THE EFFECT OF CUTTING TOOLS GEOMETRY DURING ROUGHING OPERATION FOR POCKETING PROFILES OF AEROSPACE PART.

MUHAMAD NAZHIF BIN YUSRI

B092010421

BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY (PRODUCT DESIGN) WITH HONOURS

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Faculty of Industrial and Manufacturing Technology and Engineering.

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A thesis submitted
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TAJUK: **The Effect of Cutting Tool Geometry During Roughing Operation for Pocketing Profiles of Aerospace Part.**

SESI PENGAJIAN: **2023-2024 Semester 1**

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DEDICATION

To my beloved parents

My supportive supervisor Mr Muhammad Syafik Bin Jumali

Co-supervisor Mr Syahrul Azwan Bin Sundi @ Suandi

My faithful panels, lecturers, and staffs of FTKMP

My BMMD Cohort 10 classmates

ABSTRACT

During the course of this project, in-depth research was carried out to increase comprehension and knowledge by collecting data from a variety of sources, including journals and articles connected to the " The Effect of Cutting Tool Geometry During Roughing Operation For Pocketing Profiles of Aerospace Part." This study aims to investigate the impact of cutting tool geometry, specifically the helix angle and number of flutes/teeth, on the machining performance and surface quality of pocketing profiles for aerospace components. The objective is to optimize tool geometry to address issues related to surface roughness, tool wear, and dimensional accuracy, thereby enhancing productivity and reducing expenses in the aerospace industry. The research focuses on three-axis milling of closed pocketing circular and rectangular profiles using CATIA V5 as the primary CADCAM software. The experiments utilize genuine aircraft aluminum alloy Al-6061 T651 material, commonly employed in aerospace applications. The cutting conditions remain constant throughout the experiment, and a range of cutting tools with different geometries are employed. An uncoated solid carbide end mill with a diameter of 8mm and various flute configurations (2, 3, and 4 flutes) are used, considering helix angles of 10°, 30°, and 50°. Pocketing operations are performed using the DMGMORI DMU 60 Evo, a CNC Milling Machine 3-Axis. The study evaluates surface roughness using the Mitutoyo STJ-410 surface roughness analyzer, while tool wear and dimensional accuracy are examined using the Nikon MM-80 measuring microscope. The experimental results will provide insights into the effect of tool geometry on surface finish and aid in identifying the most optimal tool geometry for milling pocketing profiles in the aerospace industry. By addressing surface roughness, tool wear, and dimensional accuracy issues through optimized tool geometry and improved machining strategies, this research aims to enhance the quality, productivity, and cost-effectiveness of pocketing operations in the aerospace sector, leading to potential reductions in material waste and increased overall efficiency.

ABSTRAK

Sepanjang projek ini, kajian yang mendalam telah dijalankan untuk meningkatkan pemahaman dan pengetahuan dengan mengumpul data dari pelbagai sumber, termasuk jurnal dan artikel yang berkaitan dengan "Kesan Geometri Pemotongan Alat Semasa Operasi Kasar untuk Profil Poket Bahagian Aeroangkasa". Kajian ini bertujuan untuk mengkaji kesan geometri pemotongan alat, khususnya sudut heliks dan bilangan lekukan/gigi, terhadap prestasi pemesinan dan kualiti permukaan profil poket untuk komponen aeroangkasa. Objektifnya adalah untuk mengoptimumkan geometri pemotongan alat untuk menangani isu-isu berkaitan dengan ketidakrataan permukaan, kehausan alat, dan ketepatan dimensi, dengan memperbaiki produktiviti dan mengurangkan kos dalam industri aeroangkasa. Kajian ini memberi tumpuan kepada pengfraisan tiga paksi profil bulatan dan segi empat tertutup menggunakan CATIA V5 sebagai perisian CADCAM utama. Eksperimen menggunakan bahan aloi aluminium pesawat sebenar Al-6061 T651, yang biasa digunakan dalam aplikasi aeroangkasa. Syarat pemotongan kekal sepanjang eksperimen, dan pelbagai alat pemotongan dengan geometri yang berbeza digunakan. Penggunaan gergaji akhir karbida padu tidak dilapisi dengan diameter 8mm dan konfigurasi lekukan (2, 3, dan 4 lekukan) yang berbeza dipertimbangkan, dengan sudut heliks 10°, 30°, dan 50°. Operasi pengfraisan dilakukan menggunakan DMGMORI DMU 60 Evo, mesin pengfraisan CNC 3-Paksi. Kajian ini menilai ketidakrataan permukaan menggunakan analisis ketidakrataan permukaan Mitutoyo STJ-410, manakala kehausan alat dan ketepatan dimensi dikaji menggunakan mikroskop pengukuran Nikon MM-80. Keputusan eksperimen akan memberikan pandangan mengenai kesan geometri alat pemotongan terhadap kualiti permukaan dan membantu mengenalpasti geometri alat pemotongan yang paling optimum untuk pengfraisan profil poket dalam industri aeroangkasa. Dengan menangani isu-isu ketidakrataan permukaan, kehausan alat, dan ketepatan dimensi melalui geometri alat pemotongan yang dioptimumkan dan strategi pengfraisan yang diperbaiki, kajian ini bertujuan untuk meningkatkan kualiti, produktiviti, dan kecekapan kos operasi pengfraisan dalam sektor aeroangkasa, dengan potensi pengurangan pembaziran bahan dan peningkatan keseluruhan kecekapan.

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LIST OF SYMBOLS AND ABBREVIATIONS

CNC	-	Computer Numerical Control
CAD	-	Computer-Aided Design
CATIA	-	Computer-aided three-dimensional interactive application
CMM	-	Coordinate Measuring Machine
WPC	-	Workpiece Coordinate
NC	-	Numerical Control
CAM	-	Computer-Aided Manufacturing
CAE	-	Computer Aided Engineering
STL	-	Standard Triangle Language
DoE	-	Design of Experiment
N	-	Spindle Speed
Vf	-	Feed Rate
Vc	-	Cutting Speed
Z	-	Number of flutes
Fz	-	Feed per Tooth
Ra	-	Arithmetic Average Roughness
Rq	-	Root Mean Square Rouhness
Rt	-	Total Height Roughness

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CHAPTER 1

INTRODUCTION

1.1 Background

In the aerospace industry, the production of high-precision parts is crucial for ensuring the safety, efficiency, and spacecraft. Machining operations, such as pocketing, play a significant role in the manufacturing process of aerospace components. Aluminum is commonly used material in the aerospace industry due to its lightweight properties and high strength-to-weight ratio. AA 6061-T6 aluminum (Al) alloy has been carried out to fabricate HDH access arm due to its lightweight, high strength ratio, corrosion resistance and compact structure studied by Suyang Li (2021). It is an ideal material for a wide range of aircraft components and aerospace applications, including aircraft wings, structures, or repair purposes. Aluminum (Al) based alloys are preferred in automotive and aerospace industries due to their advantages such as low density and high specific strength. (R.J. Barnhurst 1998).

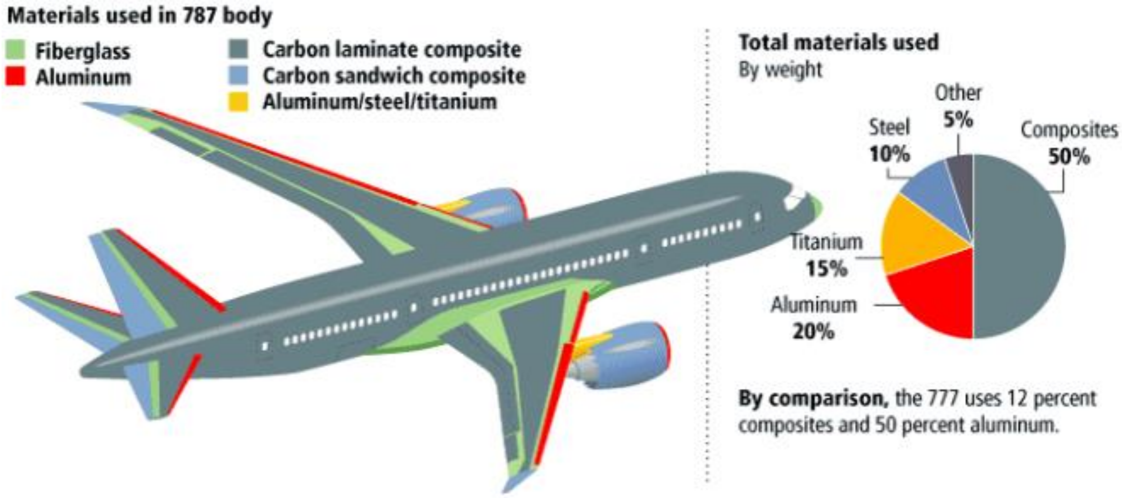


Figure 1.1: The used of Aluminum in the aerospace industry.

Source: (https://aviation.stackexchange.com/questions/35441/why-are-the-leading-edges-on-the-boeing-787-made-from-aluminum).

CNC stands for Computer Numerical Control. It refers to the automation of machine tools using computers and software programs. CNC machines can execute precise and complex machining operations with a high degree of accuracy and repeatability. In a CNC system, a computer program, often created with CAD/CAM software, provides instructions to the machine regarding the desired cutting operations. High accuracy CNC milling machines are required inmany manufactures because the demand of precisioncomponents and consistency of quality are growing.The most important factor of the precision componentsis the accuracy of machine tools. (Raksiri, Chana 2004). CNC machines can be used for a variety of manufacturing processes, including milling, turning, drilling, grinding, and routing. They are commonly employed in industries such as automotive, aerospace, electronics, and woodworking.

Cutting tools, on the other hand, are the implements used on CNC machines to shape or remove material from a workpiece. These tools can include end mills, drills, reamers, taps, inserts, and various other types. Cutting tools are typically made of high-speed steel (HSS), carbide, or other advanced materials, depending on the specific machining application. The selection of cutting tools depends on factors such as the material being machined, the desired cutting speed and feed rate, the complexity of the part geometry, and the required surface finish. However, requires machining of both simple and complex geometries. The modelling of the structural and geometrical design of a mill cutter is important because it determines the cutting force required statement by Phokobye, S. N. (2019). Different cutting tools are designed for specific operations, such as roughing, finishing, profiling, or threading. Using CNC machines with appropriate cutting tools allows for precise and efficient material removal, enabling manufacturers to produce complex parts with tight tolerances and high-quality surface finishes.

The global aerospace industry is experiencing significant growth, with the production of commercial and military aircraft on the rise. Aluminum alloys are extensively used in the construction of airframes, wings, fuselages, and other structural components due to their favorable strength-to-weight ratio.

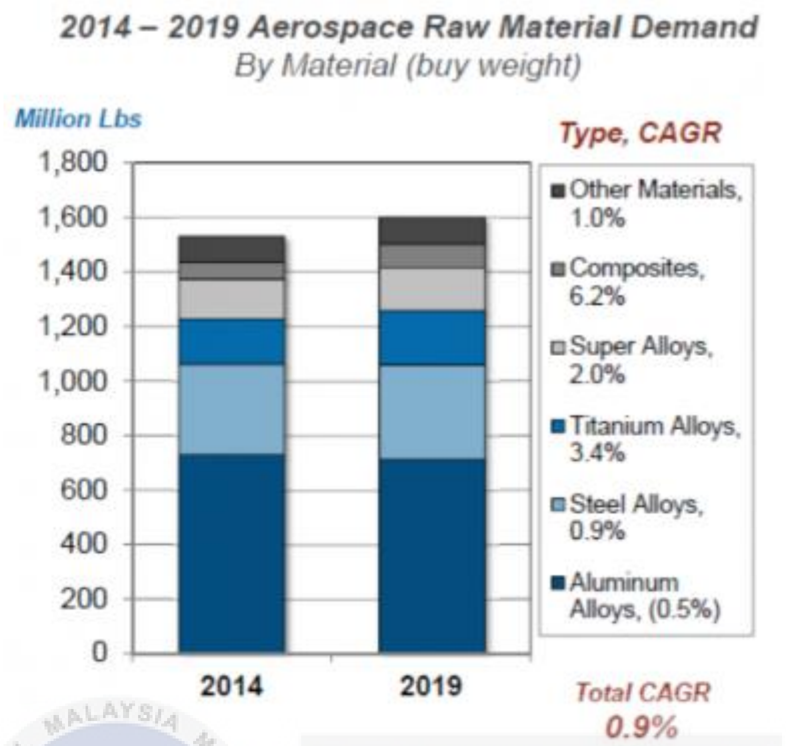


Figure 1.2: Aerospace Raw Material Demand

Source: (https://aluminiuminsider.com/aersopace-industry-trends-aluminium-use/)

The high demand for aerospace aluminum has led to a significant market for aluminum producers and suppliers. To meet this demand, companies in the aerospace aluminum sector often invest in research and development to develop new alloys with improved properties, such as increased strength and better resistance to fatigue.

1.2 Problem Statement

In the aerospace industry, there is a high demand for various pocketing profiles to meet the specific needs of different components and applications. The main aim of the present study is to investigate the effect of cutting tool geometry during machining of pocketing profiles for a sample of actual aerospace component using various machining strategies. Additionally, there are some issues with the surface roughness/quality based on the specific tool geometry. The cutting tool geometry to be considered include helix angle, and number of flutes/teeth, their impact on the machining performance and the quality of the machined surfaces which is this issue can be tackled by deciding the tool wear rate issue and will become have a big impact on industry players in saving a company's expenses then increase the quality in productivity processing. Accordingly, this action may also help to decrease material waste.

Moreover, dimensional accuracy issue due to cutting tool geometry which mean review and optimize the tool path for pocketing operations. CAM (Computer-Aided Manufacturing) software should be used to produce tool paths that avoid abrupt changes in direction and excessive tool engagement, both of which may lead to dimensional mistakes. Tool paths that are smooth and continuous may increase accuracy and reduce tool deflection. Evaluate various tool geometries and consider employing tools particularly developed for high precision machining. Tools with sharper cutting blades or unique geometries can increase dimensional accuracy.

1.3 Research Objective

The objectives of the project are:

1. To investigate the effect of end mill tool geometry namely the helix angle and no. of angle/teeth towards the surface finish.
2. To determine the most optimum end mill tool geometry (helix angle and no. of flute/teeth) during milling of pocketing profiles.

1.4 Scope of Research

The scope of this project focus on the effect of cutting tool geometry during machining three-axis milling pocketing profiles of aero-structural component utilizing CATIA V5 as the main CADCAM software. Since aluminum alloys are often used in the aerospace industry, this experiment will use a genuine aircraft aluminum alloy Al-6061 T651 material. The present research focuses on the sample aircraft components' closed pocketing circular and rectangular properties. The main approach to experimental design and analysis is accepted as the Design of Experiment (DoE). In this experiment, the Taguchi technique orthogonal array L9 will be utilized to assess the relevant factors. The Taguchi technique data will be planned using Minitab Statistical Software. In this experiment, the cutting circumstances remain constant. The study will involve experimental investigations using a range of cutting tools with different geometries while performing pocketing operations on aerospace parts. Furthermore, the cutting tool employed in this study is an uncoated solid carbide end mill with a diameter of 8mm and a number of flutes of 2, 3, 4. Helix angles of 10°, 30°, and 50° with 2, 3, and 4 flutes are among the possibilities to be considered. In this experiment, the pocketing process of milling will be carried out using DMGMORI DMU 60 Evo, a CNC Milling Machine 3-Axis. In addition, surface roughness, tool wear, and dimensional accuracy will be examined in this experiment. Mitutoyo STJ-410 is used to do surface roughness analysis. Thus, tool wear and surface inspection using the Nikon MM-80 measuring microscope.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, conversation is had on the exploration and review of earlier research that is relevant to this project. The phrase "literature review" refers to a methodical and thorough synthesis and analysis of published research and academic papers, books, dissertations, conference proceedings, and other pertinent materials on a particular topic. It entails locating, assessing, and synthesising existing literature to present a thorough summary of the most up-to-date information and understanding on a certain issue. In order to clarify the research work, a few literature studies were carried out.

2.2 Machining

Machining refers to the process of using various cutting tools and machines to shape and remove material from a workpiece to achieve the desired shape, size, and surface finish. It is a fundamental manufacturing process used in a wide range of industries, including aerospace, automotive, electronics, and general manufacturing. In the aerospace industry, where precision, reliability, and repeatability are critical, CNC machining has become a preferred method for producing complex components and parts. A recent development in computer numerical controlled (CNC) machining technology makes it feasible to produce more intricately formed components in a single piece instead of having to assemble them from separate sections. (R Izamshah 2011).

A CNC machine (Computer Numerical Control) is a highly automated industrial equipment capable of performing accurate and sophisticated machining operations. A computer software controls it and produces instructions for the machine to follow, allowing for precise and reproducible component manufacture.

Due to its capacity to create high-quality components with strict tolerances, CNC machines are extensively utilized in a variety of sectors, including aerospace, automotive, electronics, and manufacturing. Another studies by (Octavian Bologa 2016), CNC machine tools may be categorized into 3-axes and 5-axes ones based on their mechanical and kinematic structure. With reference to Figure 2.1, it is easier to comprehend.

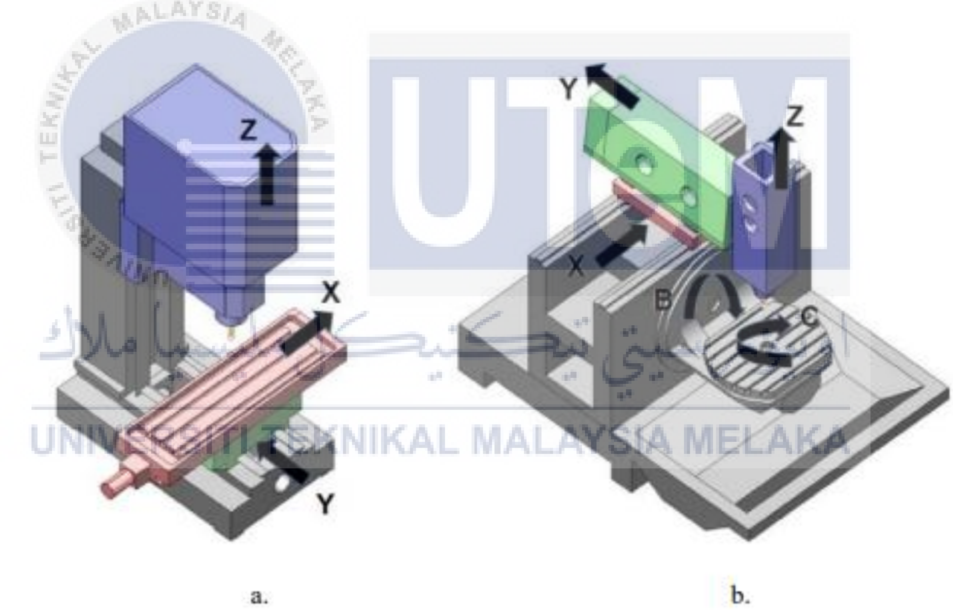


Figure 2.1: Shows that (a) 3-axis machine and (b) 5-axis machine. (Octavian Bologa 2016).

Machining in metals material refers to the process of shaping, cutting, and removing material from metallic workpieces to create desired shapes, sizes, and surface finishes. It is a fundamental manufacturing process used in various industries, including automotive, aerospace, electronics, construction, and more. There are several common machining processes used for metal machining, including:

1. Turning: Rotating the workpiece while a cutting tool removes material to create cylindrical shapes.
2. Milling: Rotating multiple cutting tools to remove material and create complex shapes or features.
3. Drilling: Creating holes in the workpiece using a rotating drill bit.
4. Grinding: Using abrasive wheels or belts to remove material and achieve fine surface finishes.
5. Boring: Enlarging or refining existing holes using single point cutting tools.
6. Sawing: Using a blade with teeth to cut through metal workpieces.

On paper, (P.J.T. Conradie 2015) have proposed since it is believed that around 15% of all mechanical components produced globally are produced directly through machining processes, metal machining is a very significant manufacturing technique.

2.3 Aluminum alloy

Aluminum alloys are a group of materials composed primarily of aluminum, along with various alloying elements to enhance their properties. Aluminum is a lightweight and highly versatile metal with excellent corrosion resistance, thermal conductivity, and electrical conductivity. Alloying elements are added to aluminum to improve specific characteristics such as strength, hardness, machinability, and heat resistance. (Nhu–Trang Le 2020), presented due to their high specific strength and resistance to corrosion, aluminum alloys are often utilized in technical applications in the automotive, aerospace, marine, and architectural fields.

Țîțu, A. M (2020) have proposed the aluminum classes that were addressed the most often in the aerospace sector were primarily 2xxx, 7xxx, and 6xxx. The aerospace industry is supported by the materials' high strength relative to their light weight as well as the fact that they often provide some level of profitability in that they may substitute for cast iron and steel in the production of components. Aluminum is lightweight, which also has a lower environmental effect. The author's graph shows that the majority of Al6061 reaches 26%, with Al7075 coming in second at 22% based on Figure 2.2. The aviation sector also makes use of the research on aluminum alloys.

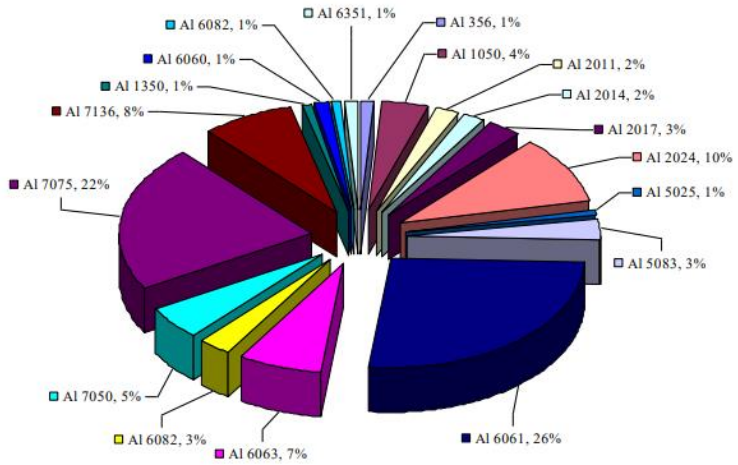


Figure 2.2: The aluminum alloys used as a percentage in the aerospace industry in the 2005–2019 period. (Țîțu, A. M 2020)

(K. Danesh Narooei 2022), describes aluminium is the third most abundant element in the earth's crust, as well as the second most consumed metal by weight, trailing only iron and its alloys. Aluminum plays a crucial role in the aerospace industry due to its desirable properties, making it a widely used material for various aerospace applications. Aluminum alloys provide structural integrity and endurance to resist the strict circumstances of aircraft operations because they have a strong strength-to-weight ratio. Aluminum alloys are lightweight materials that may be manufactured to have outstanding strength. (K. Danesh Narooei 2022), have presented aluminium alloy-T6 has medium strength, good machinability, formability, and weldability, as well as high corrosion resistance.

In the design, manufacture, and production of aircraft and aerospace components, the term "aluminium in aerospace" refers to the usage of aluminium and aluminium alloys. Aluminum is a lightweight and versatile metal that offers several desirable properties for aerospace applications.

