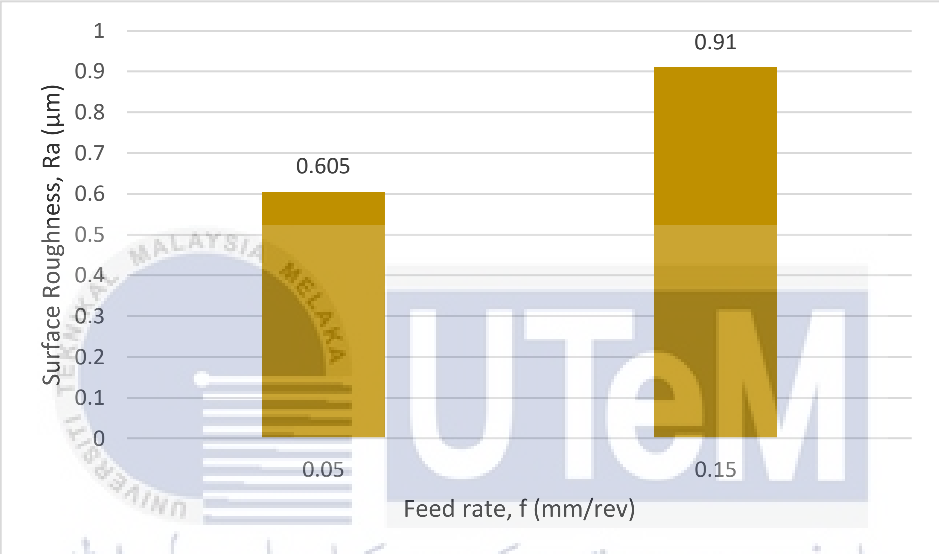

Figure 4.13: The surface roughness at 60 m/min cutting speed, 0.4 mm depth of cut and various feed rate

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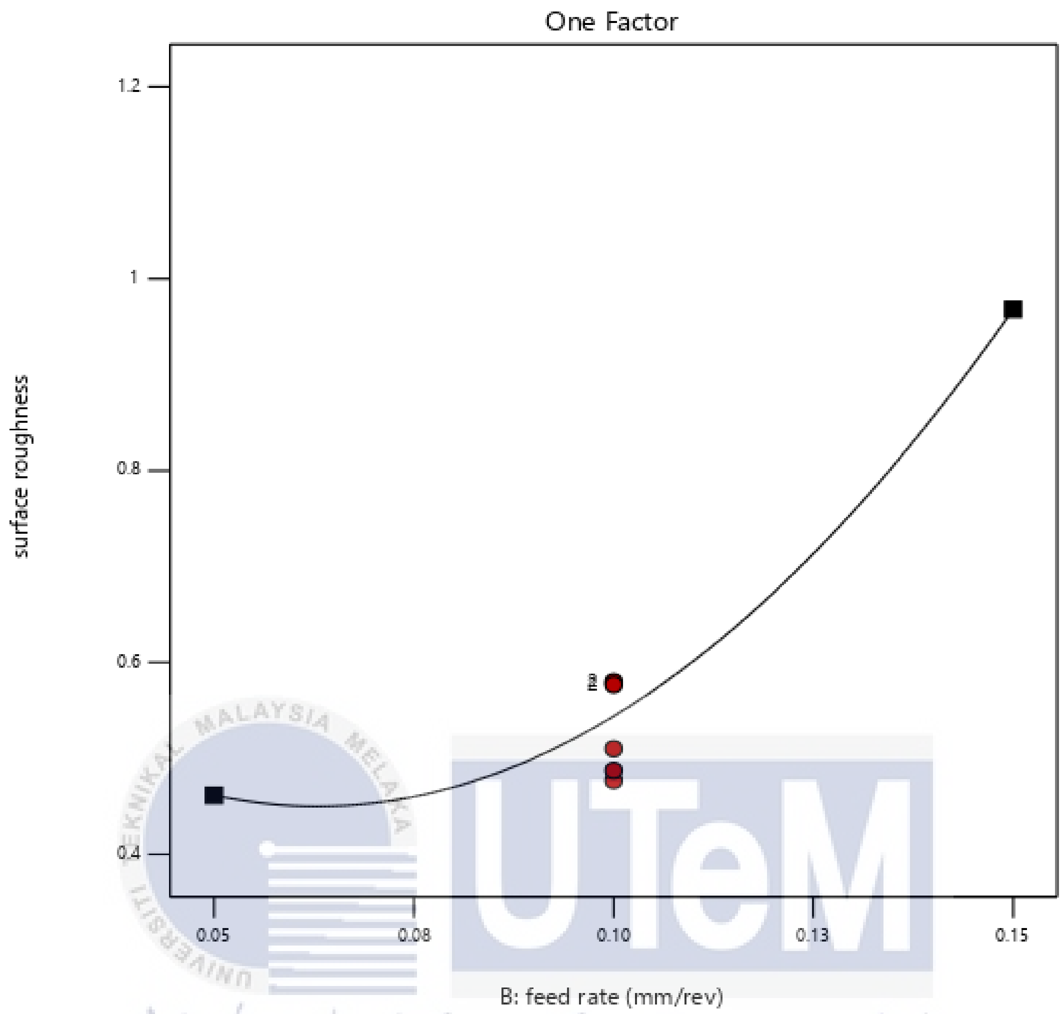