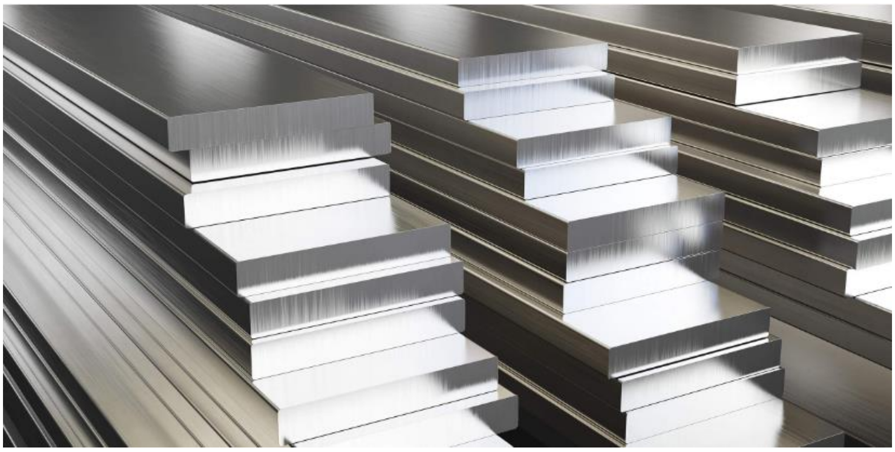


Figure 2.3: Aluminum of aerospace

Source: (https://www.aaaairsupport.com/7075-0-aerospace-aluminum/)

2.4 Machine strategy

Machine strategy refers to the overall approach or plan for performing machining operations on a workpiece using a machine tool. It involves the selection and optimization of various parameters and techniques to achieve the desired machining outcomes efficiently and effectively. Anyway, in this research only focus on pocketing files in machining aerospace parts as a main processing. The selection of an appropriate machine strategy can offer several advantages in terms of efficiency, productivity, and quality. A carefully planned machine strategy can optimize the machining process, leading to improved efficiency. It can minimize unnecessary tool movements, reduce idle time, and optimize the toolpath to minimize air cutting.

Machine techniques that consider cutting forces, chip evacuation, and heat dissipation can assist extend tool life. An excellent machine technique might help you get a better surface finish on your manufactured product. The appropriate surface finish requirements can be satisfied without the need for extra post-processing by minimising tool vibrations, chatter, and other factors that can impair surface quality. Another advantages, Chip handling is critical for efficient machining. Machine techniques that optimise chip generation and evacuation can lower the danger of chip clogging, reduce the risk of workpiece or tool damage, and increase overall machining performance.

2.4.1 Milling

Milling is a machining process that involves the use of a rotating cutting tool to remove material from a workpiece. It is a versatile and widely used machining technique that allows to produce complex shapes, features, and contours. Milling machines can be classified into various types based on their configuration and operation, Vertical milling machine: the cutting tool is mounted vertically, and the workpiece is clamped on a table that moves in the X, Y, and Z directions. Horizontal milling machine: the cutting tool is mounted horizontally, and the workpiece is secured on a table that moves in the X, Y, and Z directions.

Universal milling machine: this type of milling machine allows for both vertical and horizontal milling operations by swivelling the milling head. CNC milling machine: Computer Numerical Control (CNC) milling machines are automated milling machines controlled by computer programs. They offer high precision and can execute complex milling operations.

In research, (Phokobye, S. N. 2019) summarized that, the flexible milling process is frequently used in production when both basic and complicated geometries need to be machined. Because it affects both the level of surface smoothness and the cutting force needed for the milling process, modelling the structural and geometrical design of a mill cutter is crucial.

Figure 2.4: The experimental set for the milling operation (Phokobye, S. N. 2019).

2.4.2 Pocketing Profiles

Pocketing is a machining operation in which material is removed from a workpiece to create a recessed area or cavity, commonly referred to as a pocket. The pocket is typically characterized by defined boundaries, such as straight walls, curved surfaces, or a combination of both. Pocketing is often performed using milling machines or machining centres equipped with rotary cutting tools, such as end mills. Author showed, in order to meet the demands for strength and lightness, several pockets are used in the design of the structural components of airplanes. (Shaochun Sui 2016). This operation is utilized in various industries to create features such as pockets, slots, or recesses in workpieces, accommodating the integration of other components, reducing weight, or achieving specific design requirements.

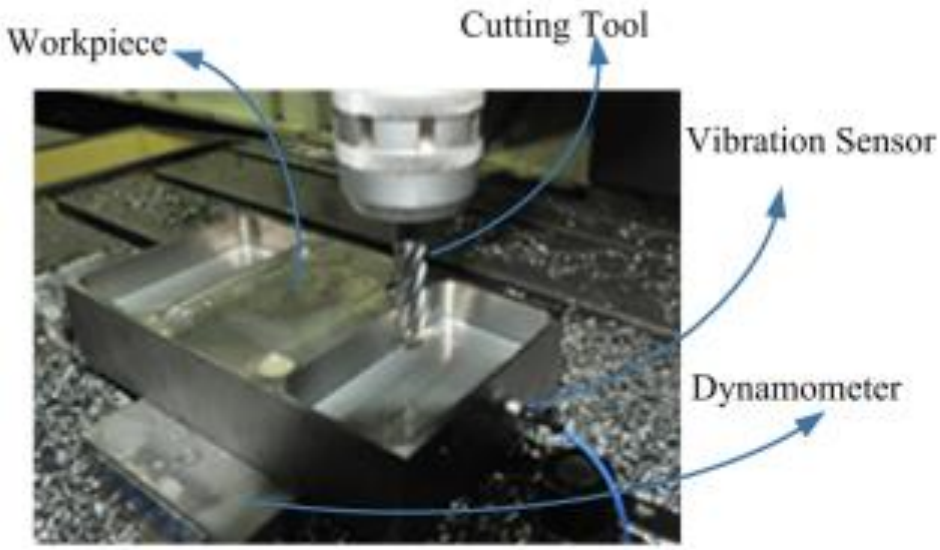


Figure 2.5: Pocket experimental (adapted from Shaochun Sui 2016).

Before initiating the pocketing operation, the pocket design is established. This includes defining the shape, size, depth, and other specifications of the pocket. The design may be based on engineering drawings or computer-aided design (CAD) models. Using one or more milling cutters, pocket milling is the process of removing material from inside a closed boundary on a flat surface of a workpiece to a certain depth. (L.W.Kariuki 2014).

The specific effect of pocketing can vary depending on the machining strategy and the desired outcome. Here are some effects of pocketing in machining, material removal: pocketing involves the efficient removal of excess material from a workpiece, creating a cavity or pocket with a specific shape or depth. This effect allows for the creation of recesses, holes, or complex internal features in the workpiece.

Muhammad Munzir bin Razak (2016) has purposed the two basic forms of tool paths are direction-parallel or zigzag (normal and smooth zigzag) and contour-parallel or spiral (normal and smooth spiral). Different cutter path strategies can be used to mill a pocket feature in machined parts. In CAM software, three of them are typically used: spiral cutter path strategies, back and forth (Zigzag) cutter path strategies, and one-direction cutter path strategies. The different path strategies that were examined are depicted in Figure 2.6. They include one-direction, circular, and spiral strategies. Figure 2 depicts the various pocket geometries, including Pocket A, Pocket B, and Pocket C. The most straightforward pocket is Pocket A, the most complicated pocket is Pocket B, and the middle pocket is Pocket C.

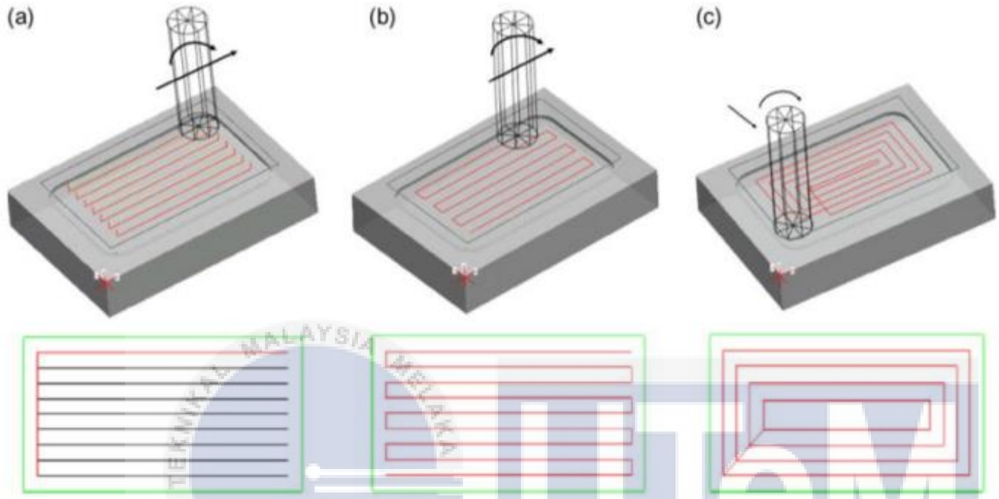


Figure 2.6: Cutter path strategies in pocket milling: (a) One direction; (b) Back and forth; and (c) Spiral. (Muhammad Munzir bin Razak 2016).

By figuring out the ideal mix of radial and axial depth of cuts with a constant spindle speed, the material removal rate (MRR) in a pocket machining was optimised. This optimisation was based on hand selection within the limit plots. (E. Budak, A. Tekeli 2005). Shape and geometry pocketing enable the machining of intricate shapes, contours, and internal features within a workpiece. The choice of tool paths and cutting strategies can influence the final shape and geometry of the pocket, allowing for customization and meeting design requirements. Surface finish pocketing can influence the surface finish of the machined pocket. Factors such as the cutting tool, machining parameters, and tool path strategy can impact the surface roughness, accuracy, and quality of the pocket's walls and floor.

C. C. Tsao (2009) has stated in the automotive and aerospace industries, cutting aluminum alloys is a major manufacturing process. Milling with an end mill is one of the important machining processes for making profiles, slots, engraving, surface contouring, and pockets in precision molds and dies. Components are frequently exposed to heat sources or operate at high temperatures in aircraft applications. By including channels or recesses that promote airflow and boost cooling, pocketing profiles can be created to optimise heat dissipation. This aids in preventing overheating, which can impair component performance and deteriorate material qualities.

Pocketing profiles can facilitate the assembly and integration of aerospace components. By creating recesses or pockets, space is provided for the placement of fasteners, connectors, electrical components, or other elements necessary for integration into larger systems or structures. This enhances the overall efficiency and ease of assembly processes. Using a pocket milled MDF material had a surface roughness related to the machining parameter. The MDF panels' surface characteristics are impacted by the CNC router. The CNC routers were initially employed by aluminum sheets into intricate patterns for the aerospace industry. (Abdullah Sütcü 2012).

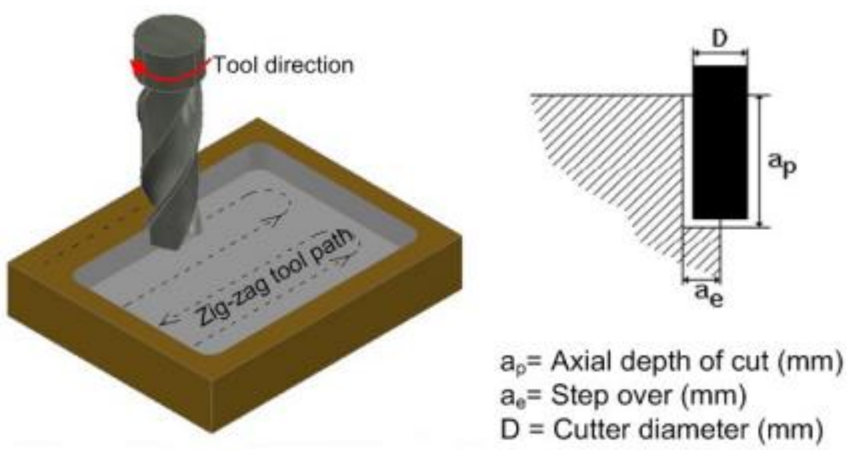


Figure 2.7: Parameters of pocket milling. (Abdullah Sütcü 2012).

Tool Life and Wear: Pocketing can affect the tool life and wear characteristics of the cutting tool. Factors such as cutting forces, heat generation, chip formation, and tool engagement can impact the tool's performance and longevity. (Le, Nhu-Trang 2020) in their research, the three parts of this study's primary contributions are as follows: Evaluations of cutting forces and tool wear in the pocket milling process include (1) assessing the impact of cutting conditions on cutting forces and tool wear, (2) modelling cutting forces and tool wear in relation to cutting conditions, and (3) assessing the link between cutting forces and tool wear.

2.4.3 Roughing

The roughing process is a term used in various industries, including manufacturing and machining, to describe the initial phase of material removal or shaping of a workpiece. It involves the removal of excess material quickly and efficiently to bring the workpiece closer to its final shape.

Xing Zhang (2022) has stated one of the primary objectives of CNC machining is high efficiency milling. Although machining accuracy requirements for roughing operations are relatively low, the selection of milling parameters typically requires taking into account the cutting force, milling stability, spindle torque, and power. Author reported that another major issue in the machining of difficult-to-cut materials is tool wear. It has been a significant problem in the realm of CNC machining to attain high efficiency milling parameters under multi-constraint conditions.

Figure 2.8: Experimental by (Xing Zhang 2022)

In another study, Peter Ižol (2022) proposed the most crucial factors in roughing optimisation are cutting parameters such cutting speed, feed rate, and depth of cut. Cutting conditions must be carefully established to prevent issues like chatter, excessive tool wear, spindle overload, or feed mechanisms that result in downtime and raise expenses. The most common way to increase machining efficiency must to enhance the cutting parameters; nevertheless, it is also required to establish the maximum set of viable machining parameters.

2.5 Machining parameter

For controlling and improve the cutting conditions during the machining process, several factors called machining parameters can be changed. The rate of material removal, surface quality, tool life, and overall effectiveness of the machining operation are all directly impacted by these variables. There are a few commonly adjusted machining parameters, cutting speed (S): cutting speed is the rate at which the material of the workpiece moves relative to the cutting edge of the tool. Surface feet per minute (SFM) or metres per minute (m/min) are the usual units of measurement.

Feed Rate (F): the feed rate is the speed at which the cutting tool advances into the workpiece along the cutting direction. It is typically measured in inches per revolution (IPR) or millimetres per revolution (mm/rev). Proper feed rate selection is important to balance material removal rates, tool life, and surface finish. Depth of cut (D): the depth of cut refers to the distance between the original workpiece surface and the final machined surface. It is typically measured in inches (in) or millimetres (mm). Cutting tool selection: the choice of cutting tool, including the tool material, geometry, and coating, is a crucial parameter in machining. Different materials and geometries are suited for specific machining applications and workpiece materials.

The cutting process is affected by several factors such as tool geometry, cutting parameters, temperature, and tool wear. The tool geometry parameters have high influence when compared by other factors on the quality of surface product. (P.J.T. Conradie 2015) observed that choosing the best cutting tool material, using creative lubrication techniques, optimizing the cutting parameters, or creating novel milling techniques may all help improve machining performance.

2.6 Cutting tool

Cutting tool machining refers to the process of manufacturing cutting tools used in various machining operations. Cutting tools play a critical role in machining processes by removing material from a workpiece to create the desired shape, size, and surface finish. Depending on the exact purpose and nature of the workpiece, cutting tools are often composed of high-speed steel (HSS), carbide, or other high-tech materials. Understanding the tool-workpiece interfaces and the mechanism of surface formation in machining is crucial for the design of high-performance cutting tools. (Jiwang Yan 2009).

Figure 2.9: Milling cutter tool

Cutting tools for milling may be used to carry out a variety of tasks, including facing, slotting, contouring, and pocketing. They provide versatility in component design and production since they may generate a variety of forms, profiles, and features on the workpiece. The availability of milling cutting tools in a range of shapes and coatings allows for the creation of superior surface finishes. Milling may provide fine surface finishes, satisfying the necessary criteria and eliminating the need for extra finishing processes, with the right tool selection and machining settings. Numerous research has been conducted up to this point to determine the impact of technical variables and cutting circumstances on tool wear and machining surface roughness in an effort to increase machining process quality while lowering costs and cycle times. (Nhu-Tung Nguyen 2021).

In another study, (John O’Hara 2019) examined subtractive machining procedures continue to be fundamentally reliant on the cutting tool. The importance of this machining component is reflected in the growing need for new microtool development which is fundamental to the progress of contemporary manufacturing. The rising need for the creation of new microtools, which is essential to the advancement of modern production, is a reflection of the significance of this machining component.

2.6.1 Tool Geometry

Tool geometry describes the precise layout and features of the contours, angles, and features of a cutting tool. When it comes to a cutting tool's performance, efficiency, and effectiveness during different machining operations, geometry is important. The shape, angles, and characteristics of a cutting tool's cutting edges, flutes, and other parts are only a few examples of its geometry. The form, angle, and arrangement of the tool's cutting edge are referred to as its "geometry." The rake angle, relief angle, cutting edge shape, and edge preparation are some of its properties. In another aspects, the angle formed by the cutting edge and a reference plane that is parallel to the surface of the workpiece is known as the rake angle. It affects tool life, chip formation, chip thickness, and cutting force direction and amplitude.

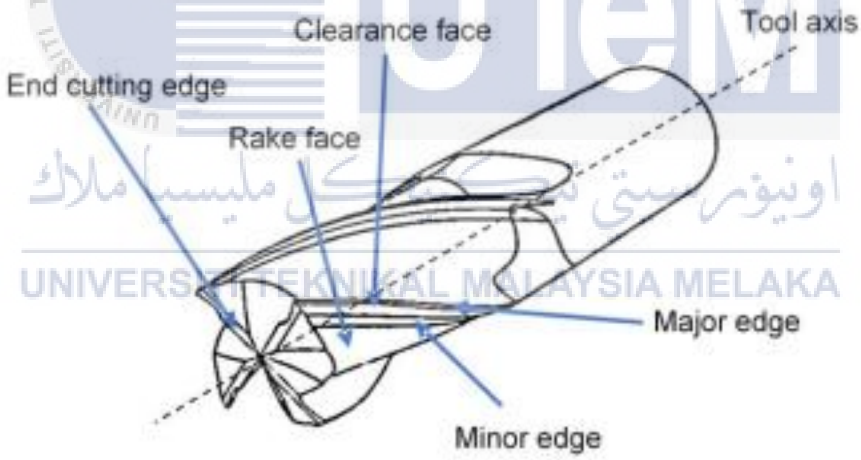


Figure 2.10: Cutting Tool Geometry (John O'Hara 2019).

Other studies by (Aslantas, K. 2021) with the increase of the edge radius, the rake angle, which is positive at the start of the cutting operation, begins to behave like a negative rake angle. Three issues arise with an increase in edge radius: (1) burr formation on the edges of the machined slot increases; (2) plowing on the working surface increases; and (3) the slot geometry deteriorates. To reduce these issues, it is crucial to identify the ideal tool shape.

Aspects of the cutting tool's flutes are the channels or grooves that help coolant and chip evacuation. Chip formation, chip evacuation, cutting forces, and tool performance are all impacted by the flute geometry, which includes the shape, width, and spacing of each flute. Various flute geometries are appropriate for various types of materials and machining processes. Besides, to increase wear resistance, lessen friction, and improve chip evacuation, tool coatings like diamond-like carbon (DLC), titanium nitride (TiN), or titanium carbonitride (TiCN) are applied to the surface of the cutting tool. Coatings can lengthen the life of a tool, quicken cutting, and enhance surface quality.

2.6.2 Helix angle

Researchers have studied the effect of helix angle on cutting tool during machining process. Regarding cutting tools that include spiral or helical flutes, including drills, end mills, and taps, the helix angle is an essential component of the cutting tool geometry. The angle made by the cutting tool's leading edge and a plane perpendicular to its axis is referred to as the helix angle. (Yu Guo 2019) presented for improving stability, variable pitch/helix cutters are a suitable option. Through irregular pitch/helix angles, they alter the time delays of a dynamic system, which in turn disturbs the surface regeneration effect between succeeding cutting edges to raise the milling process' stability limit.

According to (Yu Guo 2019), variable helix cutters have progressively been used in high-speed milling in recent years. For determining the optimal helix angle for a particular circumstance, it is crucial to seek advice from tool makers or machining specialists since different helix angles may be suited for different applications. (Turner 2007), simplified a variable pitch milling cutter and suggested an analytical approach for easily determining the stability of variable helix cutters.

Figure 2.11: Three types of cutters with different helix angle (Yu Guo 2019).

The study by (Yu Guo 2019) examined the results of the study demonstrate a broad absolute stability zone for the optimised variable helix cutter, which validates the precision of the stability model and the efficiency of the optimisation approach. The stability and stiffness of the cutting tool are also impacted by the helix angle. Higher helix angles can improve the tool's stability when cutting, lowering vibrations, and enhancing surface smoothness.

In a different study, (Iqbal, A 2006) examined the milling parameters, such as the cutter's helix angle and milling orientation (up- and down-milling), do not receive much attention with regard to their impact on the process' sustainability metrics. It was observed that when hardened steels were milled at high speeds using carbide cutters, both parameters had considerable influence on tool life and work surface roughness. The study by (Asif Iqbal 2020) examined the in comparison to 30° cutters, milling cutters with a 45° helix angle produced significantly longer tool life and somewhat improved surface finish.

According to (Wan, M 2017) a mathematical model to measure the impact of the tool's helix angle on the maximum cutting force. The peak cutting force for a single engaged cutting edge decreased with increasing helix angle, and the number of flutes, axial depth of cut, and cutter diameter were all factors in determining the best helix angle to achieve the lowest peak cutting force.

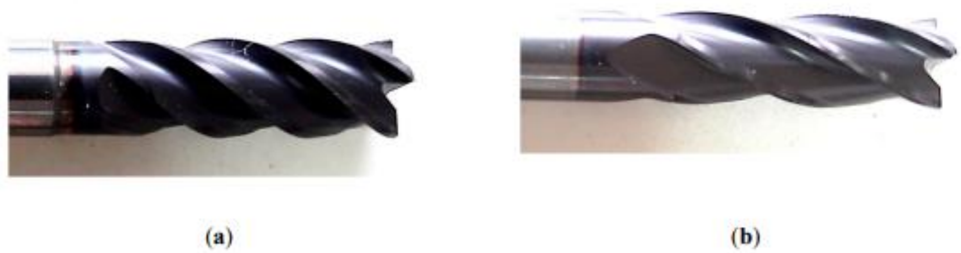


Figure 2.12: Ceramic-coated tungsten carbide side and end-mill cutters having helix angles of (a) 42° and (b) 30°.

(Asif Iqbal 2020) reported that the high amount of helix angle performed well in terms of lowering process costs, tool wear, and milling pressures in addition to being effective for lowering specific cutting energy. In deep or demanding machining operations, a larger helix angle assists in efficient chip evacuation. The probability of chip clogging is decreased, and machining efficiency is increased. (Plodzien, Marcin 2020) observed that the helix angle has an important impact on the flow direction of the chip, which for small angles is axial and for high angles turns into radial.

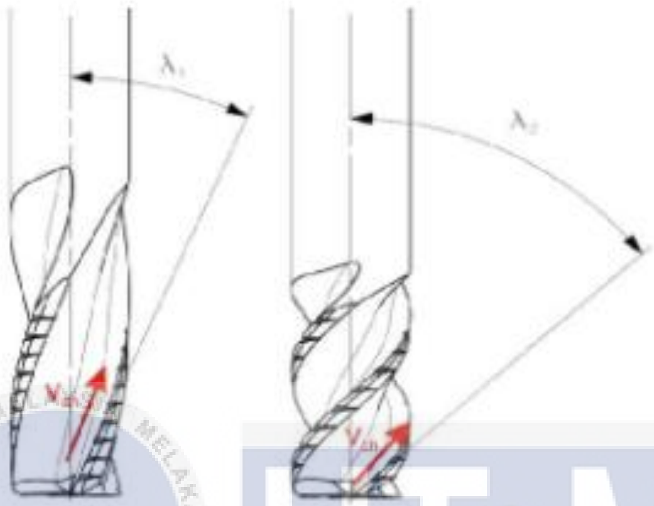


Figure 2.13: The influence of the helix angle on chip evacuation. (Plodzien, Marcin 2020).

In a different study, (Raja Izamshah 2013) examined helix angle is the angle created by a line perpendicular to the helix and a plane passing through the cutter's axis, or cutting-edge angle is the angle made by a helical cutting edge and a plane passing through the axis of a cylindrical cutter. The helix creates a good surface finish and assists in moving chips up and out of the cutting zone. Standard end mill helix angles range from 30° to 45° for cutting edge strength and sharpness in common machining processes.

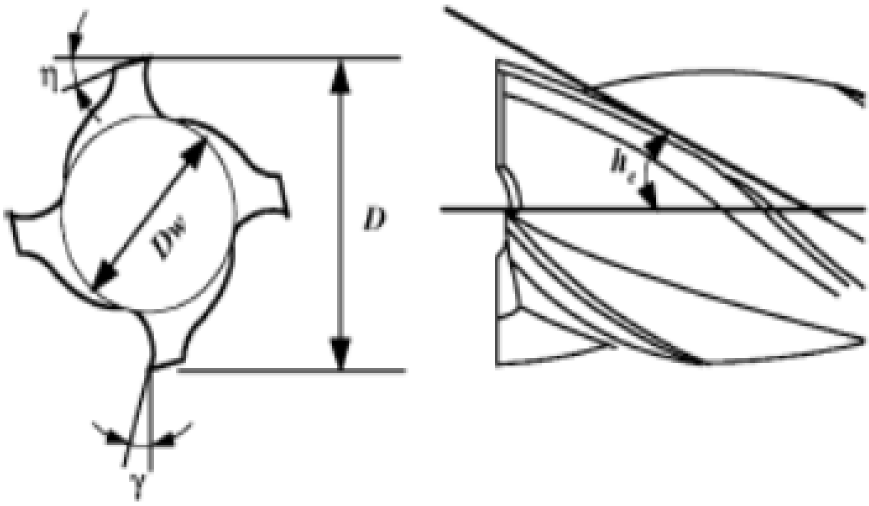


Figure 2.14: End Mill Geometrical Features. (Raja Izamshah 2013).

Studies have found that greater effective rake angle results from bigger helix angle, which enhances machinability and accuracy. Although a wide clearance angle reduces surface roughness, it is more susceptible to chipping. Further, small clearance angles are more likely to result in noise and rougher surfaces. (Raja Izamshah 2013).

2.6.3 Number of flute

Previous studies have primarily concentrated on number of flutes. The amount of cutting edges or grooves on a cutting tool is indicated by the number of flutes on the tool. Each flute runs the full length of the tool and is usually evenly spaced all the way around. The material being machined, the kind of operation, and the preferred balance between cutting performance and chip evacuation all play a role in determining the number of flutes to use. (Liming Wang 2015) describes the major component of a solid end mill is a flute, which has a considerable impact on the tool's lifespan and machining quality during milling operations. The tool's ability to cut can be impacted by its flute count. Tools with multiple flutes equally distribute the cutting forces throughout the flutes, resulting in less load per flute. This can lessen vibrations and tool deflection while also enhancing surface smoothness.

The number of flutes has an impact on how chips are evacuated during milling. Chips develop as the tool slices through the material and must be efficiently removed from the cutting zone. The study by (Raja Izamshah 2013) examined the End mill stiffness may be affected by the number of flutes. Particularly in deep or heavy-duty machining processes, higher flute counts can offer additional routes for chip evacuation, enabling effective chip removal and lowering the danger of chip clogging. (Aydin, Mehmet 2021) reported that the force coefficients are produced using the average cutting force and a linear regression model, and the cutting forces are computed using the undeformed chip thickness calculated from the trochoidal flute path.

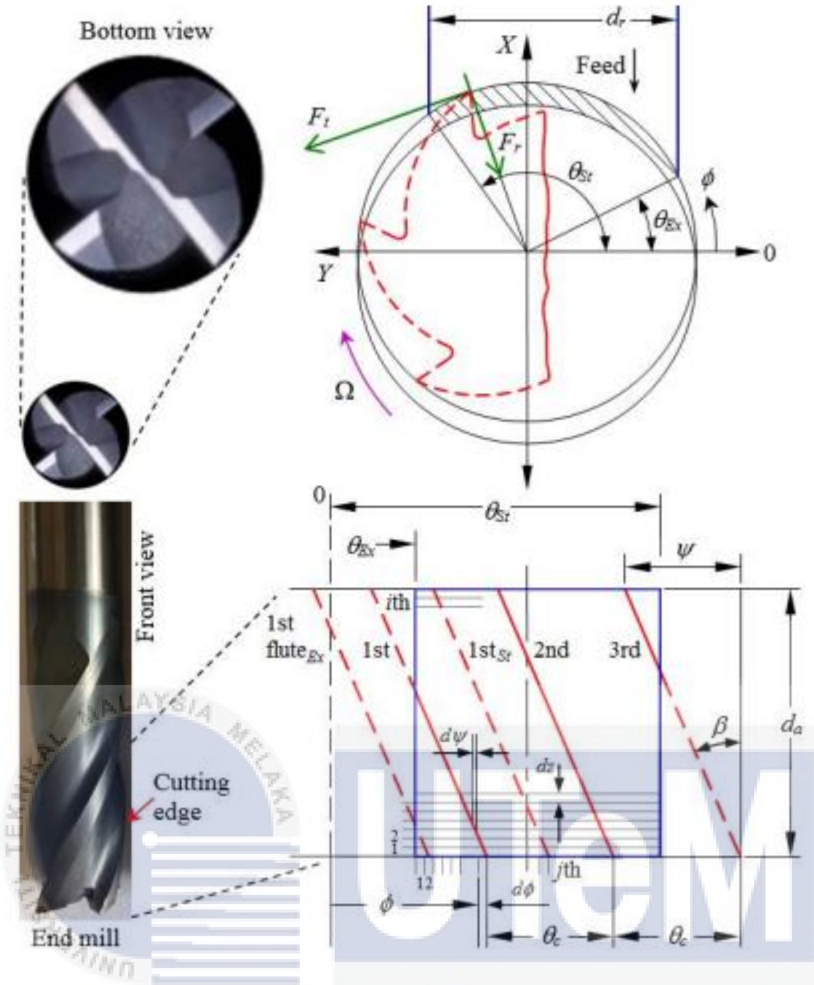


Figure 2.15: Helical-flute end milling (Aydin, Mehmet 2021).

The feed rate and material removal rate are influenced by the number of flutes. larger feed rates may typically be accommodated by tools with a larger flute count, leading to quicker material removal. To provide the best cutting conditions, it's crucial to consider the material being machined and the capabilities of the machine. The author in their research, measured the spindle's tool holder, which had either straight or helical flutes, was holding uncoated tungsten carbide flat-end mills with a 12 mm diameter. (Aydin, Mehmet 2021). The surface quality of the machined object can be impacted by the number of flutes. Due to the more frequent contact between the cutting edge and the workpiece, tools with more flutes can create a better surface finish. In situations where a high-quality surface finish is sought, this may be helpful.

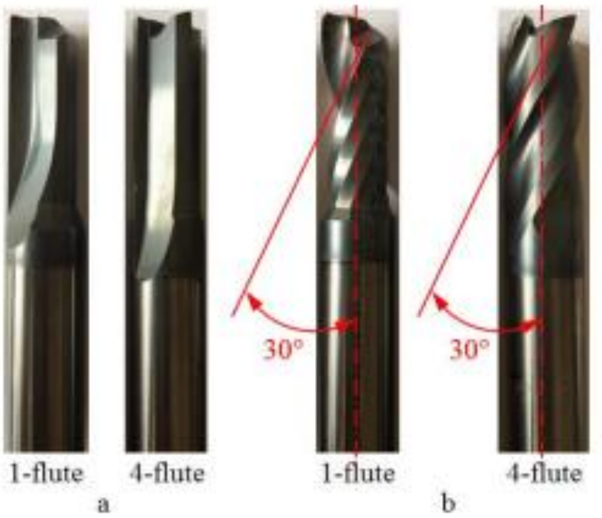


Figure 2.16: Cutting tools: (a) Straight-flute (b) Helical-flute. (Aydin, Mehmet 2021).

The stiffness of the cutting tool can be affected by the number of flutes. Larger chip gaps are more common in tools with fewer flutes, which leads to more robust tool geometry and maybe higher resistance to deflection and chatter. This may be advantageous when cutting tougher materials or in jobs that call for stronger cutting pressures. (Aydin, Mehmet 2021) summarized that in a rigid end milling operation, tool runout creates significant variation in the cutting force curve across the rotation of a multi-flute tool. Furthermore, the flutes on the high side of a cutting tool with runout experience higher force peaks than those on the opposite side. Thus, the runout effect should be considered while analysing cutting forces in end milling.

2.7 Tool Wear

Tool wear is the term for the slow degradation or harm that occurs to cutting tools during machining or other material removal processes. It is a typical occurrence in manufacturing and machining operations and can have a significant effect on the quality of the machined part, tool life, and production costs.

Nguyen, Nhu Tung (2021) presented tool deterioration, machining surface roughness, etc. are chosen as the parameters that characterize for the quality and efficiency of the milling process because they are very important characteristics. Numerous studies have been conducted up to this point to assess the impact of technological variables and cutting conditions on tool wear and machining surface roughness to enhance quality and decrease cost and time of machining processes.

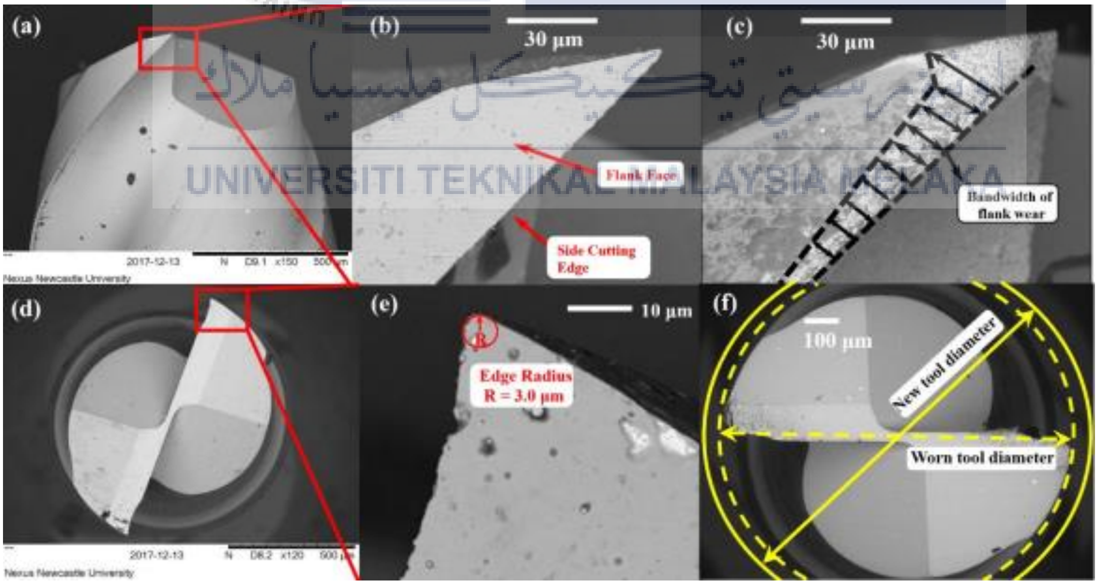


Figure 2.17: a) A side view of a brand new tool; (b) the flank face of the brand new tool; (c) the measurement method of the tool flank wear; (d) a top view of brand new tool; (e) the mesurement method of the tool edge radius; (f) the measurement method of the worn tool diameter loss. (Lu Zheng 2020).

2.8 Dimensional Accuracy

Dimensional analysis is a mathematical method used in physics and engineering to examine and comprehend the relationships between various physical quantities. To learn more about the behavior and connections between the quantities in a given problem or equation, one must look at their dimensions. Omar Monir Koura (2021) summarized that Increasing the spindle speed beyond 800 RPM offers improvements in both pocket dimensional accuracy and pocket roundness for the part. Operating at lower speeds can lead to built-up edge issues, while higher speeds introduce greater deflection to the end mill, resulting in errors in diameter size and pocket roundness.

2.9 Surface Roughness

Surface roughness refers to the irregularities or deviations present on the surface of an object. It provides a quantitative assessment of a surface's waviness, unevenness, and texture. A wide variety of products and components' performance, functionality, and appearance can all be significantly impacted by surface roughness. Surface roughness is typically characterized by several parameters, Ra (Arithmetic Average Roughness),Ra represents the arithmetic average of the vertical deviations from the mean surface. It provides a measure of the average roughness of the surface texture.

Additionally, Rz (Average Maximum Height), Rz measures the average of the vertical distances between the highest and lowest points within sampling lengths on the surface. Rq (Root Mean Square Roughness), Rq calculates the root mean square of the vertical deviations from the mean surface. It provides a measure of the standard deviation of the roughness profile. Rt (Total Roughness), Rt represents the vertical distance between the highest peak and the lowest valley within a sampling length. In the machining process, surface roughness is a crucial quality indicator, including three-axis pocketing profiles milling for aero-structural parts.

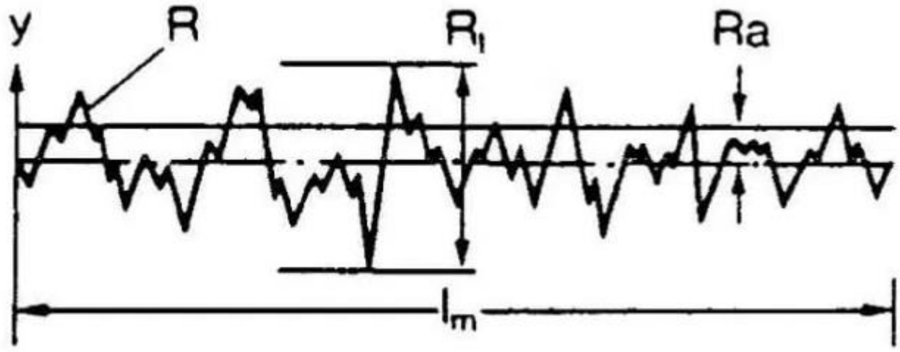


Figure 2.18: Surface Roughness Parameters

Source: (https://www.stahliusa.com/stahli-publication/the-technique-of-lapping/surface-finish-quality/)

Previous studies have primarily concentrated on surface roughness in machining milling process. In CNC milling, the texture or imperfections on the milled surface are referred to as surface roughness. Several variables, such as the cutting settings, tool choice, workpiece material, and machine condition, affect achieving the appropriate surface roughness. Nguyen, Nhu Tung (2021), have proposed not only is milling a typical machining procedure, but it is also one of the ones that CNC machines employ the most. Tool wear, machining surface roughness, and other crucial traits are often chosen as the metrics that define the effectiveness and quality of the milling process. Numerous research has been conducted up to this point to determine the impact of technical variables and cutting circumstances on tool wear and machining surface roughness to increase machining process quality while lowering costs and cycle times.

Theoretical models were used to predict tool wear and surface roughness based on physical, chemical, and geometrical processes including friction, temperature, cutting, etc. K. Danesh

Narooei (2022) measured the surface roughness in milling machining of AA6061-T6 in their experimental work. Regression analysis is used to create a realistic surface roughness prediction model once the experiment is run to gather the necessary data. Surface roughness is greatly influenced by the cutting parameters, such as cutting speed, feed rate, and depth of cut. To achieve the appropriate surface quality, these factors must be properly chosen and optimised. While severe cutting conditions may produce rougher surfaces, higher cutting speeds and lighter feed rates often provide smoother surfaces.

Figure 2.19: Surface roughness tester Mitutoyo SV-C3100W4. (K. Danesh Narooei 2022).

(DUAN, Zhenjing 2021) reported that surface smoothness is determined by surface roughness, which is a crucial measure for evaluating the workpiece's surface quality. Surface roughness is defined as a small area of the processed surface and small, irregular features of micro-geometry. High surface smoothness is reflected in low surface roughness. Surface roughness has a significant positive impact on workpiece corrosion resistance, contact stiffness, and fatigue strength. Surface roughness also affects the dependability and service life of industrial goods. Poor surface quality will reduce a workpiece's performance and cause it to fail earlier than intended.

2.10 CATIA V5

The computer-aided design (CAD) software package CATIA V5, created by Dassault Systèmes, is robust and extensively used. In a variety of sectors, such as aerospace, automotive, and consumer products, it provides a complete set of tools for product design, engineering, and production. Robust 3D modeling capabilities offered by CATIA V5 enable users to build intricate 3D models of components and assemblies. It supports both surface and solid modeling methods, allowing the development of complex geometries and slick surfaces. (Sundi Syahrul Azwan 2017) proposed, The CAM software is made using the Advanced Machining Workbench in Catia V5. Surface machining method supplied by Catia V5 is known as the "Sweeping" method.

(Rozmarina Dubovska 2014) showed the following specific actions are required for the design of machining on CNC machining centers in the CATIA V5 Lathe and Prismatic Machining modules of the CAD/CAM system.:

- Determining appropriate and Geometric BODY SET for parts and semi-on working tree. Create a 3D model.
- Creating a blank (rough stock) with those allowances which will be model.
- Going to the machine mode of CAD/CAM system and set tool parameter, which will perform roughing model.
- Defining the strategy of machining operations, which are determined semi-alone model, the machining allowance, tolerances, cutting speed and feed motion of the machine tool path.
- Setting the proper parameters of the other cutting tools which will perform profiling.

- Milling and turning machine tools to be stored in the machining centre in preparation for the fabrication and inspection of the CAM. Running simulations output control machining (can see on Fig. 2.16, 2.17).
- CNC program in the ISO format, as appropriate CNC machine tool and CNC control system.

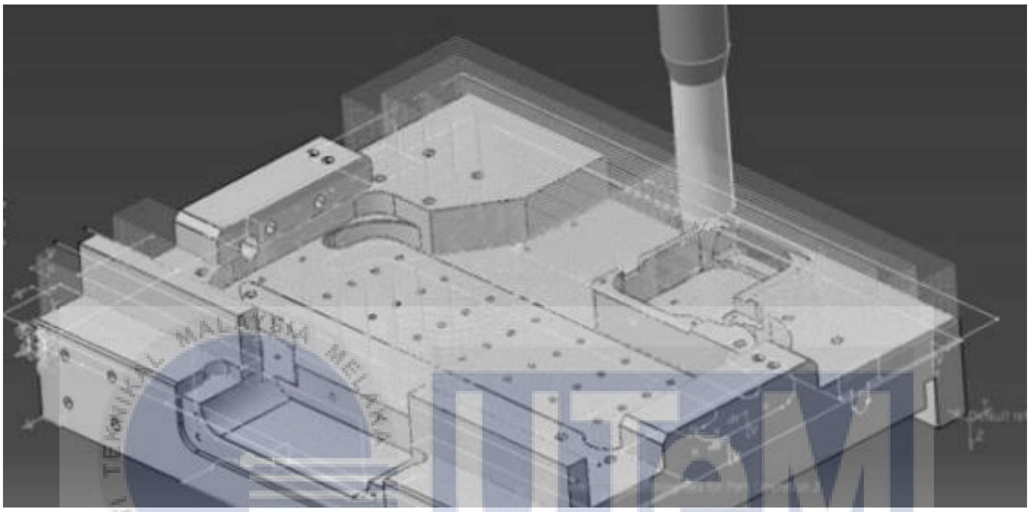


Figure 2.20: Milling Process (Rozmarina Dubovska 2013).

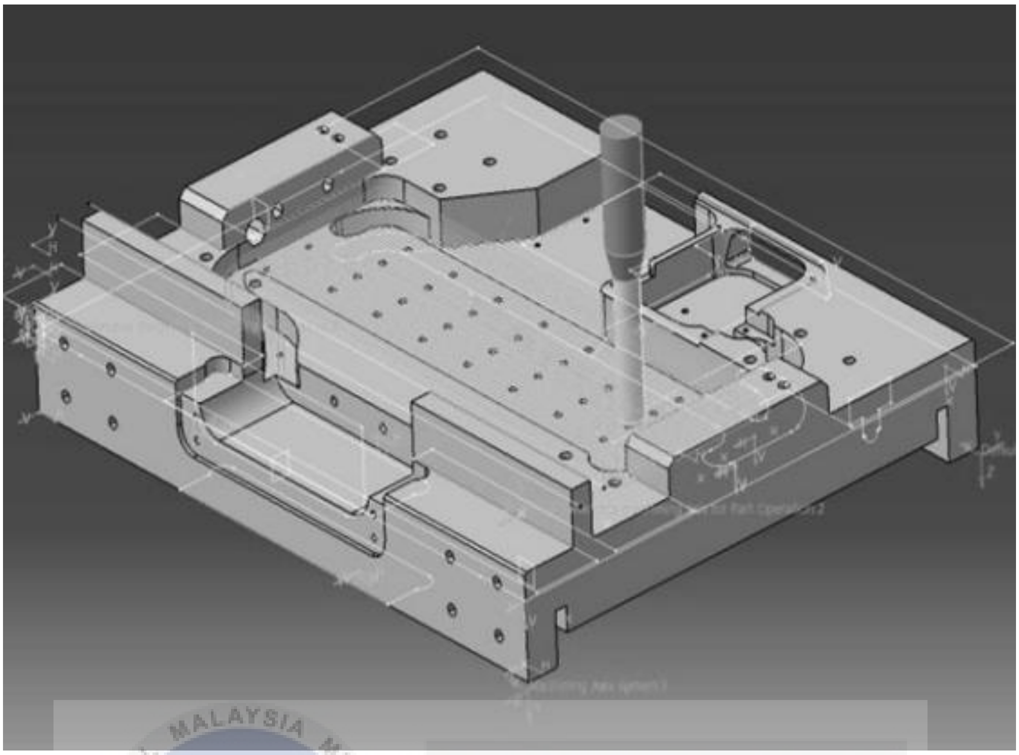


Figure 2.21: Virtual simulation in CATIA V5 (Rozmarina Dubovska 2013).

2.11 Design of Experiment (DoE)

In recent years, several studies have focused on design of experiments it a methodical strategy used to design, carry out, analyse, and improve experiments. It entails planning a systematic experiment to collect information and make inferences about the variables or factors that affect a process or system. DOE helps in comprehending the linkages between these variables and their effects on the desired outputs or responses. By methodically altering the factors and identifying the corresponding answers, DoE enables researchers to obtain enough information to make meaningful choices about how the factors affect the response variables. Nevertheless, the Taguchi orthogonal array method will be employed for planning.

2.12 Taguchi Method

The Taguchi technique uses statistical methodology to designing experiments for product or process quality improvement and optimisation. It is frequently used in many different sectors to lower variation, increase performance, and increase resilience. The goal of the Taguchi approach is to minimise quality loss brought on by deviation from the target value. It estimates the cost or loss resulting from departures from the required standards and works to reduce it. The Taguchi approach reduces experimental time, cost, and variance, and improves product or process quality. It simplifies experimental design and optimisation, improving problem-solving and performance. The Taguchi approach has been criticised for its use of orthogonal arrays, linear relationship assumptions, and inability to handle complicated systems. For meaningful results, statistical techniques must be used, interpreted, and considered in context. Taguchi's method of Analysis has been prompted to be an efficient method to study the behaviour and to finalize optimal combinations of the control factors so as to achieve the efficient output response. (Thankachan, Titus 2019).