Figure 4.14: Variation in feed rate and surface roughness behavior

The result obtained in figure 4.15 below is the value of surface roughness at cutting feed rate of 0.1 mm/rev, 0.3 mm depth of cut and at variant value of cutting speed. At cutting speed of 60 m/min, the Ra value is 0.7248 µm. But when the cutting speed arising to 120 m/min, the Ra value starts to decrease to 0.4768 µm. When cutting speed is raised, surface roughness decreases as well, resulting in a superior surface finish. The connection of the surface roughness value and the cutting speed cutting parameter, Vc, was demonstrated in the figure 4.16. The surface roughness value reduced when the cutting speed was raised, resulting in a good surface finish. This occurred because of the rapid cutting speed, which resulted in a high rate of removal. Same as in the flood condition, machining in dry condition also showed that the surface roughness value is in a good range when the cutting speed is at medium level (90 m/min).

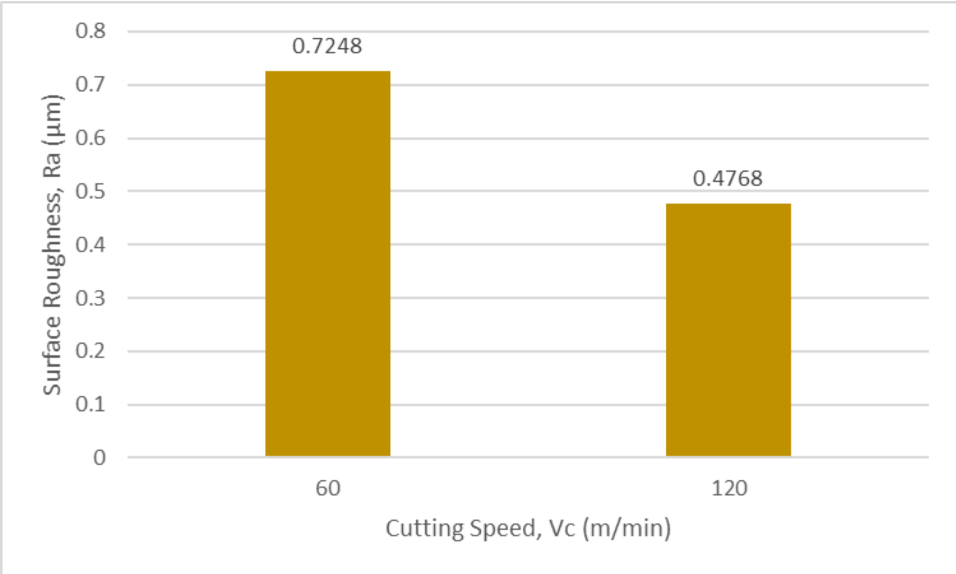

Figure 4.15: The surface roughness at 0.1 mm/rev feed rate, 0.3 mm depth of cut and various cutting speed