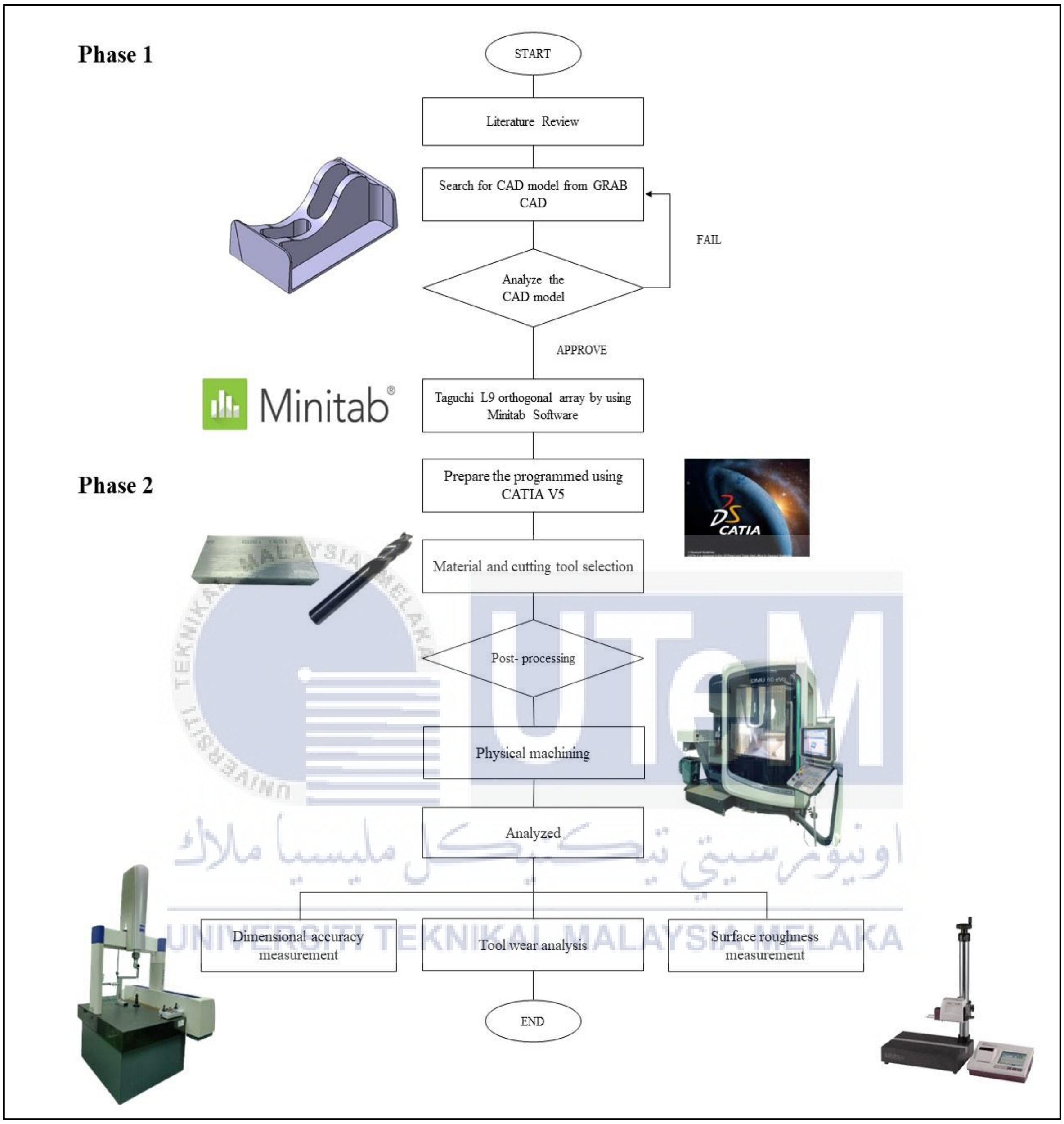
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the flow of the project in studying the proposed project. The proposed project is titled ‘the effect of cutting tools geometry during machining pocketing profiles of aerospace part – various machining strategies. Phase I and Phase II constitute the two sections of the strategy. Phase I's activities included a review of the literature, seeking out CAD models, and analysing those models. However, Phase II of the process begins with the creation of the CAM programme, the selection of the material and the tool, the choice of the machining settings, and the measurement of the surface roughness.

3.2 Process Flowchart



3.3 CAD model selection

In the cad model search phase, the search was conducted using the Grab Cad website, aerospace parts being the priority in this study. The model also needs to relate to the given title of pocketing profiles to study the effect of cutting tools. Therefore, there are several parts of aerospace that have been found. Next, the found parts of aerospace need to be discussed and get the project supervisor's approval. Therefore, agreed with the aerospace part named Jazk Aileron Bracket for Airbus A320 as presented in figure 3.1.

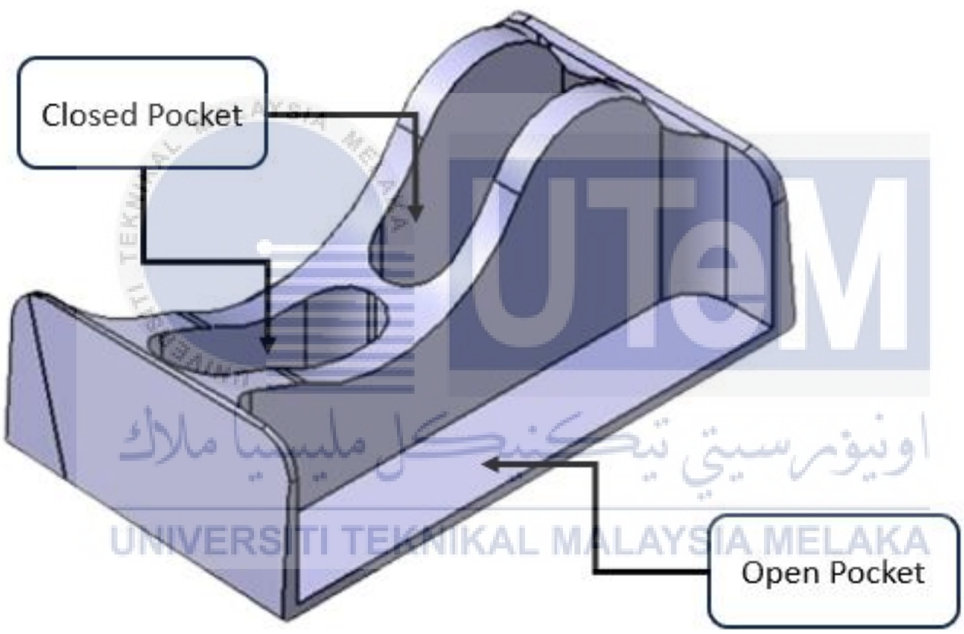


Figure 3.1 CAD model

It has been shown that this CAD model has a bigger dimension than expected during this step of the selecting process. As a result, this CAD model must be scaled for better size. After analysing the dimension, the CAD model is scaled to 0.6 using SolidWorks 2023 software.

3.4 Material Details

Aluminum alloys from the 6xxx range were the material employed in this experiment. The 6xxx series of aluminum alloys is a widely used group of alloys that are known for their excellent combination of strength, formability, and corrosion resistance. These alloys primarily contain magnesium and silicon as their main alloying elements. Figure 3.2 shows the material used in this experiment.

Figure 3.2 Aluminum 6061 T651 (6series)

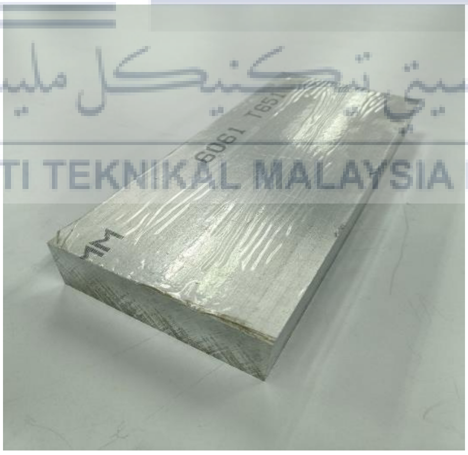


Figure 3.3:Aluminum 6061 T651 (6series)

3.5 Cutting tool selection

The cutting tool used in this experiment was end mill carbide with diameter 8mm, and 2, 3, 4 number of flutes and standard helix angle 10°,30°, and 50° based on Figure 3.5, 3.7, 3.9, 3.11, 3.13, 3.15, 3.17, 3.19, and 3.21. The drawing of the cutting tool is displayed in Figure 3.6, 3.8, 3.10, 3.12, 3.14, 3.16, 3.18, 3.20, and 3.22. The cutting tool specification is stated on Table 2.

Figure 3.4: End mill carbide with diameter 8mm, 2 flutes and helix angle 10°

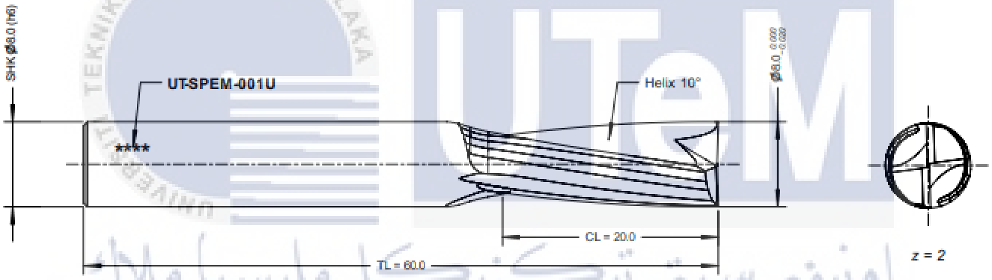


Figure 3.5: Drawing of end mill carbide with diameter 8mm, 2 flutes and helix angle 10°

Figure 3.6: End mill carbide with diameter 8mm, 2 flutes and helix angle 30°

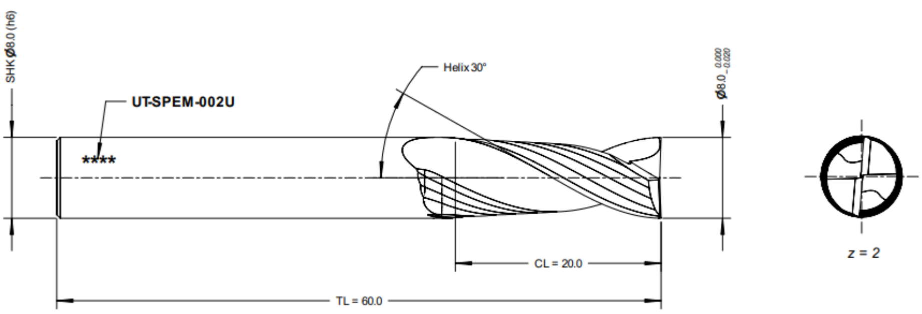


Figure 3.7: Drawing of end mill carbide with diameter 8mm, 2 flutes and helix angle 30°

Figure 3.8: End mill carbide with diameter 8mm, 2 flutes and helix angle 50°

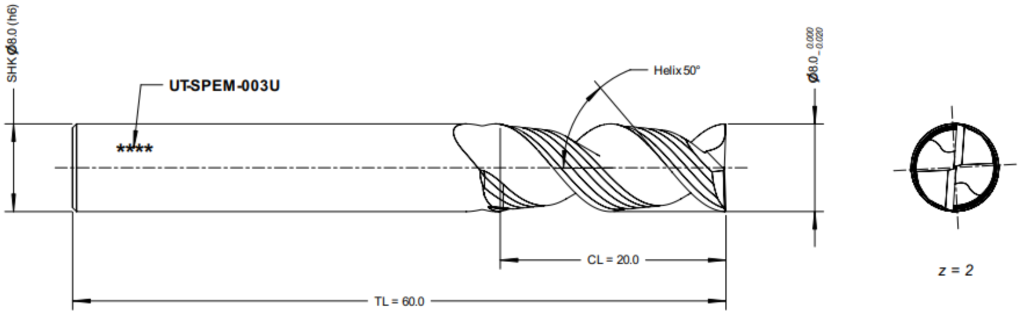


Figure 3.9: Drawing of end mill carbide with diameter 8mm, 2 flutes and helix angle 50°

Figure 3.10: End mill carbide with diameter 8mm, 3 flutes and helix angle 10°

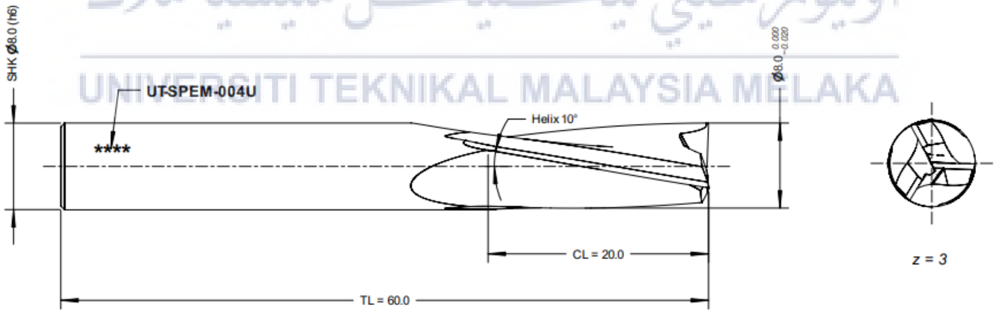


Figure 3.11: Drawing of end mill carbide with diameter 8mm, 3 flutes and helix angle 10°

Figure 3.12: End mill carbide with diameter 8mm, 3 flutes and helix angle 30°

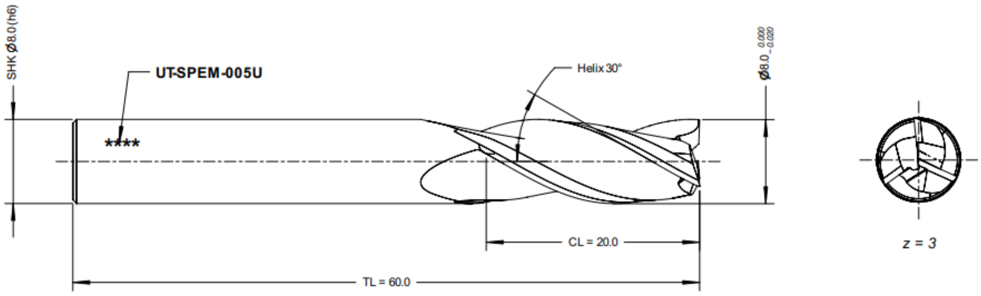


Figure 3.13: Drawing of end mill carbide with diameter 8mm, 3 flutes and helix angle 30°

Figure 3.14: End mill carbide with diameter 8mm, 3 flutes and helix angle 50°

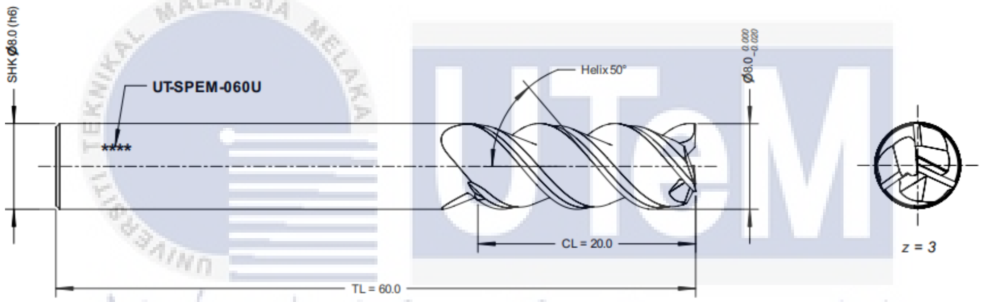


Figure 3.15: Drawing of end mill carbide with diameter 8mm, 3 flutes and helix angle 50°

Figure 3.16: End mill carbide with diameter 8mm, 4 flutes and helix angle 10°

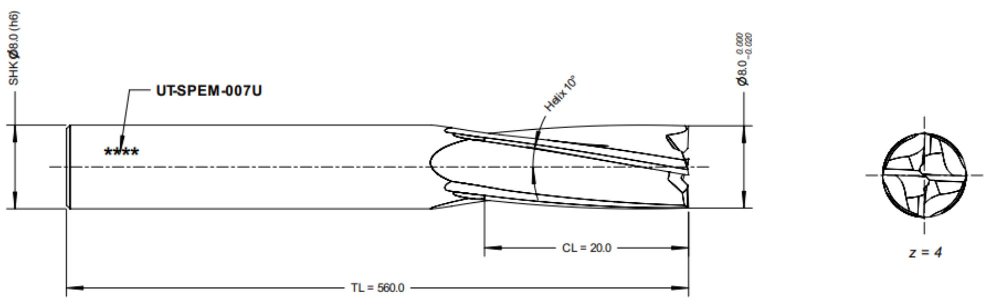


Figure 3.17: Drawing of end mill carbide with diameter 8mm, 4 flutes and helix angle 10°

Figure 3.18: End mill carbide with diameter 8mm, 4 flutes and helix angle 30°

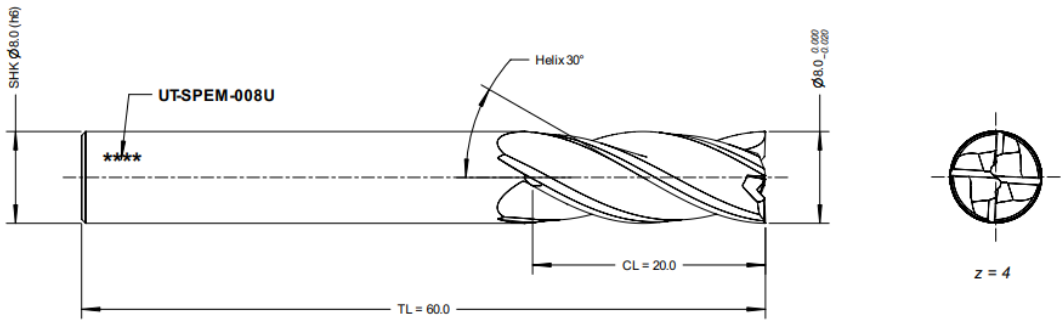


Figure 3.19: Drawing of end mill carbide with diameter 8mm, 4 flutes and helix angle 30°

Figure 3.20: End mill carbide with diameter 8mm, 4 flutes and helix angle 50°

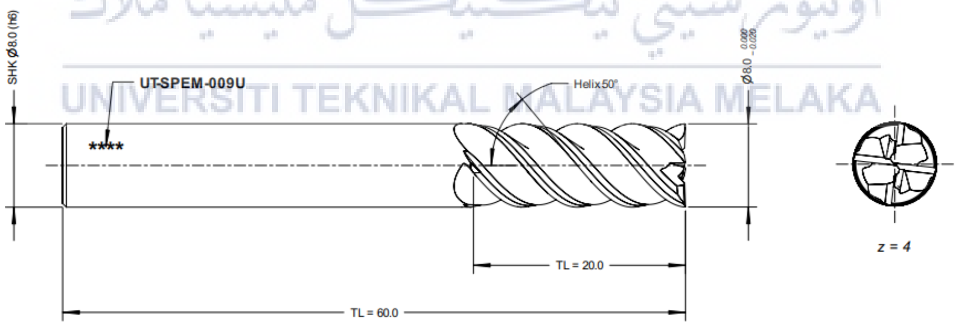


Figure 3.21: Drawing of end mill carbide with diameter 8mm, 4 flutes and helix angle 50°

Table 1: Cutting Tool Specifications

Type of cutting tool	Diameter (mm)	Number of flutes	Helix angle (°)	Cutting length (mm)	Total length (mm)
End mill	8.0	2	10	20.0	60.0
End mill	8.0	2	30	20.0	60.0
End mill	8.0	2	50	20.0	60.0
End mill	8.0	3	10	20.0	60.0
End mill	8.0	3	30	20.0	60.0
End mill	8.0	3	50	20.0	60.0
End mill	8.0	4	10	20.0	60.0
End mill	8.0	4	30	20.0	60.0
End mill	8.0	4	50	20.0	60.0

3.6 Machine specification

DMG MORI DMU 60 eVo three axis machine was used to perform the machining process in this research based on figure 3.22. Table 2 proven specification of the machine.

Figure 3.22: DMG MORI DMU 60 eVo

Table 2: Machine Specification

Parameter	Specification
Max. X-axis travel distance	600 mm
Max. Y-axis travel distance	500 mm
Max. Z-axis travel distance	500 mm
Spindle speed	20 000 rpm
Working area	850 x 600 x 450 mm
Max workpiece weight	400 kg

3.7 Preparation for the CAM program

This experiment provided an important opportunity to advance the understanding of using CATIA V5 software. In order to successfully complete this experiment, it is necessary to prepare the CAM program by using CATIA V5 software. However, the process involved in this CAM program preparation is various machining strategies. It is most important to consider the machining parameters in order to achieve the main objective of this experiment.

3.7.1 Stock

The aluminum raw material will cut to 352mm x 151mm x 40mm. By using a bandsaw machine. The raw material will be cut into 9 pieces. The size of stock is 100mm x 70mm x 50mm. One of the parts is prepared as reserve stock in case there is any accident happening and to avoid postponing the machining period. Figure 3.23 showing the stock will be used in the experiment.

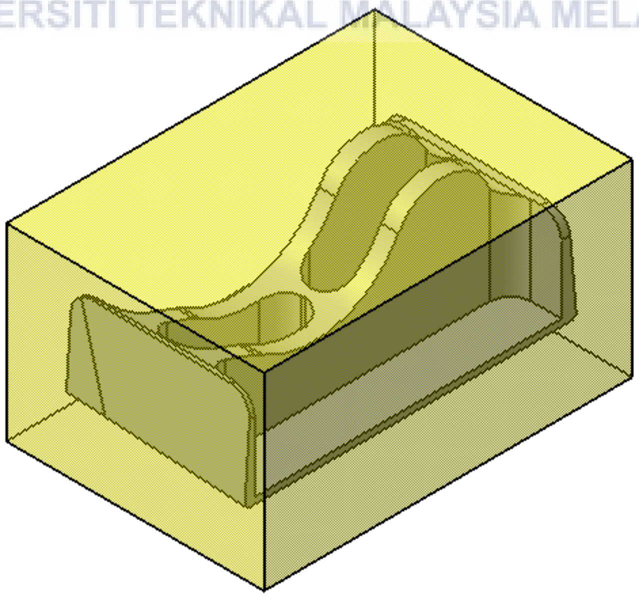


Figure 3.23: Stock

3.7.2 Plane

There are two planes built in a plane system with dimensions of Z = + 100 mm which define them as home, Z = + 50 as approach plane. A point was set at the top of plane system as home position. The Axis system is set to further assembly process. Figure 3.24 demonstrates as plane system.

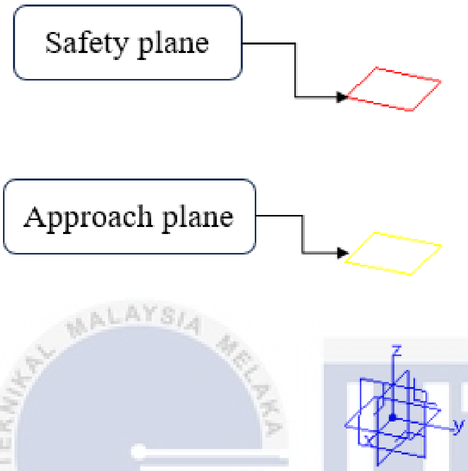


Figure 3.24: Plane system

3.7.3 Assembly process

It is necessary to assemble the plane system and stock once the creation of the pieces has been completed. Figure 3.25 trade shows the assembly process between plane sytem and stock.

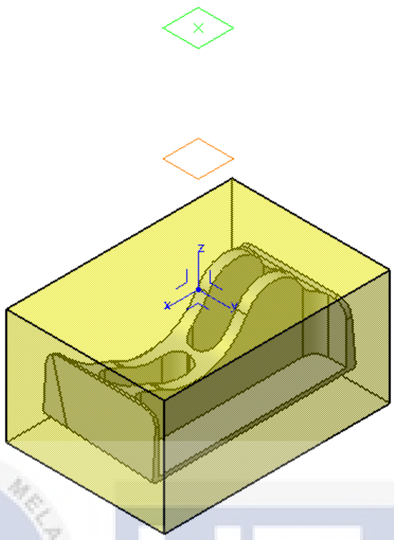


Figure 3.25: Assembly plane system and stock

3.7.4 Part operation

Firstly, CAM process in CATIA V5 starts with definition of part operation. The basic components in part operation that necessary set are type of machine, product or part, reference machining axis system, design part for simulation, and stock of product as establishes in figure 3.26.

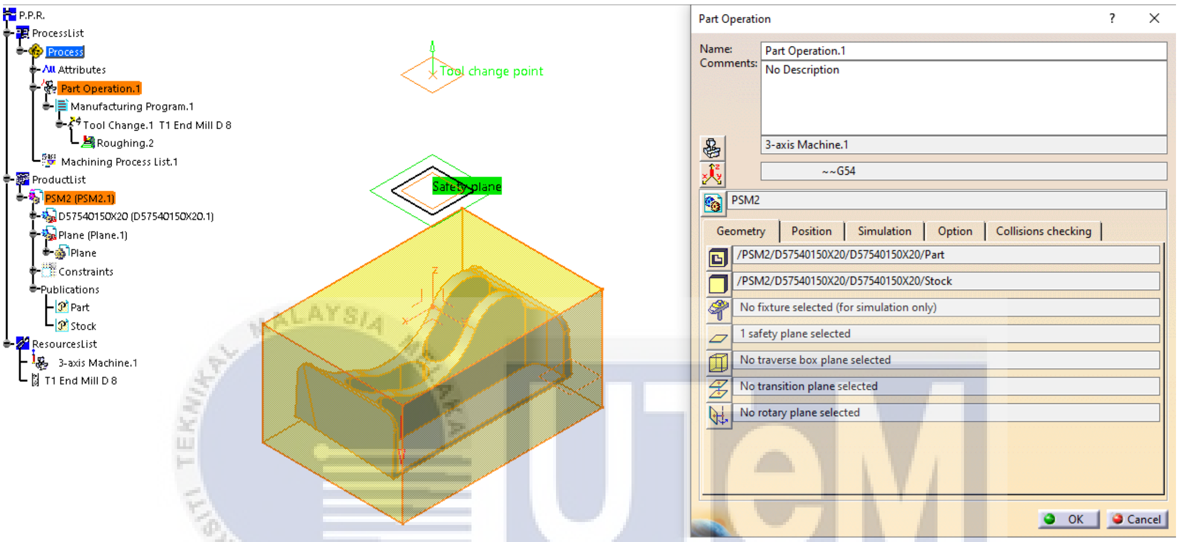


Figure 3.26: Operation

3.7.5 Define machine

In machine editor, three axis machine was selected due to the complexity of part and machining movement. The post processor words table was selected is IMSPPCC-V6. pptable. Figure 3.27 exhibits the selected machine and post processor.

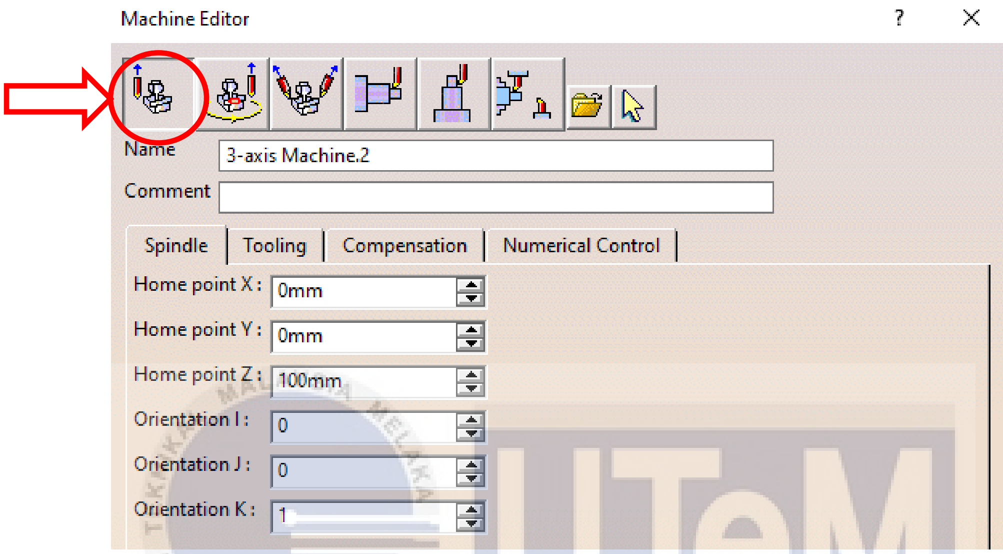


Figure 3.27: Machine Selection

3.7.6 Define axis system.

Axis system is selected on axis system that have been assembly during process of assembly. Axis system always set at the origin of the part as it functions as tool position before start and end of machining. Axis system helps to ensure movement of cutting tools will not damage the part or product before, during and after machining process. Figure 3.28 shows the selected reference axis.

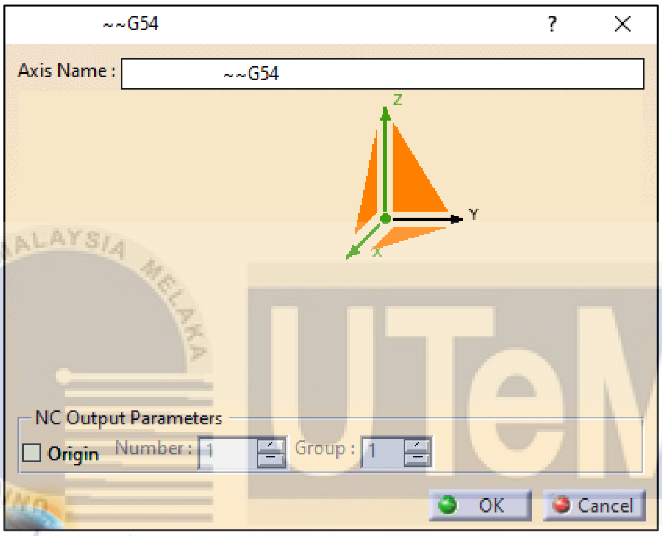


Figure 3.28: Axis system

3.7.7 Define the product

Product in part operation is defined by browsing the CAD model product which consists of assembly plane system and stock in CATIA product file type. Product defined in part operation is very important as it shows part that undergoes machining process during this part operation. Figure 3.29 illustrates how to select product.

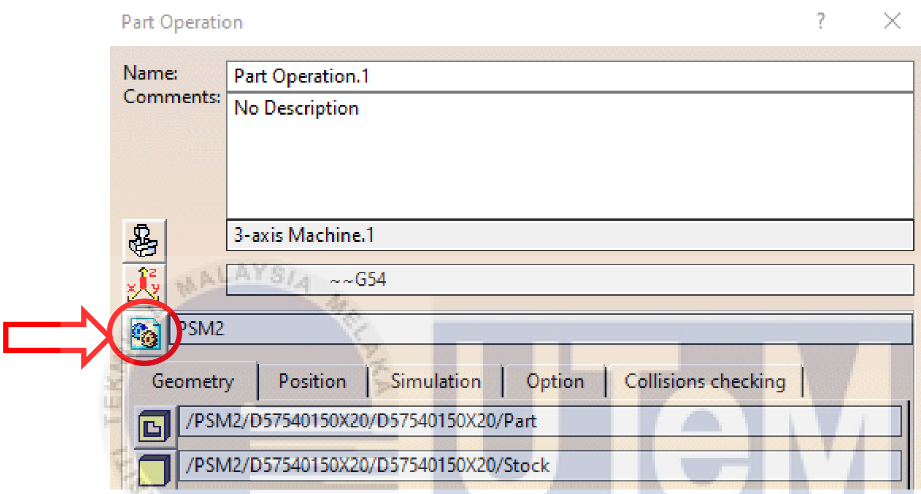


Figure 3.29: Product Select

3.7.8 Define the part

After defined product, cad part inside defined product was selected with the stock and plane system. Hidden stock before the part is needed to avoid stock being selected and confusion on the selection. Figure 3.30 show up how selected part.

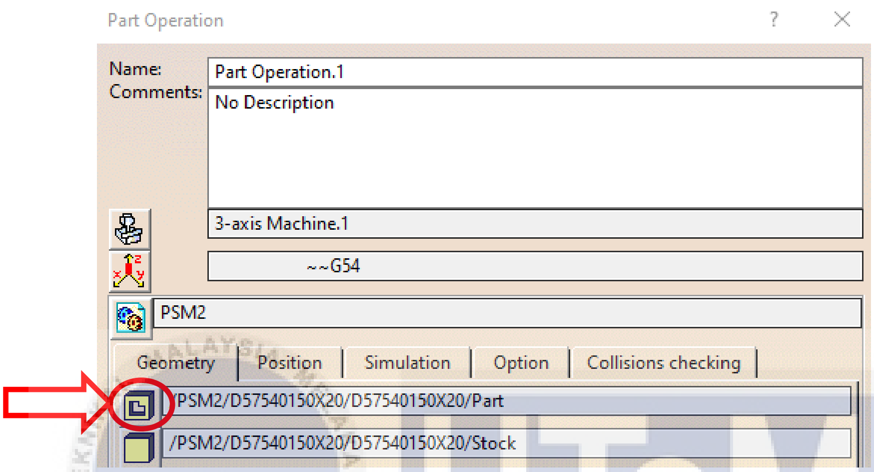


Figure 3.30: Selected part

3.7.9 Define the stock

Stock will be selected after the part has been selected. Stock was selected appropriately after unhidden to provide the information for machine. This information helps to differentiate between part body and stock. Figure 3.31 indicates how to define the stock.

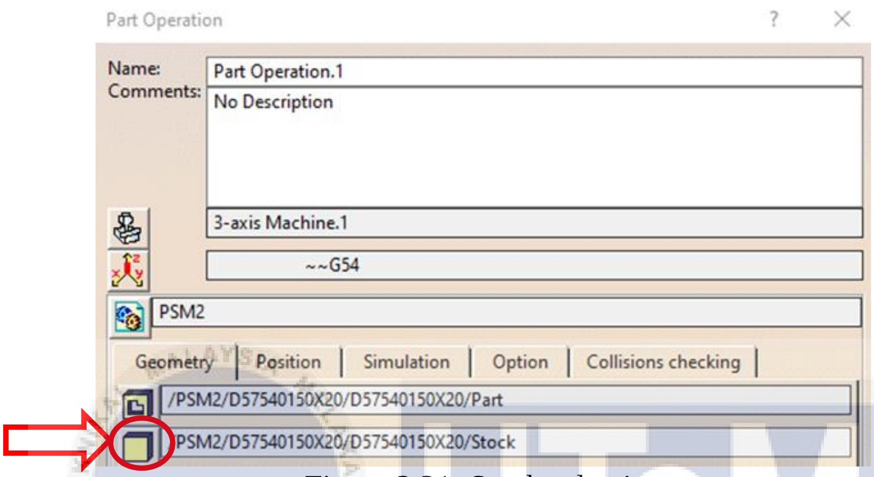


Figure 3.31: Stock selection

3.7.10 Define the tool

Dimension, surface, and the shape of the product in CAD will decide the appropriate tools for machining. Selection of cutting tools also depends on the machining strategy and the minimum radius of tip. Also, by using the efficient dimension of cutting tools are able to reduce the cutting time and increase the accuracy. Creation appropriate tools were required for machining process and the dimensional detail of each tool were filled. There were two cutting tools that will used which was End Ø10 mm for roughing, and for pocketing milling Ø 8 mm.

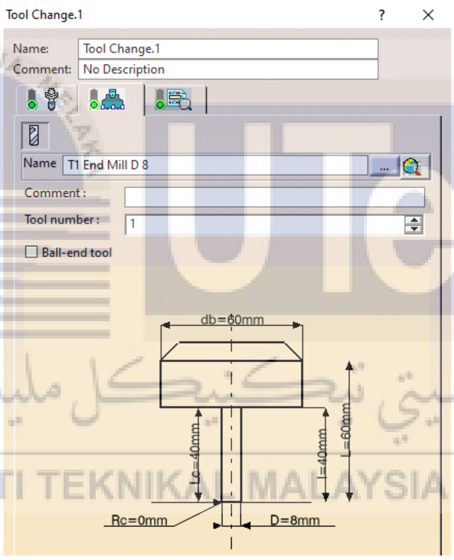


Figure 3.32: Tool selection

3.7.11 Manufacturing program

The compilation of process standards is referred to as the manufacturing program. Each machining process includes tool change settings, geometry to machine, strategy to machine, and macro. The machining method of this research is depicted in figure 3.33, and the details of each operation are discussed further.

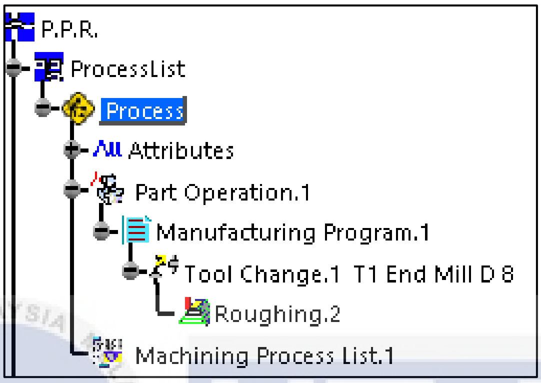


Figure 3.33: Program for machining

Machining strategy can be customized for each programmer; there is no standard method for configuring machining strategies. The methods for determining machining techniques were determined by the CAM programmer's expertise and experience. The machining planning approach should be developed early on. As a result, machining planning is a critical step before determining the sequencing of the machining process. The CAM process flow chart is presented below.

3.7.12 Roughing operation

Roughing operation helps to remove non-essential material quickly and obtain machining part as close as possible to the desire shape. It can greatly reduce the cutting time. Roughing is the initial process before semi finishing and finishing process are different machining processes. 1mm left by roughing process before part entering pocketing milling process. By using 8mm diameter of flat end mill. In axial page, maximum cut depth was set as 1.25mm. Maximum depth of cut help to prevent damage of tool during machining process. The higher value maximum depth of cut, the higher the percentage damaging of tool. Besides, value offset on part and offset on check are set as 1mm which means material left after roughing process. Purpose of excess material is to undergo semi finishing and pocketing milling operation. Detail about settings have been shown by figures 3.34.

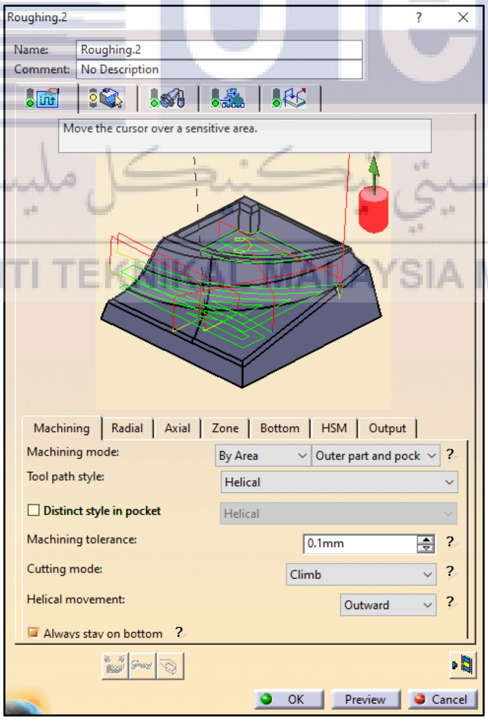


Figure 3.34: Machining strategy

The figures 3.35 appears, define the rough stock, part, bottom of the part and so on. This could improve how well the programme understands what the programmer wants.

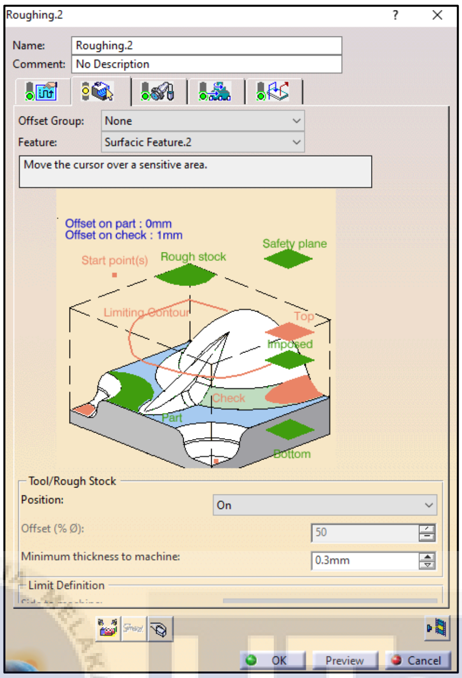


Figure 3.35: Rough stock and parts

Figure 3.36 illustrates the machining parameter (feed rate and spindle speed) can be setting in this section. The approach and retract feed rate can be different by setting the parameter in this section.

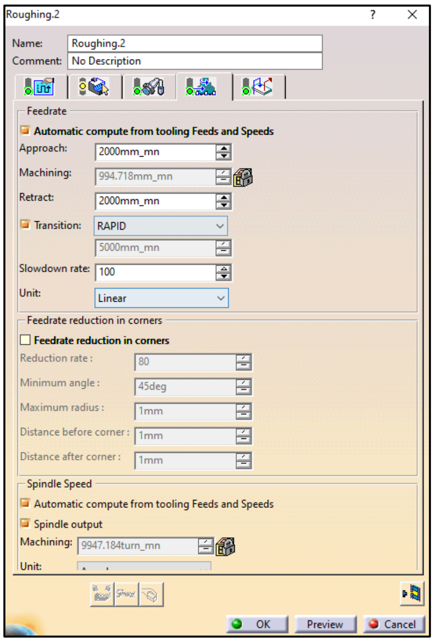


Figure 3.36: Machine parameter

Figure 3.37 presents the macro plane, which define the approach plane and safety plane. Pre-motions refers to approach and post motions refers to retract.

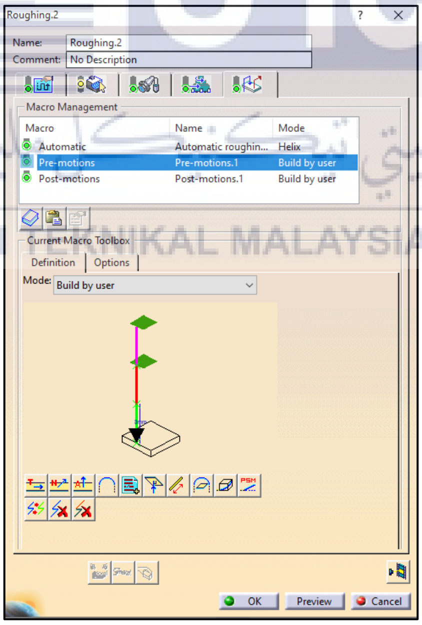


Figure 3.37: Macro plane section

After the arrangement has been made, the roughing process simulation can be carried out. The simulation's final findings are displayed in Figure 3.38.

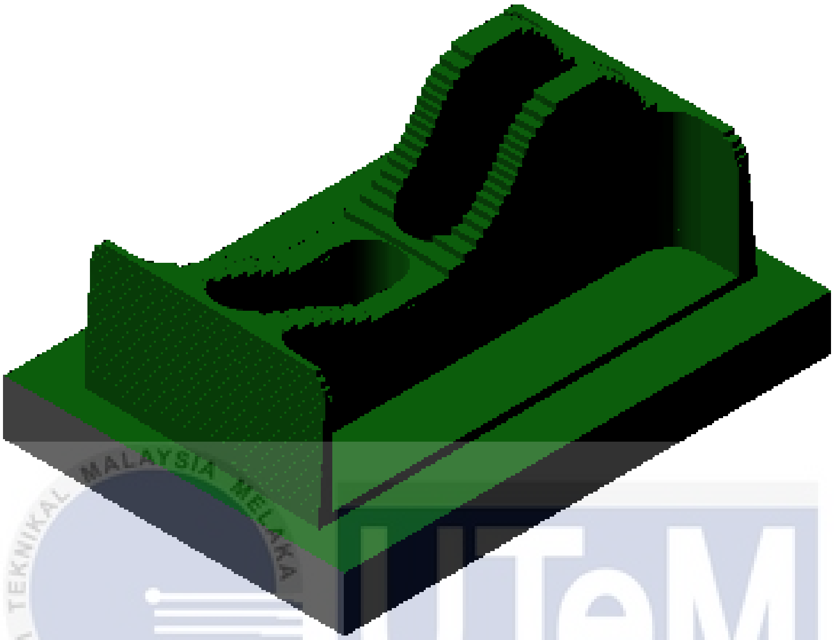


Figure 3.38: Results of simulation

3.8 Surface roughness measurement

Roughness of the surface was measured used the Mitutoyo Surfest SJ-410 machine on the materials machining component. This equipment was frequently used in the industry for measurements since it could measure up to 0. 0001 mm. Ra was calculated by using the arithmetic mean roughness to measure surface roughness for quality purposes. The stylus's travel distance was set at 5 mm for each measurement. Five measurement points were used on each machined surface to assess this work in the longitudinal measurement direction. As a result, the final average Ra for each specimen would indicate the surface finishing result. Figure 3.39 indicates Surfest SJ-410.

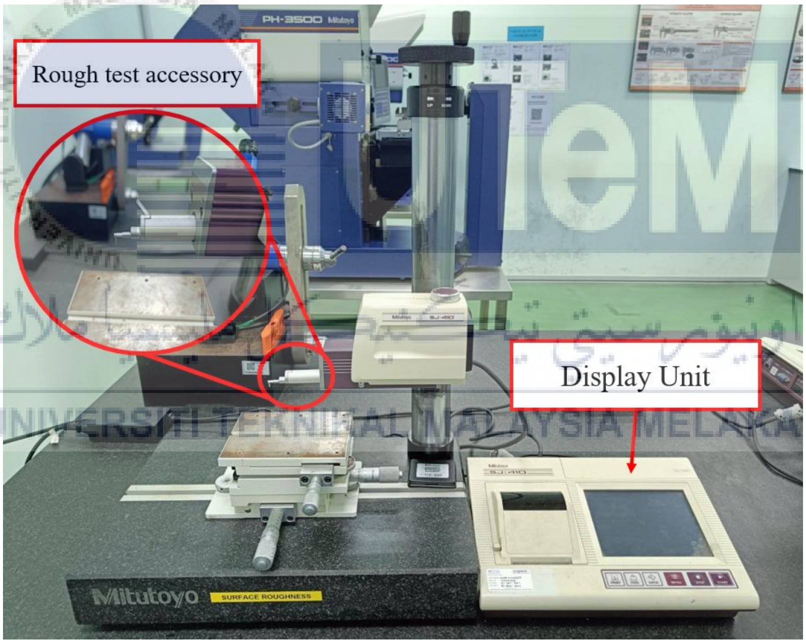


Figure 3.39: Mitutoyo STJ-410

3.9 Dimensional accuracy

Geometry of the parts was measured used the WENZEL X0 55. Cad machine on the machining component. It is a sophisticated piece of equipment that accurately determines the position of points on the object's surface in a three-dimensional Cartesian coordinate system (X, Y, and Z axes). CMMs utilize a probing system, typically a touch-trigger or continuous contact probe, to gather data points by physically contacting the object being measured. These probes are attached to precision linear scales or encoders that track their position along the CMM's axes. The collected data points are processed by specialized software that calculates various geometric parameters and dimensions of the object, such as distances, angles, straightness, flatness, and more. CMMs are known for their high accuracy, often capable of measuring with sub-micron or even nanometer-level precision. The machine of CMM was shows in Figure 3.40.

Figure 3.40: Coordinate Measuring Machine (CMM WENZEL X0 55).

3.10 Observation on tool wear

The Nikon measuring microscope MM-800 will be used to examine tool wear. This microscope can be zoomed from 1x magnification to 100x magnification. This will make it easier to notice the tool damage. To observe tool wear, hold the router tool horizontally. The picture captured by the microscope was processed using the data processing program E-Max. This E-Max program includes a comprehensive picture analysis for evaluating the structure and size of visual information. Aside from that, it has the capacity to manipulate data and collect sophisticated picture analysis, which converts photos into a trustworthy statistic. The Nikon measuring microscope MM-800 was illustrates in Figure 3.41.