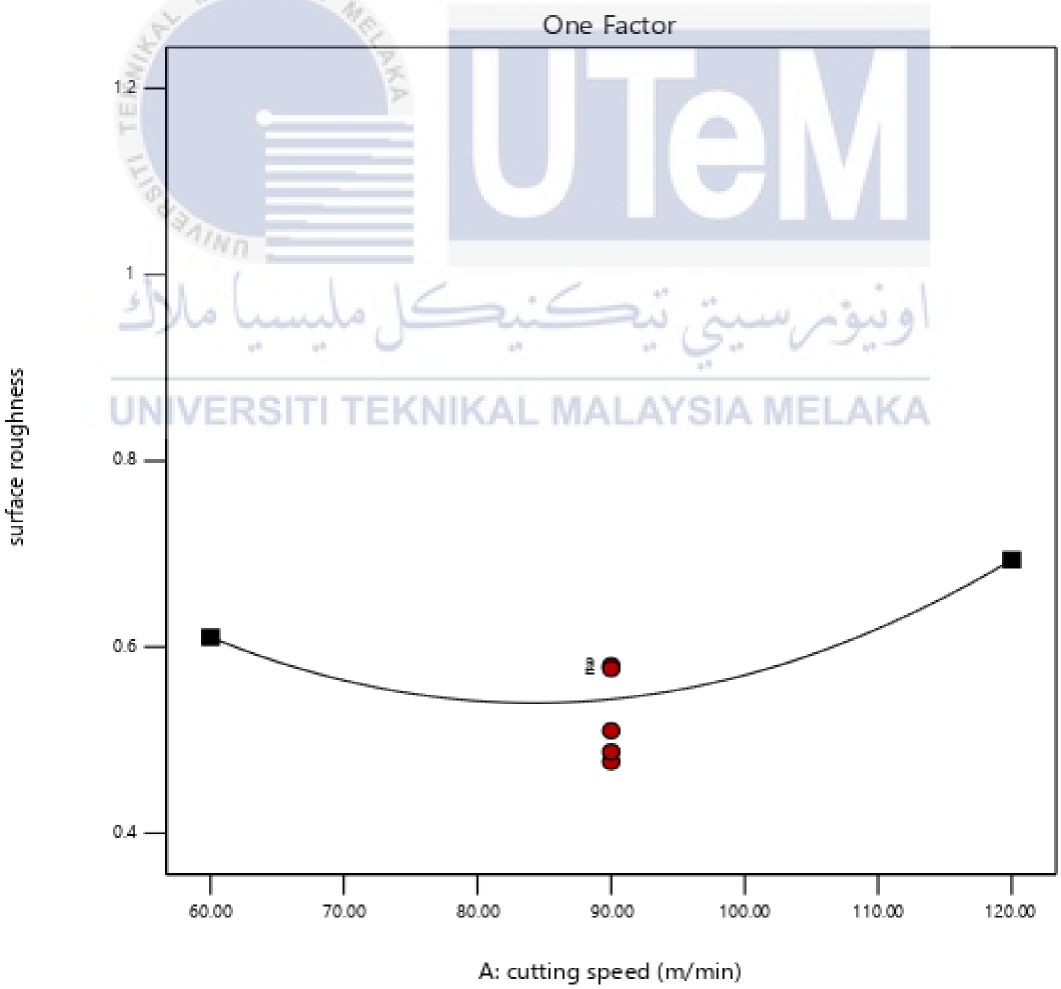

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Figure 4.16: Variation in cutting speed and surface roughness behavior