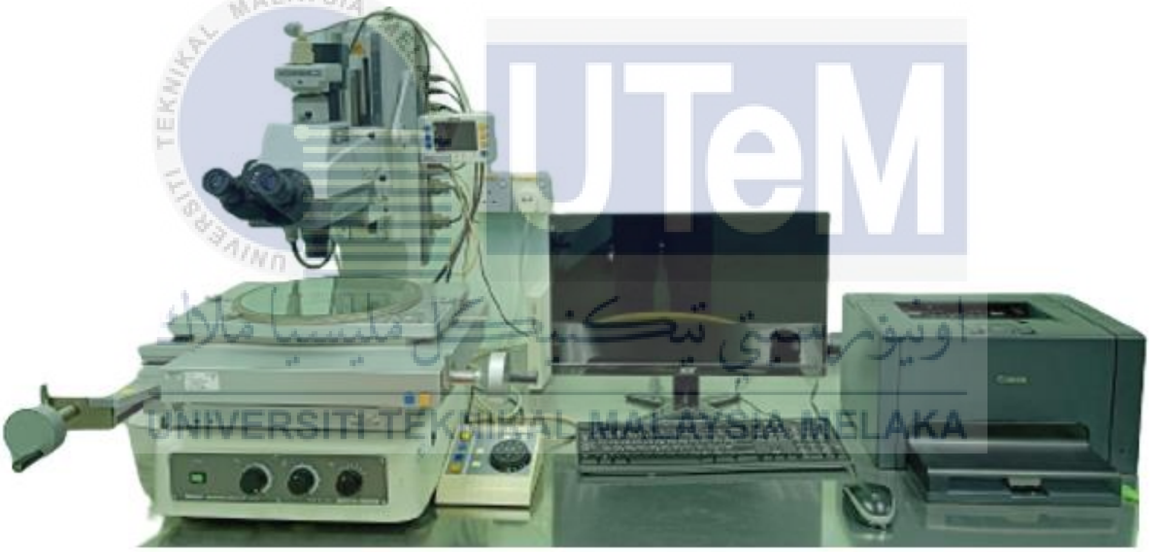


Figure 3.41:Nikon MM-800

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 Introduction

The projected outcomes based on surface roughness, tool wear, and dimensional accuracy will be presented in this chapter. This chapter addressed the analytical issue. The anticipated outcome of the study, which concentrates on examining the impact of cutting tool geometry during roughing operations for aerospace pocketing profiles, involves the analysis and discussion of the results obtained from the surface roughness analysis conducted using the SJ-410 instrument, the study involves the observation of damage on the cutting tool and the machined surface using the Nikon MM-800 microscope, as well as the analysis of dimensional accuracy of the machined parts using a Coordinate Measurement Machine (CMM). To accomplish these objectives, various tool geometries and techniques will be utilized. A total of nine different tool geometries will be employed, which involve different helix angles (10°, 30°, and 50°) and varying numbers of flutes (2, 3, and 4) during the machining process. An 8mm end mill will be utilized as the cutting tool diameter for the roughing operation.

In addition, the study will examine the dimensional accuracy, conduct surface roughness analysis, and observe tool wear that arises during the machining process. The anticipated findings of this research will provide valuable insights into the impact of cutting tool geometry on roughing operations for aerospace pocketing profiles, thereby enhancing the overall understanding in this field.

4.2 Surface roughness

Surface roughness refers to the texture or irregularities on the surface of a material, specifically the deviations from an ideal flat surface. It is crucial aspect in manufacturing and engineering, as it can affect the functionality,appearance, and performance of machined of manufactured parts. Surface roughness is typically measured in terms of the small-scale variations in the height of the surface features. The surface finish is influenced by factors such as cutting speed, spindle speed, and feed rate. In the intial phase of the experiment, the focus is analyzing surface roughness. The examination involves the utilization of the Surftest SJ-410 surface roughness tester manufactured by Mitutoyo, as detailed in Section 3.8. The assessment is carried out on two distinct regions of the pocket, the open pocket and closed pocket. There are a total of 10 points located within the closed pocket and 16 points within the open pocket, as visuall depicted in Figures 4.1, 4.2, and 4.3.

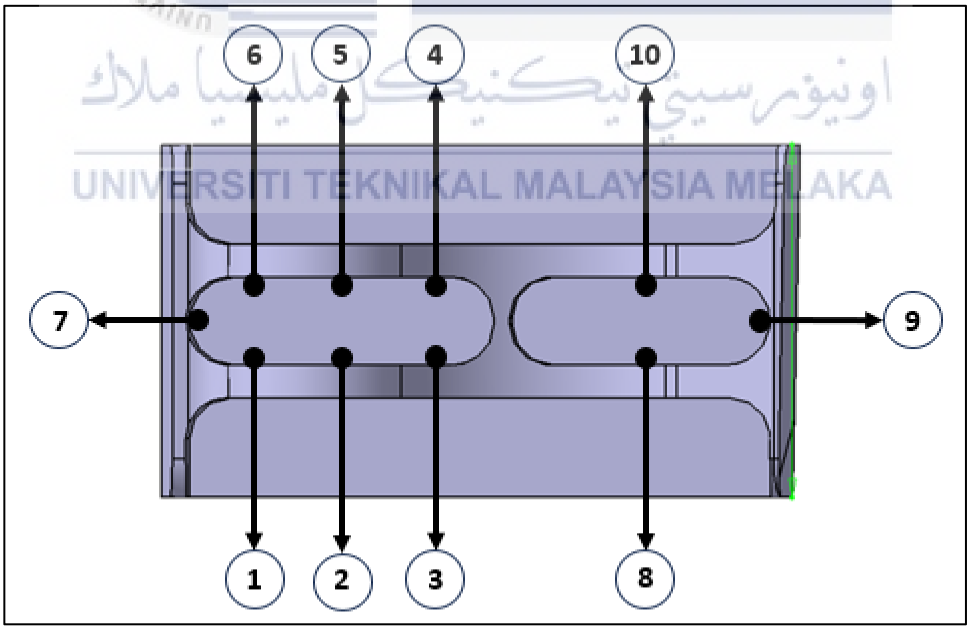


Figure 4.1: Points selected for the analysis of surface roughness within the ***closed pocket***.

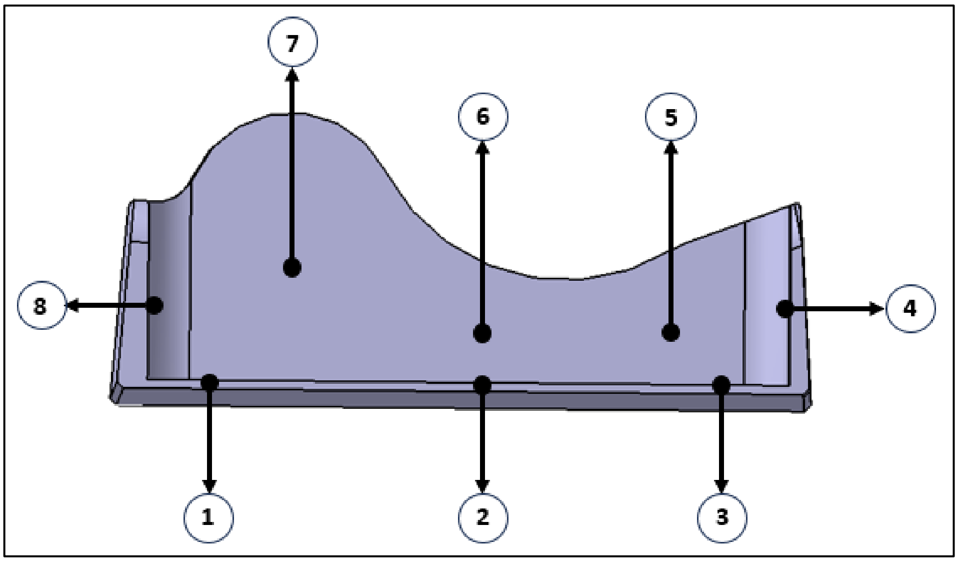


Figure 4.2: Points chosen for the analysis of surface roughness on the left side of the ***open pocket.***

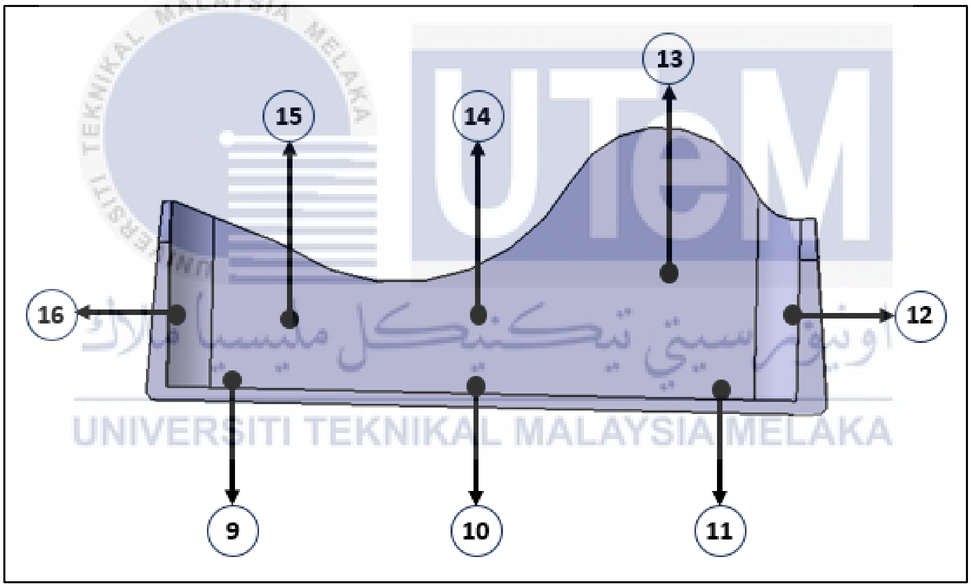


Figure 4.3: Points chosen for the analysis of surface roughness on the right side of the ***open pocket.***

Table 3: Surface roughness data for the ***closed pocket*** area of the part.

			surface roughness		CLOSED POCKET												AVG	AVG No. Flutes
					1								2					
TOOL	FLUTE	HELIX ANGLE	weight before	weight after	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	AVG	Point 8	Point 9	Point 10	AVG		
T1	2F	10	36.087	36.088	1.51	1.46	1.28	1.97	1.67	1.86	1.69	1.63	1.14	1.76	1.42	1.44	**1.53**	**2.44**
T2		30	35.565	35.564	1.74	1.71	1.65	2.76	2.57	2.63	2.61	2.24	2.20	1.75	2.47	2.14	**2.19**	
T3		50	35.399	35.397	4.04	4.25	4.30	3.05	3.18	2.99	3.84	3.66	3.90	3.97	2.75	3.54	**3.60**	
T4	3F	10	34.983	34.981	1.68	1.57	1.05	2.44	3.36	2.33	1.14	1.94	1.77	1.57	1.03	1.45	**1.70**	**2.31**
T5		30	35.903	35.900	2.38	2.17	1.60	2.04	2.46	2.57	2.13	2.19	2.33	1.60	2.12	2.02	**2.10**	
T6		50	36.556	36.553	3.22	2.88	3.39	2.83	3.05	3.31	3.74	3.20	3.21	2.33	3.71	3.08	**3.14**	
T7	4F	10	36.847	36.844	0.84	0.97	0.56	1.10	1.50	0.90	0.96	0.98	1.40	1.80	1.06	1.42	**1.20**	**2.29**
T8		30	37.043	37.040	1.22	1.24	1.18	1.50	2.00	2.20	2.60	1.70	2.40	2.42	2.70	2.51	**2.11**	
T9		50	37.198	37.196	1.59	1.50	1.80	4.73	4.88	4.74	4.24	3.35	4.36	2.38	4.63	3.79	**3.57**	

Table 4: Surface roughness data for the ***closed pocket*** area of the part.

			surface roughness		CLOSED POCKET												AVG	AVG Helix Agl.
					1								2					
TOOL	FLUTE	HELIX ANGLE	weight before	weight after	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	AVG	Point 8	Point 9	Point 10	AVG		
T1	2F	10	36.087	36.088	1.51	1.46	1.28	1.97	1.67	1.86	1.69	1.63	1.14	1.76	1.42	1.44	**1.53**	**1.17**
T2		30	35.565	35.564	1.74	1.71	1.65	2.76	2.57	2.63	2.61	2.24	2.20	1.75	2.47	2.14	**2.19**	
T3		50	35.399	35.397	4.04	4.25	4.30	3.05	3.18	2.99	3.84	3.66	3.90	3.97	2.75	3.54	**3.60**	
T4	3F	10	34.983	34.981	1.68	1.57	1.05	2.44	3.36	2.33	1.14	1.94	1.77	1.57	1.03	1.45	**1.70**	**2.43**
T5		30	35.903	35.900	2.38	2.17	1.60	2.04	2.46	2.57	2.13	2.19	2.33	1.60	2.12	2.02	**2.10**	
T6		50	36.556	36.553	3.22	2.88	3.39	2.83	3.05	3.31	3.74	3.20	3.21	2.33	3.71	3.08	**3.14**	
T7	4F	10	36.847	36.844	0.84	0.97	0.56	1.10	1.50	0.90	0.96	0.98	1.40	1.80	1.06	1.42	**1.20**	**3.69**
T8		30	37.043	37.040	1.22	1.24	1.18	1.50	2.00	2.20	2.60	1.70	2.40	2.42	2.70	2.51	**2.11**	
T9		50	37.198	37.196	1.59	1.50	1.80	4.73	4.88	4.74	4.24	3.35	4.36	2.38	4.63	3.79	**3.57**	

Table 5: Surface roughness data for the ***open pocket*** area of the part.

			OPEN POCKET																			
			1									2										
TOOL	FLUTE	HELIX ANGLE	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	AVG	Point 9	Point 10	Point 11	Point 12	Point 13	Point 14	Point 15	Point 16	AVG	AVG	AVG No. Flutes
T1	2F	10	1.27	1.24	1.11	1.25	0.83	0.86	0.80	0.70	1.01	0.80	1.04	1.23	0.95	1.04	0.96	0.94	1.00	0.99	**1.00**	
T2		30	0.77	0.71	1.15	2.51	1.30	1.42	1.28	1.80	1.37	0.96	0.62	0.96	2.65	1.70	1.75	1.76	1.24	1.45	**1.41**	**1.68**
T3		50	1.09	0.90	1.47	4.49	2.35	2.14	1.98	3.23	2.21	1.70	0.92	1.24	4.84	3.25	3.59	3.78	5.20	3.07	**2.64**	
T4	3F	10	1.21	1.60	1.09	1.37	0.97	0.86	1.01	0.91	1.13	1.16	1.02	1.14	0.84	0.61	0.88	1.14	1.33	1.01	**1.07**	
T5		30	1.23	0.79	1.23	3.12	1.89	1.71	1.61	2.00	1.70	1.19	0.81	0.99	2.41	2.12	1.90	1.80	2.23	1.68	**1.69**	**1.45**
T6		50	0.85	0.41	1.21	3.10	1.33	1.75	2.05	2.30	1.63	0.68	0.50	0.88	2.06	1.51	1.63	1.97	3.01	1.53	**1.58**	
T7	4F	10	0.12	0.46	1.10	1.38	0.82	0.85	0.88	0.93	0.82	0.69	0.44	1.84	1.13	0.75	0.64	0.89	1.33	0.96	**0.89**	
T8		30	0.43	0.49	1.05	2.08	1.13	1.27	1.51	1.44	1.17	0.69	0.41	1.40	1.39	1.06	1.00	1.19	1.96	1.14	**1.15**	**1.15**
T9		50	0.74	0.51	0.99	2.78	1.43	1.68	2.13	1.95	1.53	0.69	0.38	0.96	1.65	1.38	1.35	1.49	2.60	1.31	**1.42**	

Table 6: Surface roughness data for the ***open pocket*** area of the part.

			OPEN POCKET																			
			1									2										
TOOL	FLUTE	HELIX ANGLE	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	AVG	Point 9	Point 10	Point 11	Point 12	Point 13	Point 14	Point 15	Point 16	AVG	AVG	AVG Helix Agl.
T1	2F	10	1.27	1.24	1.11	1.25	0.83	0.86	0.80	0.70	1.01	0.80	1.04	1.23	0.95	1.04	0.96	0.94	1.00	0.99	**1.00**	
T2		30	0.77	0.71	1.15	2.51	1.30	1.42	1.28	1.80	1.37	0.96	0.62	0.96	2.65	1.70	1.75	1.76	1.24	1.45	**1.41**	**1.22**
T3		50	1.09	0.90	1.47	4.49	2.35	2.14	1.98	3.23	2.21	1.70	0.92	1.24	4.84	3.25	3.59	3.78	5.20	3.07	**2.64**	
T4	3F	10	1.21	1.60	1.09	1.37	0.97	0.86	1.01	0.91	1.13	1.16	1.02	1.14	0.84	0.61	0.88	1.14	1.33	1.01	**1.07**	
T5		30	1.23	0.79	1.23	3.12	1.89	1.71	1.61	2.00	1.70	1.19	0.81	0.99	2.41	2.12	1.90	1.80	2.23	1.68	**1.69**	**1.81**
T6		50	0.85	0.41	1.21	3.10	1.33	1.75	2.05	2.30	1.63	0.68	0.50	0.88	2.06	1.51	1.63	1.97	3.01	1.53	**1.58**	
T7	4F	10	0.12	0.46	1.10	1.38	0.82	0.85	0.88	0.93	0.82	0.69	0.44	1.84	1.13	0.75	0.64	0.89	1.33	0.96	**0.89**	
T8		30	0.43	0.49	1.05	2.08	1.13	1.27	1.51	1.44	1.17	0.69	0.41	1.40	1.39	1.06	1.00	1.19	1.96	1.14	**1.15**	**3.60**
T9		50	0.74	0.51	0.99	2.78	1.43	1.68	2.13	1.95	1.53	0.69	0.38	0.96	1.65	1.38	1.35	1.49	2.60	1.31	**1.42**	

4.2.1 Analysis of surface roughness data – Closed Pocket

Following the guidance provided in Table 3, an analysis of surface roughness data for the closed pocket was conducted, employing various graphs to scrutinize potential effects or trends. The average data for each surface was utilized for the comprehensive analysis. Figure 4.4 illustrates the average surface roughness data for the closed pocket plotted against the number of runs. On the Y-axis, the average value for the surface roughness of all closed pocket surfaces is depicted in micrometers (μm). Simultaneously, the X-axis represents the nine cutting tools of the experimental setup.

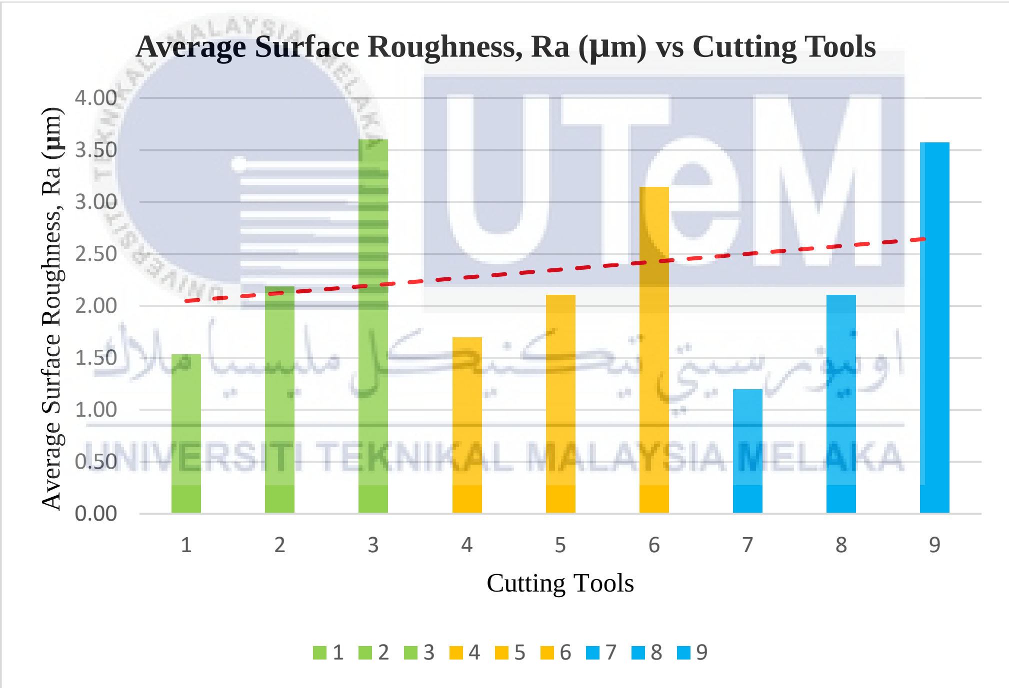


Figure 4.4: Graph data for surface roughness analysis on the ***closed pocket*** of the part

The premise is that an increase in the number of flutes and a higher helix angle corresponds to a rise in surface roughness. Essentially, the expectation is that employing tools with more flutes and an increased helix angle will result in rougher machined surfaces. This proposition is based on the belief that a greater number of flutes and a steeper helix angle might lead to challenges in chip evacuation, potentially heightened cutting forces, and reduced stability during machining, culminating in higher surface roughness. The aim is to practically test and validate these expectations through machining experiments and subsequent statistical analysis.

The anticipated outcome regarding surface roughness was derived from a comprehensive review of existing literature. (Nguyen, Nhu Tung 2021), have proposed not only is milling a typical machining procedure, but it is also one of the ones that CNC machines employ the most. Tool wear, machining surface roughness, and other crucial traits are often chosen as the metrics that define the effectiveness and quality of the milling process. Numerous research has been conducted up to this point to determine the impact of technical variables and cutting circumstances on tool wear and machining surface roughness to increase machining process quality while lowering costs and cycle times.

4.2.2 Analysis of surface roughness data – Open Pocket

The scrutiny of surface roughness data for the open pocket, as outlined in Table 4, involved a thorough examination employing various graphs to discern potential effects or trends. The overall analysis incorporated the average data for each surface. As depicted in Figure 4.5, the graph visually represents the average surface roughness data for the open pocket plotted against the number of runs. The Y-axis indicates the average surface roughness value for all surfaces within the open pocket, measured in micrometers (µm). Simultaneously, the X-axis corresponds to the nine cutting tools executed in the experimental setup.

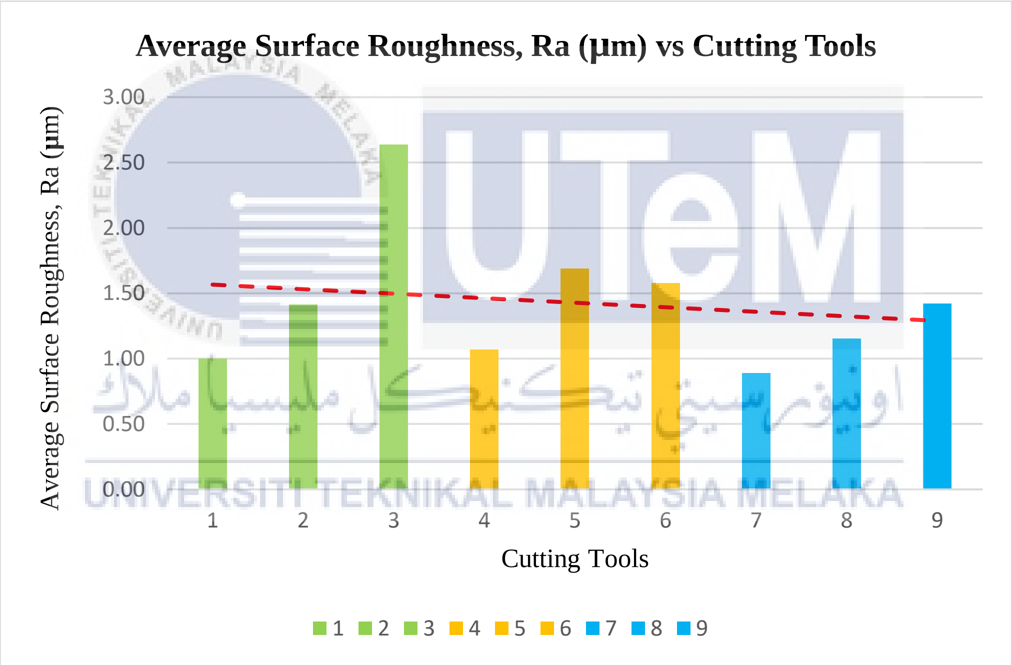


Figure 4.5: Graph data for surface roughness analysis on the ***open pocket*** of the part.

The proposition is that with an augmentation in the number of flutes and an increased helix angle, a corresponding reduction in surface roughness can be anticipated. Simply put, the expectation is that utilizing tools featuring more flutes and a higher helix angle will contribute to achieving smoother machined surfaces. This notion is grounded in the belief that an elevated number of flutes and a steeper helix angle can enhance chip evacuation, diminish cutting forces, and foster heightened stability during machining. The ultimate outcome is presumed to be a lower surface roughness. The objective is to practically verify and substantiate these expectations through machining experiments and subsequent statistical analysis.