Besides, figure 4.17 depicted below shows the surface roughness value at constant cutting speed of 90 m/min, 0.15 mm/rev of feed rate and various depth of cut. Result showed that the surface roughness tremendously increasing from 0.4885 µm to 0.7821 µm when the depth of cut start to arising from 0.3 mm to 0.5 mm. This relationship shows that surface roughness is directly proportional to the depth of cut. Figure 4.18 below shows the gradient line of the graph of Ra against the depth of cut is horizontal, indicating that the depth of cut is particularly less or not significant to the surface roughness value. Furthermore, (Damir et al., 2018) data further backed up this rationale, stating that when the depth cut value increased, the surface roughness value increased as well. Some research, however, argue that the depth of cut factor has a negligible effect on surface roughness (Asiltürk & Akkuş, 2011).

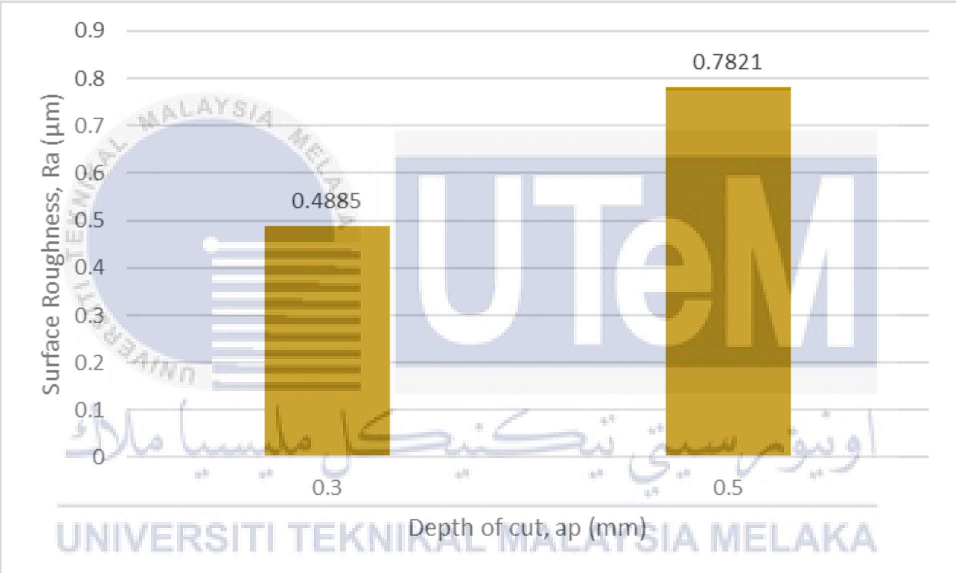

Figure 4.17: The surface roughness at 90 m/min cutting speed, 0.15 mm/rev feed rate and various depth of cut