K. Danesh Narooei (2022) measured the surface roughness in milling machining of AA6061-T6 in their experimental work. Regression analysis is used to create a realistic surface roughness prediction model once the experiment is run to gather the necessary data. Surface roughness is greatly influenced by the cutting parameters, such as cutting speed, feed rate, and depth of cut. To achieve the appropriate surface quality, these factors must be properly chosen and optimised. While severe cutting conditions may produce rougher surfaces, higher cutting speeds and lighter feed rates often provide smoother surfaces.

4.3 Dimensional accuracy

In the second phase of the experiment, our aim to assess the dimensional accuracy of machined pocketing profiles. This critical analysis is conducted using the CMM (Coordinate Measurement Machine), as elaborated in Section 3.9. To delve into dimensional accuracy, we categorize the machined part into three key aspects: surface, perpendicularity, and flatness. The surface aspect focuses on the targeted area, while perpendicularity evaluates the precision between two surface planes. Meanwhile, flatness gauges the straightness of each surface. To ensure a comprehensive analysis, we examine the surface at 6 points, perpendicularity at 10 points, and flatness at 14 points, as illustrated in Figures 4.6, 4.7, and 4.8. Referencing Table 5, 6, and 7 results are color-coded for easy interpretation. A deviation percentage below 50% is represented in green, while exceeding 50% turns it yellow. If the deviation percentage surpasses 100%, it is prominently indicated in red. This systematic approach allows for a thorough evaluation of the machined pocketing profiles in terms of dimensional accuracy.

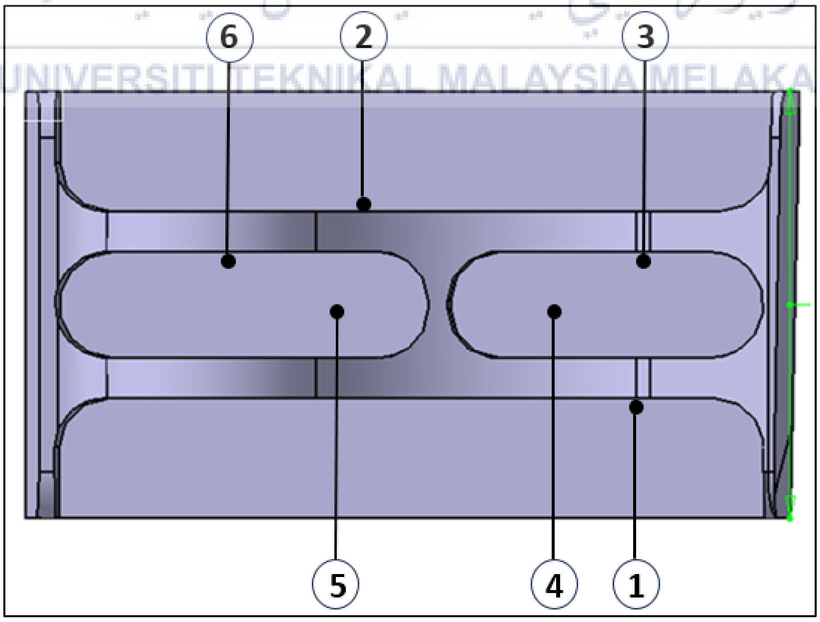


Figure 4.6: Points taken for dimensional accuracy of the ***surface*** aspects.

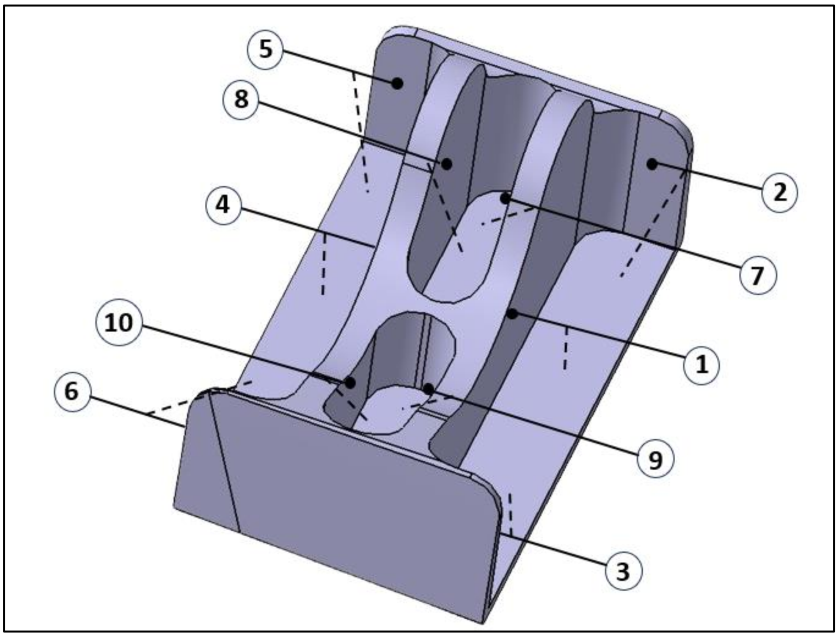


Figure 4.7: Points taken for dimensional accuracy of the ***perpendicularity*** aspects.

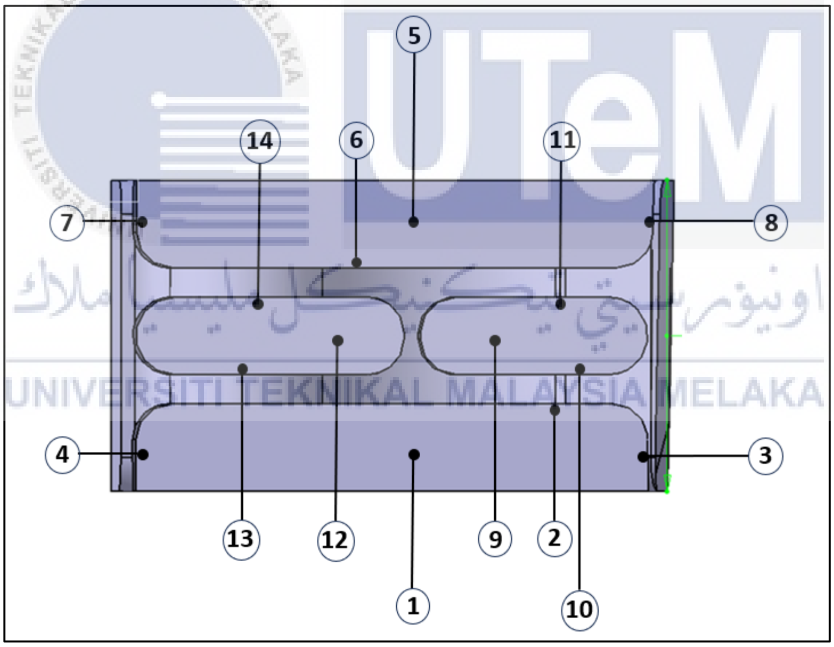


Figure 4.8: Points taken for dimensional accuracy of the ***flatness*** aspect.

Table 7: Deviation percentage data for ***surface***.

TOOL	FLUTE	HELIX ANGLE	Deviation percentage %							
			Surface						Average surface	Average
			1	2	3	4	5	6		
T1	2F	10	127	98	62	25	73	106	81.833	68.667
T2		30	80	83	58	13	76	85	65.833	
T3		50	49	71	43	72	39	76	58.333	
T4	3F	10	120	59	49	16	56	95	65.833	62.500
T5		30	27	73	55	17	89	101	60.333	
T6		50	32	72	81	25	72	86	61.333	
T7	4F	10	22	20	31	39	53	58	37.167	44.389
T8		30	24	57	47	30	56	45	43.167	
T9		50	27	53	63	31	68	75	52.833	

Table 8: Deviation percentage data for ***perpendicularity***.

TOOL	FLUTE	HELIX ANGLE	Deviation percentage %											
			Perpendicularity										Average perpendicularity	Average
			1	2	3	4	5	6	7	8	9	10		
T1	2F	10	2	4	13	43	11	3	2	18	29	21	14.600	12.700
T2		30	18	1	1	29	1	7	4	1	20	15	9.700	
T3		50	16	3	1	56	22	6	2	13	0	19	13.800	
T4	3F	10	29	8	8	40	22	16	36	36	6	34	23.500	16.200
T5		30	3	12	1	27	20	4	1	16	6	32	12.200	
T6		50	6	6	6	42	15	6	14	13	3	18	12.900	
T7	4F	10	23	24	4	7	28	14	28	27	69	13	23.700	20.167
T8		30	10	18	3	1	14	11	18	16	30	15	13.600	
T9		50	90	13	2	27	18	9	8	6	42	17	23.200	

Table 9: Deviatiom percentage data for ***flatness***.

TOOL	FLUTE	HELIX ANGLE	Deviation percentage %															
			Flatness														Average flatness	Average
			1	2	3	4	5	6	7	8	9	10	11	12	13	14		
T1	2F	**10**	6	0	8	5	6	10	4	8	7	5	13	0	9	1	5.857	4.881
T2		**30**	6	2	1	1	4	1	5	4	0	1	16	1	5	3	3.571	
T3		**50**	2	2	2	5	2	11	3	15	3	9	1	6	6	6	5.214	
T4	3F	**10**	3	1	2	3	2	2	7	3	1	0	6	4	3	7	3.143	3.881
T5		**30**	0	10	1	6	2	0	0	3	2	5	3	0	13	4	3.500	
T6		**50**	5	2	8	1	2	1	7	5	3	5	2	17	4	8	5.000	
T7	4F	**10**	0	1	3	1	1	8	4	3	6	0	3	7	3	4	3.143	3.238
T8		**30**	6	2	3	1	1	4	3	2	1	0	2	4	2	3	2.429	
T9		**50**	14	9	4	1	1	1	3	1	4	3	0	2	12	3	4.143	

4.3.1 Dimensional Accuracy Data Analysis – Surface

Based on the data presented in Table 5, 6, and 7 regarding deviation percentages for surface, perpendicularity, and flatness, several graphs have been generated to explore these aspects. In Figure 4.9, the graph visually portrays the data analysis for dimensional accuracy concerning surface aspects plotted against the number of cutting tools. The Y-axis represents the average deviation percentage (%) of surface aspects, while the X-axis aligns with the nine cutting tools carried out in the experimental setup.

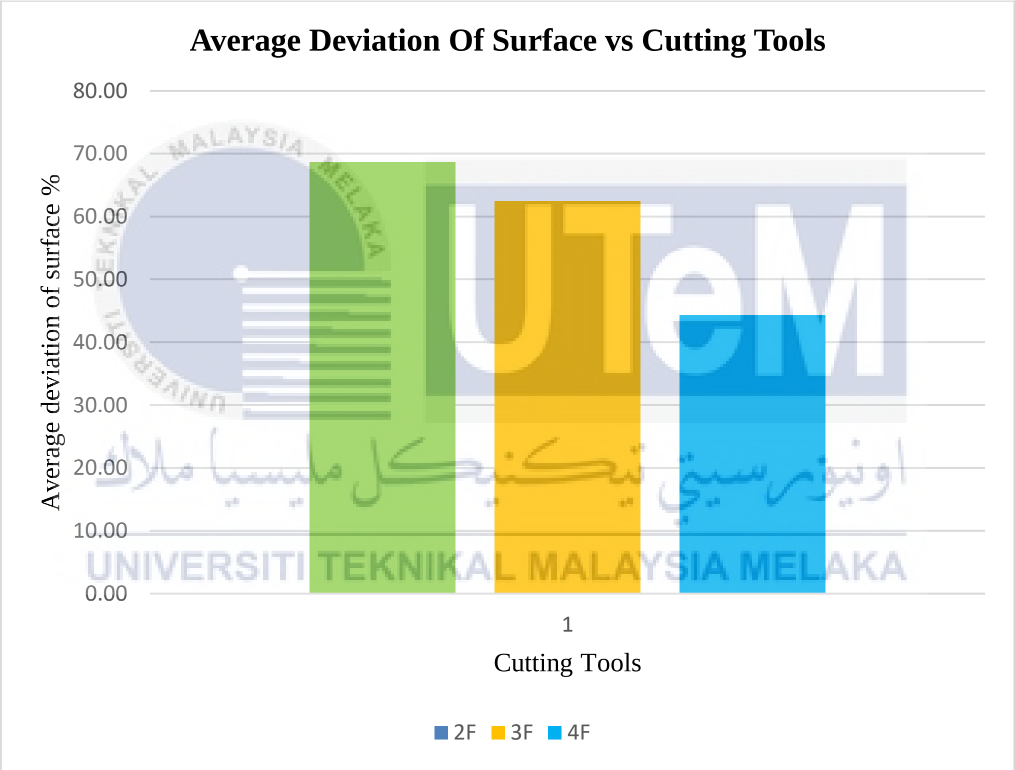


Figure 4.9: Graph data for dimensional accuracy analysis on the ***surface***.

The premise involves considering the influence of different combinations of flutes 2, 3, and 4 and helix angles 10°, 30°, and 50° on the average deviation of surface measurements. The expectation is that variations in the tool configurations, stemming from different numbers of flutes and helix angles, will result in distinct effects on the dimensional accuracy of machined surfaces. By exploring their impact on the average deviation of surface measurements, the goal is to discern patterns and relationships that indicate whether specific combinations lead to more precise or less accurate machining outcomes. Conducting practical experiments and subsequent statistical analyses is crucial for substantiating these observations in the context of machining processes.

Operating at lower speeds can lead to built-up edge issues, while higher speeds introduce greater deflection to the end mill, resulting in errors in diameter size and pocket roundness. In a significant study conducted by Raja Izamshah in (2013), experimental investigations were carried out to examine the impact of end mill helix angle on accuracy during the machining of thin-rib aerospace components. The findings revealed that a higher helix angle results in an increase in the effective rake angle, leading to improved machinability and precision.

4.3.2 Dimensional Accuracy Data Analysis – Perpendicularity

In Figure 4.10, graphical data is presented, illustrating the analysis of dimensional accuracy concerning perpendicularity aspects across the specified cutting tools. The Y-axis depicts the average deviation percentage (%) related to perpendicularity aspects, with the X-axis aligning with the nine cutting tools conducted in the experimental setup.

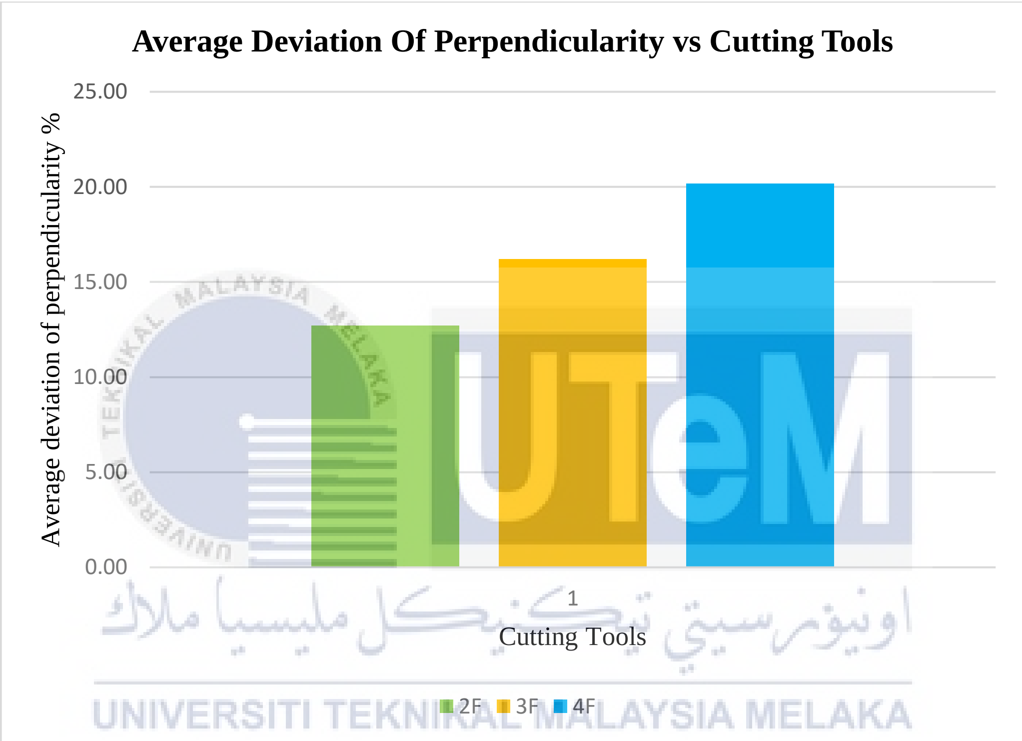


Figure 4.10: Graph data for dimensional accuracy analysis on the ***perpendicularity***

The expectation is that variations in the number of flutes specifically 2, 3, and 4 flutes and helix angles 10°, 30°, and 50°will influence the average deviation of perpendicularity measurements. The premise suggests that different combinations of flutes and helix angles in tool configurations will lead to distinct effects on the dimensional accuracy of machined surfaces, specifically in terms of perpendicularity. The hypothesis is that certain combinations within the specified range of flutes and helix angles may result in more precise or less accurate perpendicularity measurements. This forms the basis for experimental investigation and subsequent statistical analyses to validate these expectations in the context of machining processes.

4.3.3 Dimensional Accuracy Data Analysis – Flatness

Figure 4.11 showcases graphical data that illuminates the scrutiny of dimensional accuracy in relation to flatness aspects across the designated cutting tools. The Y-axis captures the average deviation percentage (%) associated with flatness aspects, harmonizing seamlessly with the X-axis, which traces the progression through the nine cutting tools executed in the experimental setup.

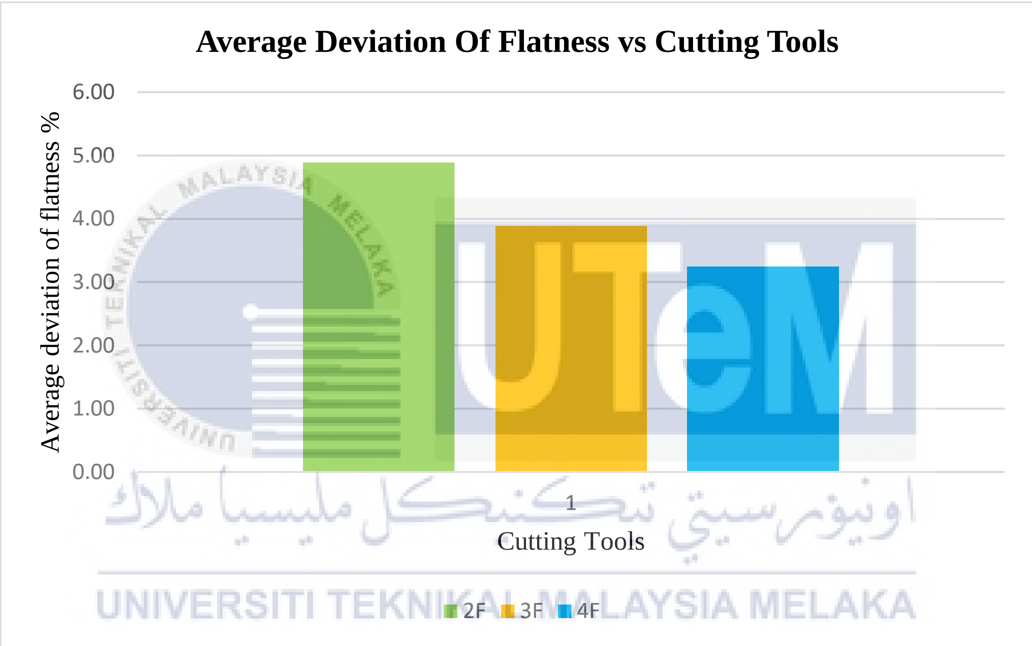


Figure 4.11: Graph data for dimensional accuracy analysis on the ***flatness.***

The consideration lies in understanding how variations in the number of flutes—specifically 2, 3, and 4 flutes—and helix angles—ranging from 10°, 30°, to 50°—may influence the average deviation of flatness measurements. The premise is that diverse combinations of flutes and helix angles within tool configurations could yield distinct effects on the dimensional accuracy of machined surfaces, particularly concerning flatness. This suggests that certain combinations within the specified range of flutes and helix angles may either improve or diminish precision in flatness measurements. This framework establishes the groundwork for conducting practical experiments and subsequent statistical analyses to affirm these expectations within the context of machining processes.

The projected outcome concerning dimensional accuracy was informed by a review of relevant literature, which indicated that the helix angle plays a significant role in predicting chatter. Additionally, the number of teeth and the radial immersion ratio were identified as potentially crucial factors that can affect the accuracy of prediction, as they influence the continuity of the milling process similar to the helix angle. In study from Omar Monir Koura (2021) summarized that increasing the spindle speed beyond 800 RPM offers improvements in both pocket dimensional accuracy and pocket roundness for the part.

4.4 Tool wear observation

Throughout every phase of the experiment, the third analysis following the examination of dimensional accuracy is the observation of tool wear. This investigation aims to explore the wear of cutting tools influence from selected parameter. In this research, the assessment of tool wear is carried out through physical observation using an optical microscope. By closely examining the wear patterns on cutting tools, this analysis analysis yields valuable insights into the impact of varying cutting parameters on tool durability. The optical microscope serves as a precise instrrument for visually inspecting and quantifying the degree of wear, facilitating the establishment of connections between cutting conditions and tool deterioration. Through this observational methodology, the experiment endeavors to provide crucial information for optimizing machining processes, ensuring the longevity and effectivenss of cutting tools in practical applications.