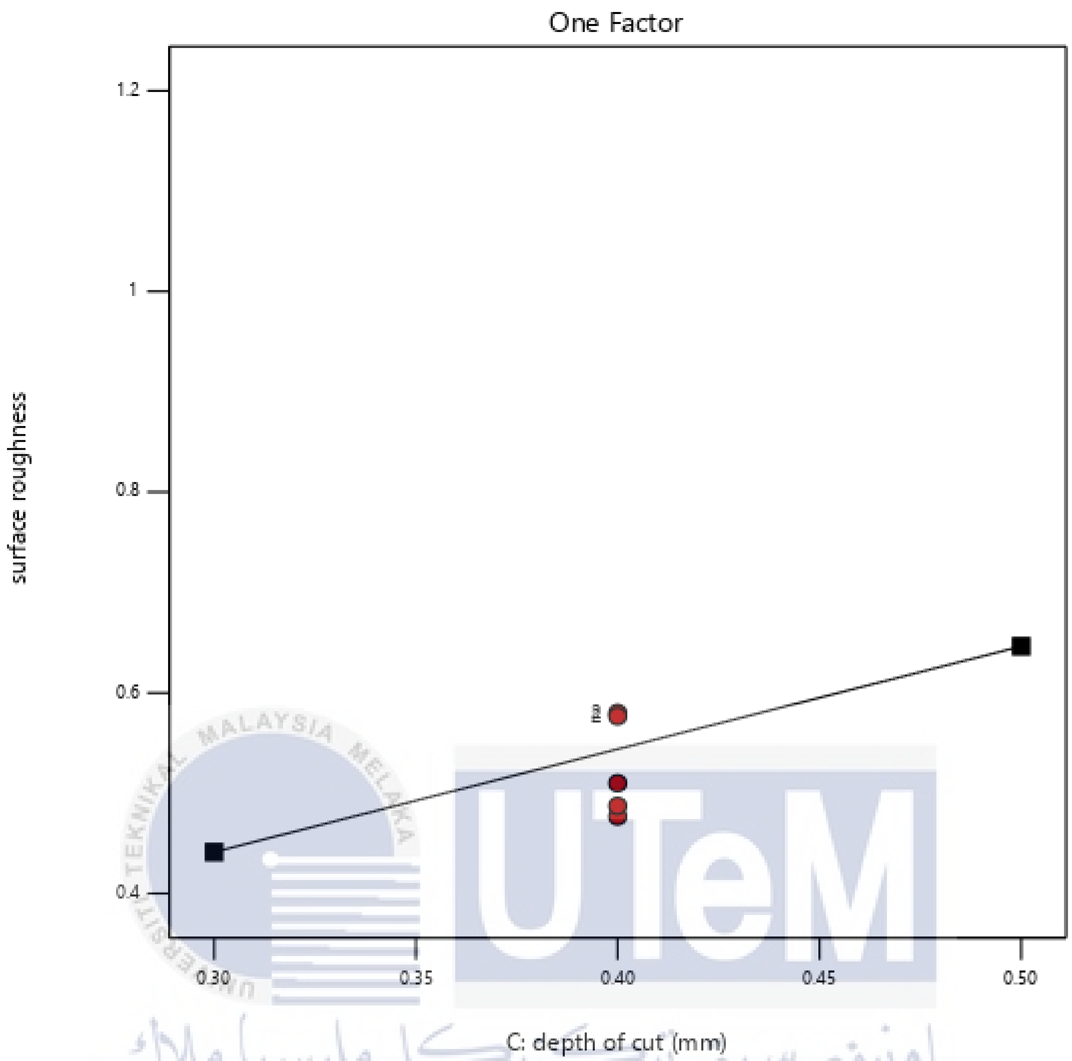

Figure 4.18: Variation in depth of cut and surface roughness behavior

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4.3 Surface Roughness Analysis using RSM Method

Design Expert software was used for RSM method in defining the mathematical modelling and data analysis of this experiment. The extracted data from chapter 3 in design expert were used in this chapter. Therefore, the general factorial in design expert was selected to build the response surface in order to generate analysis. Below is the data that obtained in this experiment.

4.3.1 ANOVA Analysis of Surface Roughness in Flooded Coolant

The depth of cut factor is not or only slightly significant to surface roughness, according to the ANOVA analysis, as shown in table 4.3, where the percent contribution of the cutting depth factor to surface roughness is the smallest, which is 2.02 percent, compared to 74.77 percent for the feed rate factor and 7.18 percent for the cutting speed factor. When compared to the feed rate factor and cutting speed, the depth factor's interaction with surface roughness was found to have a minor yet considerable influence when shown as a bar chart. During this experiment, it was revealed that as the cutting depth grew, the Ra value increased slightly.

This arises because the cutting depth is related to the cutting force applied to the workpiece and tool tip while cutting. When the cutting depth is raised, the cutting force value will increase proportionately. The workpiece and tool points bend when a strong cutting force is applied, the machine structure is squeezed and deflected, and rattling occurs throughout the machining operation. Indirectly, this will lead to poor machined surface quality. Furthermore, (Sivalingam et al., 2018) discovered that as the cutting depth increased, so did the machined surface roughness for the titanium alloy escape. Other researchers, on the other hand, claim that the machined surface roughness is unaffected by cutting depth (Ulutan & Ozel, 2011).

Table 4.3: Linear Model of ANOVA Analysis for Surface Roughness in Flood Condition

Source	Sum of Squares	DF	Mean Square	F-value	p-value	
Model	1.06	6	0.1773	26.80	< 0.0001	significant
A-Cutting Speed	0.0718	1	0.0718	10.85	0.0081	
B-Feed Rate	0.7477	1	0.7477	113.01	< 0.0001	
C-Depth of Cut	0.0202	1	0.0202	3.06	0.1109	
AB	0.0836	1	0.0836	12.64	0.0052	
A^2	0.0677	1	0.0677	10.24	0.0095	
B^2	0.0651	1	0.0651	9.84	0.0106	
Residual	0.0662	10	0.0066			
Lack of Fit	0.0439	6	0.0073	1.31	0.4142	not significant
Pure Error	0.0223	4	0.0056			
Cor Total	1.13	16				

Table 4.3 depicted above is revealed the linear model of ANOVA analysis for surface roughness in flood condition. The table below indicated that the p-value is 0.0001 which is much more lower than the significant value which is 0.05. P-values less than 0.0500 indicate model terms are significant. This p-value observed that the model terms are significant and in this case A, B, AB, A^2, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant whereby if there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. Obtaining from this analysis, it shown that cutting speed and feed rate model are significant. Furthermore, with the value of "Lack of Fit" = 1.31 implies which means that this is not significant and the surface roughness model fits with the data. Moreover, there is a 41.42% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good as the model fit the data well.

The resulting ANOVA table obtained the value of F-value for feed rate, B (113.01) which is higher than F-value for cutting speed,A (10.85) and the depth of cut, C (3.06). This result obtained that the feed rate is more significant factor in determining the surface roughness value compare to cutting speed. However, in order to support the construction of the empirical model, the depth of cut element was taken into consideration in the ANOVA analysis. Furthermore, the Model F value of 26.80 indicates the model is significant. Based on the result, there is only 0.01% chance that a "Model F value" is higher cause of the noise. Addition to that, because increased friction and contact between the workpiece and the tool wear surface leads in an increase in the temperature generated in the cutting zone, the feed rate appears to have a greater influence on the surface roughness value. Previous research had reached the same conclusion (Vetri Velmurugan & Venkatesan, 2021).

4.3.2 Final Equation in terms of actual factors (flood condition):

The equation below is developed from surface response modeling which is relating input parameters to the surface roughness shown below. Term A is consisting of cutting speed while term B is consisting of feed rate and term C is represents the depth of cut.

Surface Roughness (μm) = $2.3285 - 0.0318*A - 12.4965*B - 0.5030*C + 0.0964*A*B + 0.0001*A^2 + 49.6757*B^2$

4.3.3 ANOVA Analysis of Surface Roughness in Dry Coolant

Table 4.4: ANOVA Analysis of Surface Roughness in Dry Condition

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.8525	7	0.1218	27.27	< 0.0001	significant
A-cutting speed	0.0138	1	0.0138	3.10	0.1121	
B-feed rate	0.5128	1	0.5128	114.84	< 0.0001	
C-depth of cut	0.0843	1	0.0843	18.87	0.0019	
AB	0.0411	1	0.0411	9.21	0.0142	
BC	0.0187	1	0.0187	4.20	0.0708	
A^2	0.0493	1	0.0493	11.04	0.0089	
B^2	0.1232	1	0.1232	27.59	0.0005	
Residual	0.0402	9	0.0045			
Lack of Fit	0.0305	5	0.0061	2.53	0.1946	not significant
Pure Error	0.0097	4	0.0024			
Cor Total	0.8927	16				

Table 4.4 above shows the ANOVA analysis of surface roughness model. From the table, it indicates that the p-value is 0.0001 which is much more lower than the significant value which is 0.05. P-value which less than 0.05 will indicate the significant model. This p-value observed that the model terms are significant. This p-value observed that the model terms are significant and in this case B, C, AB, A^2 and B^2 and are significant model terms. Values greater than 0.1000 indicate the model terms are not significant whereby if there are many insignificant model terms which is not counting those required to support hierarchy, model reduction may improve the model. In this analysis shown that feed rate and depth of cut model are significant. With the value of "Lack of Fit" = 2.53 it means that this is not significant and the surface roughness model fits with the data. There is a 19.46% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good as model required to be fit.

The resulting ANOVA table obtained the value of F-value for feed rate, B (114.84) which is much more greater than F-value for depth of cut, C (18.87) and cutting speed,A (3.10). This result obtained that the feed rate is more significant factor in determining the

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surface roughness value compare to cutting speed and the depth of cut. Furthermore, the Model F value of 27.27 indicates the model is significant. Based on the result, there is only 0.01% chance that a "Model F value" is higher cause of the noise.

4.3.4 Final Equation in terms of actual factors (dry condition):

The equation below is developed from surface response modeling which is relating input parameters to the surface roughness shown below. Term A is consisting of cutting speed while term B is consisting of feed rate and term C is represents the depth of cut.

Surface Roughness (µm) $= 1.7663 - 0.0270*A - 14.6853*B + 1.0264*C + 0.0676*A*B + 0.0001*A^2 + 68.3326*B^2$

4.3.5 Summary ANOVA Analysis of Surface Roughness

Based on the result obtained, the most significant parameter for surface roughness in both flood and dry conditions is the feed rate. It was revealed by the result on table 4.2 whereby consist of F-value (113.01) for flood condition while 87.02 for dry condition. The highest F-value of the model represents the most significant model with the desired p-value which was less than 0.05. P-value <0.0001 which less than 0.05 was classified as the most significant factor which influence the surface roughness.

Based on the one factor effect graph that have been attached in previous section, it observed that the gradient line against the feed rate is quite large which means that the feed rate is the most significant factor in determining the surface roughness value. Moreover, the surface roughness value will increase with the increasing of the feed rate. This trend is found to be similar with Venkata Ramana (2017) in his study that the experimental results revealed that the feed rate played a significant role in reducing surface roughness.

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter is about the conclusion and recommendation of this research study. This section also involves recommendations, sustainability development, lifelong learning as well as complexity element.

5.2 Conclusion of Research

The comparison of surface roughness value has been investigated in this research. There are some conclusions can be reached based on the research findings for each case and the discussion proposed in order to articulate the study's findings and achieve the objective requirements:

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i. The first objective is to determine the significant factors onto surface roughness for both conditions which is dry and flood through ANOVA analysis. Based on the ANOVA Analysis obtained in the result and discussion section, it revealed that the most significant factor onto surface roughness for flood condition was feed rate followed by the cutting speed and the depth of cut. Differ for the dry condition, the most significant factor that effected the surface roughness of Nimonic C-263 alloy is the feed rate followed by the depth of cut and the cutting speed. This result observed that the most significant factor that effecting the surface roughness in both conditions is the feed rate. This result also has been supported in most of the research before that related to the material and conditions used.

ii. The last objective for this experiment is to investigate the surface roughness values of Nimonic Alloy C263 under dry and flood condition. Result obtaining shows that the highest value of surface roughness in flood coolant is 1.309 µm at 120 m/min cutting speed, 0.15mm/rev of feed rate and 0.4mm depth of cut. Meanwhile the best surface roughness value is 0.2563 µm at the cutting parameter 90 m/min of cutting speed, 0.05 mm/rev of feed rate and 0.5 mm of depth of cut. As for the dry condition, the highest value of surface roughness is 1.199 µm which occur at 120 m/min of cutting speed, 0.15 mm/rev of feed rate and 0.4 mm of depth of cut. Lastly, the smallest value of surface roughness is 0.414 µm at 90 m/min of cutting speed, 0.05 mm/rev of feed rate and 0.3 mm of depth of cut. The cutting parameter that influences the surface roughness value for both conditions would be varied as stated on the result table as depicted in the result table.

iii. The performance of surface roughness value for both conditions are quite good. The machined surface quality of Nimonic C-263 alloy is good due to its surface integrity in terms of machined surface roughness, a large feed rate factor, and a high cutting speed. Grain distortion below the machined surface is created according to the feed direction due to the microstructure of the machined surface and the high heat effect. This only happens in flood coolant but not in dry machining. Surface hardness is the outcome of hardening work that is impacted by high cutting temperatures and a high rate of tool wear.

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iv. The regression model for both conditions is stated below:

Flood (Surface Roughness, µm) = 2.3285 - 0.0318*A - 12.4965*B - 0.5030*C + 0.0964*A*B + 0.0001*A² + 49.6757*B²

Dry (Surface Roughness, µm) = 1.7663 - 0.0270*A - 14.6853*B + 1.0264*C + 0.0676*A*B + 0.0001*A² + 68.3326*B²

5.3 Recommendations

Because of its ability to operate at elevated temperatures for long periods of time and higher resistance to corrosion and oxidation in acidic and aqueous environments, Nimonic C-263 is extensively used in main part of submarine, jet engines, chemical industries, heat exchangers, ultra-supercritical power plants and gas turbine components. High shear strength, low heat conductivity, high strain hardening tendency, high hot hardness, and chemical affinity for tool material present a bigger challenge to the industries in terms of obtaining increased productivity and good component surface quality with long-term machining. Below is several recommendations and suggestions in improving the research for the next future:

i. The other machining parameter such as cutting edge, machine time, tool radius and other cutting conditions should be study further.

ii. Dry and flood conditions should be compared with other multi coolants such as MQL and Cryogenic in terms of surface roughness.

iii. Further analysis should be investigated for chip formation, surface microstructure and microhardness.

iv. Portable Surface Roughness Tester need to calibrate regularly so that it will result an accurate result

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v. The experimental equipment needs to be service regularly to maintain the performance.

5.4 Sustainability Development

Due to the disadvantages previously mentioned, cutting fluid becomes a serious issue during machining. As a result of these issues with cutting fluid and severe government regulations about environmental issues, businesses are moving toward dry machining. Dry machining causes a difficulty at high cutting speeds because of excessive tool wear, which reduces surface quality. For penetrating the cutting fluid with a high flow rate into the machining zone, a novel technology called as minimal quantity lubrication (MQL) was adopted. Although the amount of fluid used is reduced by using it in a mist or droplet form and at a fast speed, there is a risk to the operator's health.

Furthermore, improper handling of such fluids can harm water and soil resources, requiring manufacturers to follow strict and costly disposal protocols (Hosseini Tazehkandi et al., 2014). Furthermore, long-term exposure to typical emulsion coolants has been scientifically proven to induce significant skin and respiratory disorders. This cooling process, when compared to dry machining, improves the machined surface integrity, and increases tool life by reducing tool wear, even while machining difficult-to-cut alloys. Even while near-dry machining is unquestionably cleaner than typical flooding, residual oil particles are retained on the workpieces, which must be eliminated in biomedical applications.

5.5 Lifelong Learning

The lifelong learning for this experiment is the outstanding performance of Nimonic C-263 Alloy. The machinability of the Nimonic C-263 alloy also has been discovered in this research where this kind of material is very famous in nowadays industry application due to the outstanding performance.

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5.6 Complexity Element

The complexity in this experiment is the performance of the CNC machine. The machine sometimes breakdown and take time to be maintenance. Other than that, the complexity that have been faced is in measure the surface roughness value. This is due to the performance of the portable surface roughness tester as sometimes error will be pop up. This equipment also needs to calibrate back if there is nonconformance results have been obtained.

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