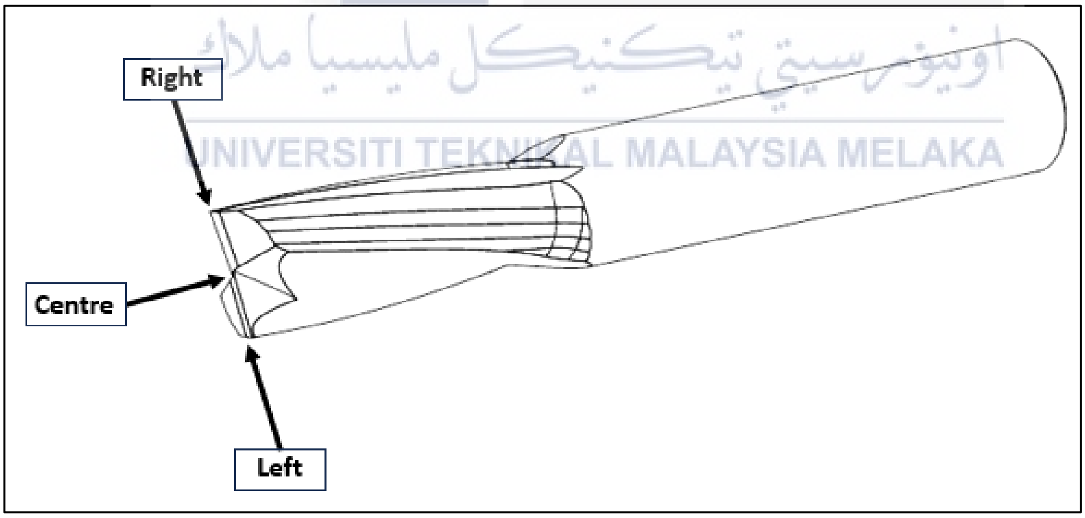
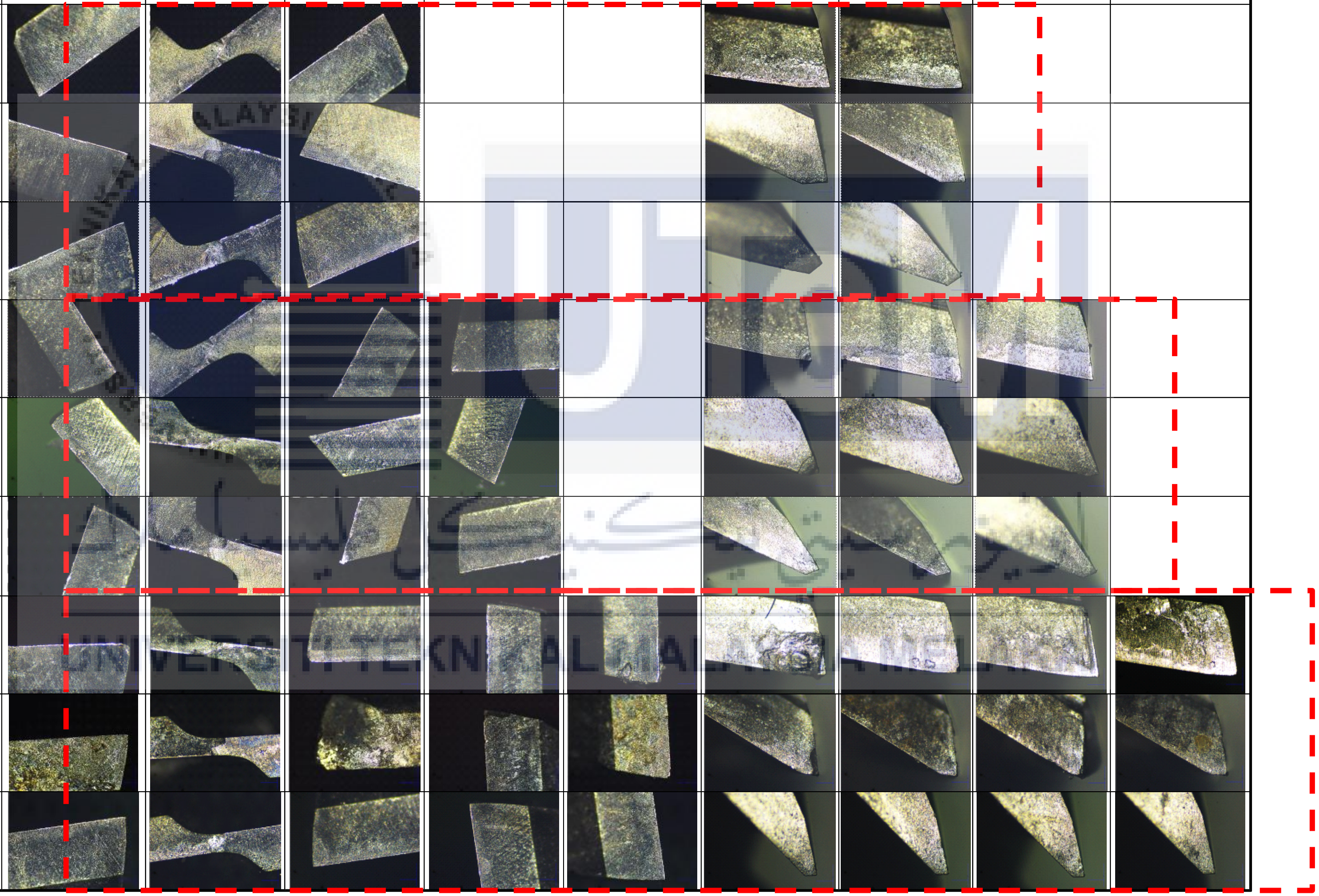


Figure 4.12: Tool wear observation ***(left, centre, and right)***.

The anticipated observation of tool wear in this experiment is informed by a literature review, which highlights the influence of the helix angle and number of teeth on the prediction of tool wear. Based on the studies of Nguyen, Nhu Tung (2021) presented tool deterioration, machining surface roughness, etc. are chosen as the parameters that characterize for the quality and efficiency of the milling process because they are very important characteristics. Numerous studies have been conducted up to this point to assess the impact of technological variables and cutting conditions on tool wear and machining surface roughness to enhance quality and decrease cost and time of machining processes. In this study, the chosen methodology will be employed to investigate the impact of tool geometrical features during five-axis multi-axis flank milling for aero-structural components. This particular methodology is deemed suitable as it aligns with the objective of investigating tool wear. The data required for this investigation will be obtained using the Nikon MM-800 instrument.

Table 10: The observation of tool wear.

TOOL	FLUTE	HELIX ANGLE	FLUTE 1	CENTRE	FLUTE 2	FLUTE 3	FLUTE 4	EDGE 1	EDGE 2	EDGE 3	EDGE 4
1		10									
2	2F	30									
3		50									
4		10									
5	3F	30									
6		50									
7		10									
8	4F	30									
9		50									



4.5 Chip Observation

Chip observation involves a meticulous examination of the generated chips during machining processes. This practice is crucial for understanding the efficiency and effectiveness of the machining operation. By closely scrutinizing the size, shape, color, and overall characteristics of the chips, engineers and machinists can glean valuable insights into various aspects of the machining process. Chip observation provides essential information about tool performance, material properties, and cutting conditions. Additionally, it serves as a practical diagnostic tool, enabling adjustments to optimize machining parameters for improved efficiency and product quality. Consulting Table 11 reveals the chip thickness results derived from the conducted tests for each cutting tool. Each chip underwent five measurements, allowing the determination of the average chip thickness produced by a specific cutting tool in this experiment.

Table 11: Chip thickness data of the part.

Tool Geometry	Chip Thickness					Avg.	Tool Flutes	Avg.	Tool Helix Angle	Avg.
	1	**2**	**3**	**4**	**5**					
T1	0.19	0.15	0.20	0.21	0.10	**0.17**	2F	0.15	10°	0.13
T2	0.17	0.15	0.10	0.11	0.09	**0.12**				
T3	0.11	0.20	0.22	0.10	0.09	**0.14**				
T4	0.12	0.11	0.09	0.11	0.09	**0.10**	3F	0.13	30°	0.12
T5	0.16	0.12	0.11	0.08	0.07	**0.11**				
T6	0.21	0.19	0.16	0.18	0.17	**0.18**				
T7	0.11	0.14	0.13	0.15	0.10	**0.13**	4F	0.11	50°	0.14
T8	0.11	0.10	0.11	0.13	0.13	**0.12**				
T9	0.09	0.10	0.07	0.09	0.08	**0.09**				

4.6 DOE Taguchi Analysis

DOE Taguchi analysis utilizing Minitab 21 is a methodical approach designed to identify the optimal combination of input factors for minimizing the impact of variation and enhancing overall performance resilience against uncontrollable factors. This process involves leveraging the advanced features of Minitab 21 to conduct a comprehensive analysis, typically focusing on specific factors such as flute and helix angle. The objective is to systematically explore the interplay of these factors and their impact on critical outcomes like surface roughness, dimensional deviation and chip thickness. By employing Minitab 21, a powerful statistical software, researchers can efficiently navigate the intricacies of Taguchi analysis, facilitating data-driven decisions for improved product or process design.

4.6.1 SN ratio analysis of Surface Roughness

Examining the main effects plot presented in Figure 4.13, which investigates the influence of flute and helix angle on surface roughness in open pocket machining, the inclination of the graph implies that the helix angle exerts a more pronounced effect in comparison to the flute. Moreover, pinpointing the optimal tool geometry through the highest mean SN values indicates that a tool configuration with 4 flutes and a 10° helix angle is deemed the most effective for attaining the desired machining outcome.

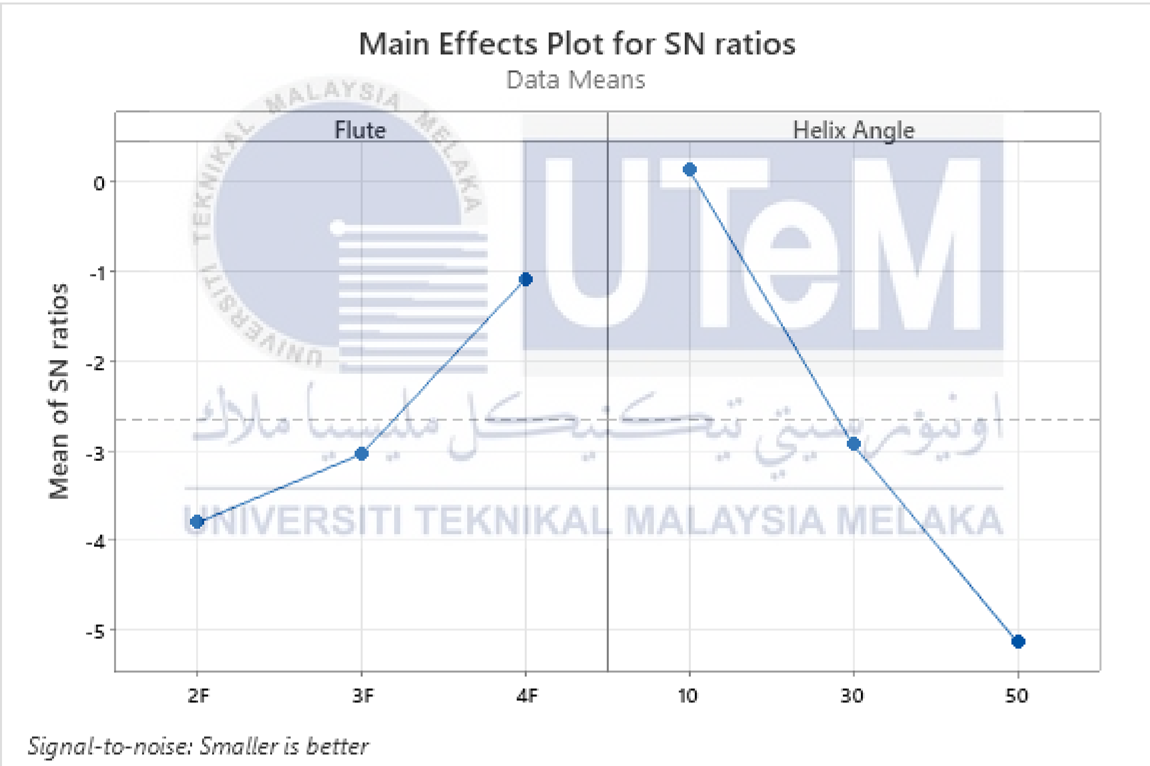


Figure 4.13: Mean of SN ratios for Flute and Helix Angle ***(open pocket).***

Upon scrutinizing the main effects plot in Figure 4.14, which investigates the interplay between flute and helix angle in open pocket machining's impact on surface roughness, the graph's trend implies a more notable influence from the helix angle as opposed to the flute. Furthermore, the identification of the most effective tool geometry, guided by the highest mean SN values, points towards a tool configuration featuring 3 flutes and a 10° helix angle as the optimal choice for attaining the desired machining outcome.

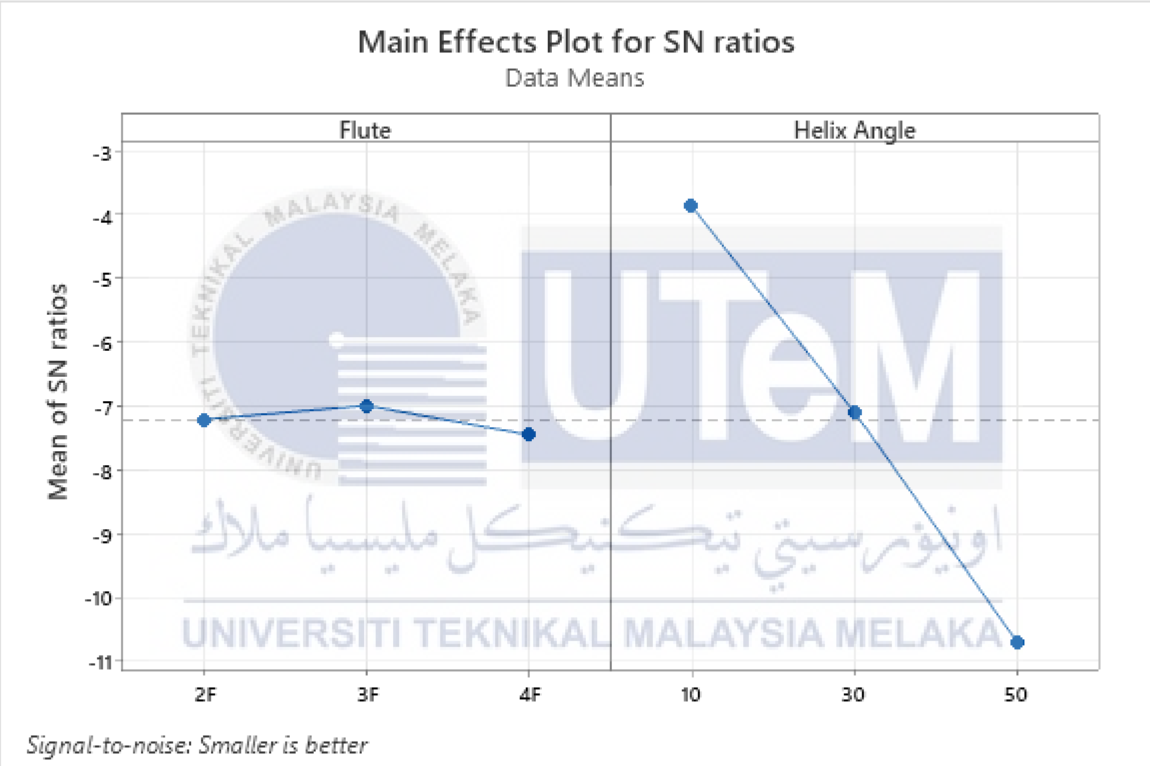


Figure 4.14: Mean of SN ratios for Flute and Helix Angle ***(closed pocket).***

4.6.2 SN ratios analysis of Dimensional Accuracy.

In analyzing the main effects plot depicted in Figure 4.15, tailored to explore how flute and helix angle impact dimensional deviation in surface machining, the inclination of the graph suggests a more significant influence from the helix angle compared to the flute. Furthermore, identifying the optimal tool geometry based on the highest mean SN values indicates that a tool setup with 4 flutes and helix angles of both 10° and 30° is considered the most effective for achieving the desired machining outcome.

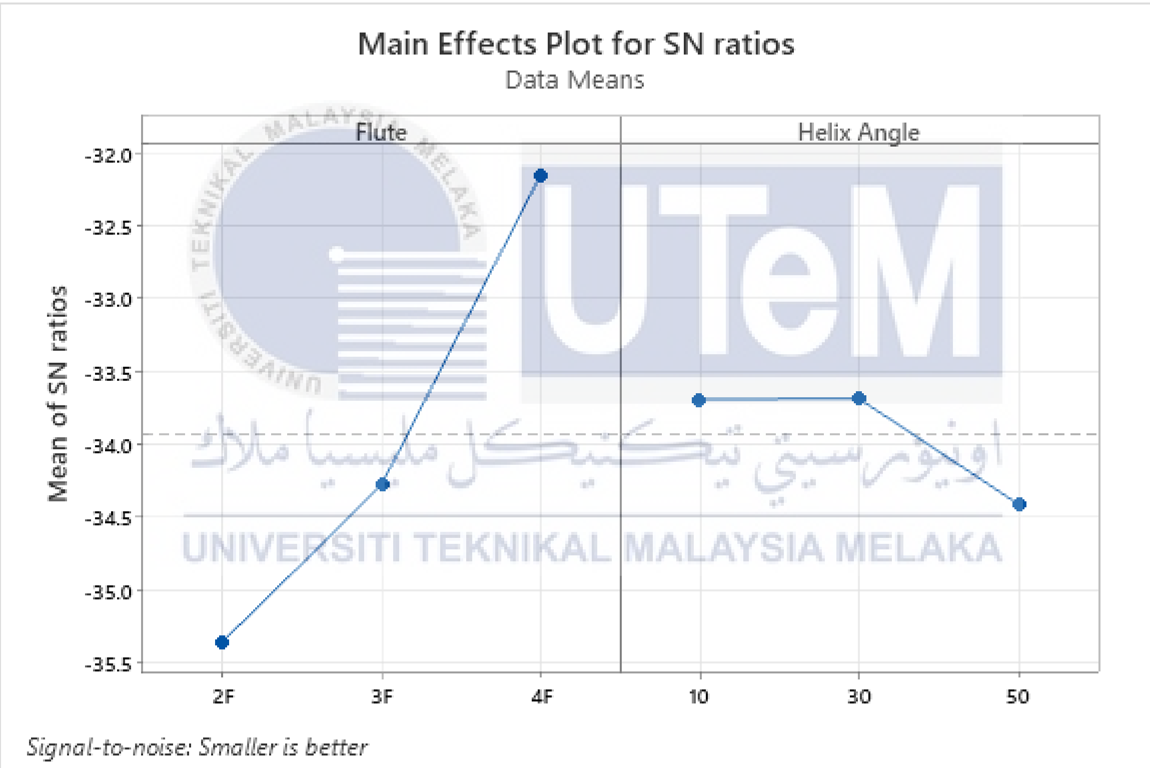


Figure 4.15: Mean of SN ratios for flute and helix angle ***(surface).***

Examining the main effects plot illustrated in Figure 4.16, crafted to investigate the impact of flute and helix angle on dimensional deviation in perpendicularity machining, the trend of the graph implies a more substantial influence from the flute as opposed to the helix angle. Moreover, pinpointing the optimal tool geometry through the highest mean SN values suggests that a tool configuration with 2 flutes and helix angles of 30° is considered the most effective for achieving the desired machining outcome.

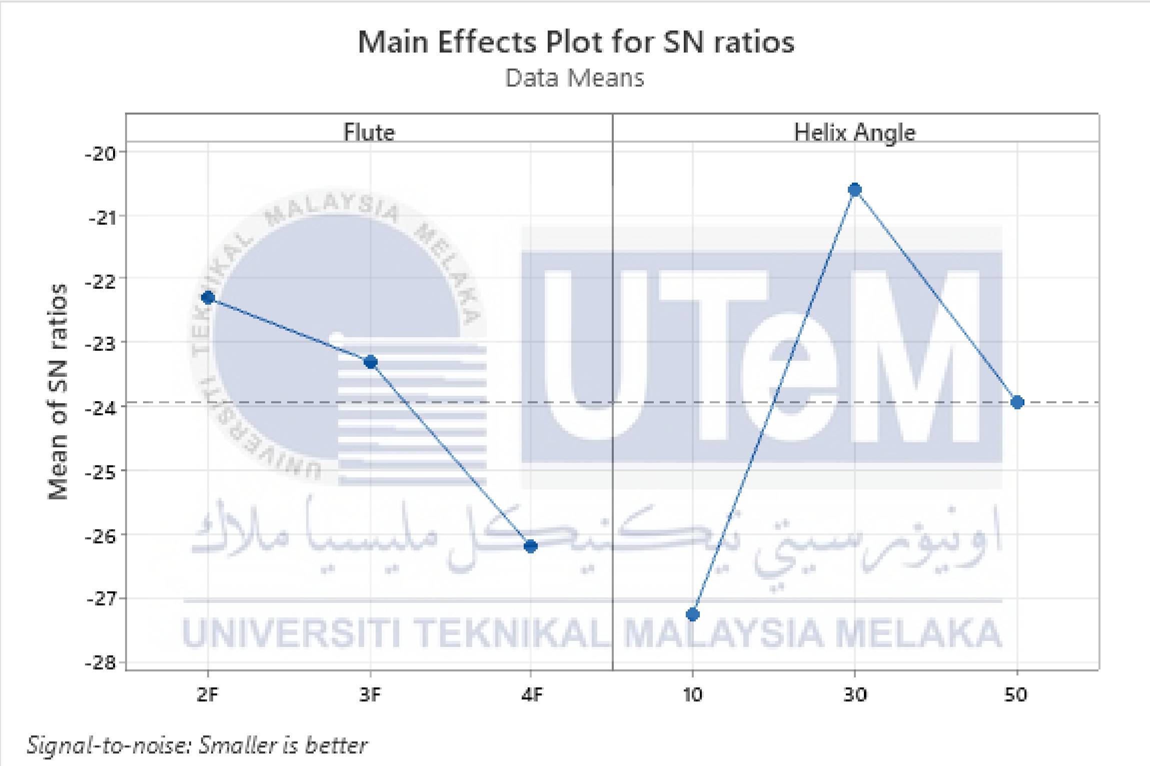


Figure 4.16: Mean of SN ratios for flute and helix angle ***(perpendicularity).***

Analyzing the main effects plot presented in Figure 4.17, specifically designed to uncover how flute and helix angle impact dimensional deviation in flatness machining, the graph's slope suggests a more substantial effect from the helix angle when juxtaposed with the flute. Moreover, identifying the optimal tool geometry based on the highest mean SN values indicates that a tool configuration with 4 flutes and a 30° helix angle is considered the optimum for achieving the desired machining outcome.

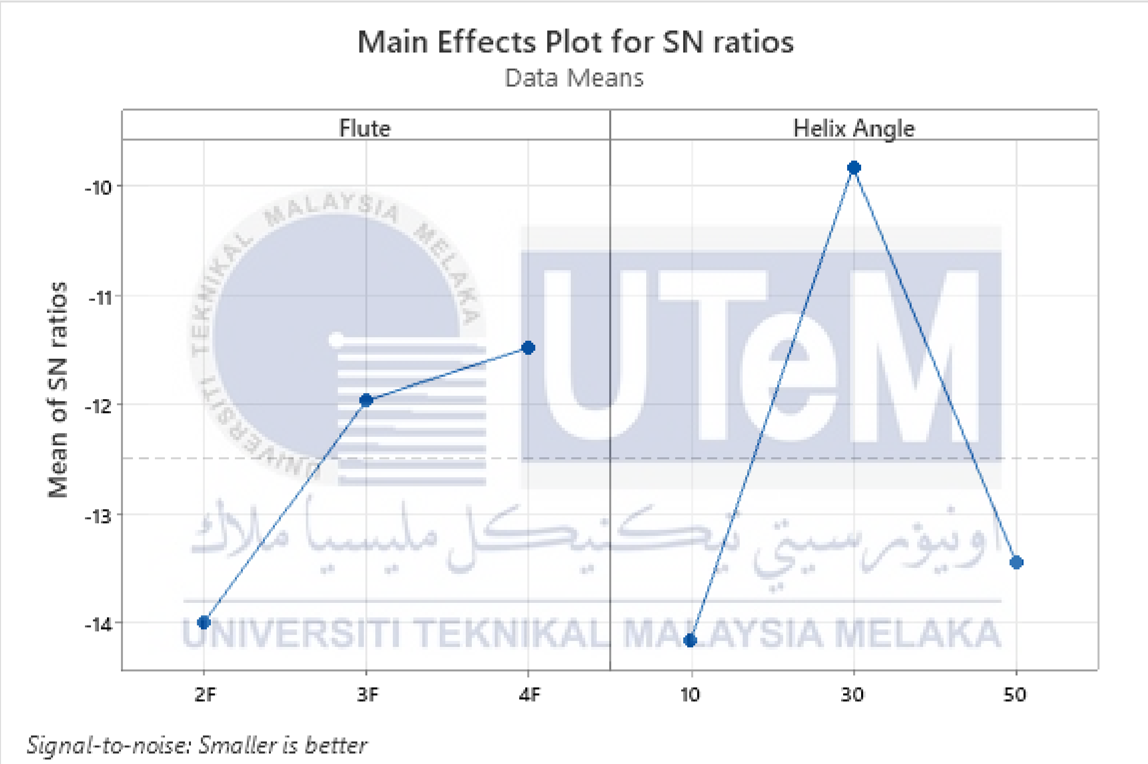


Figure 4.17: Mean of SN ratios for flute and helix angle ***(flatness).***

4.6.3 SN ratios analysis of Chip Thickness.

Examining the main effects plot illustrated in Figure 4.18, specifically designed to uncover how flute and helix angle impact chip thickness in open pocket machining, the graph's slope implies a more substantial effect from the helix angle when compared to the flute. Furthermore, pinpointing the optimal tool geometry guided by the highest mean SN values suggests that a tool setup with 4 flutes and a 30° helix angle is considered optimum for achieving the desired machining outcome.

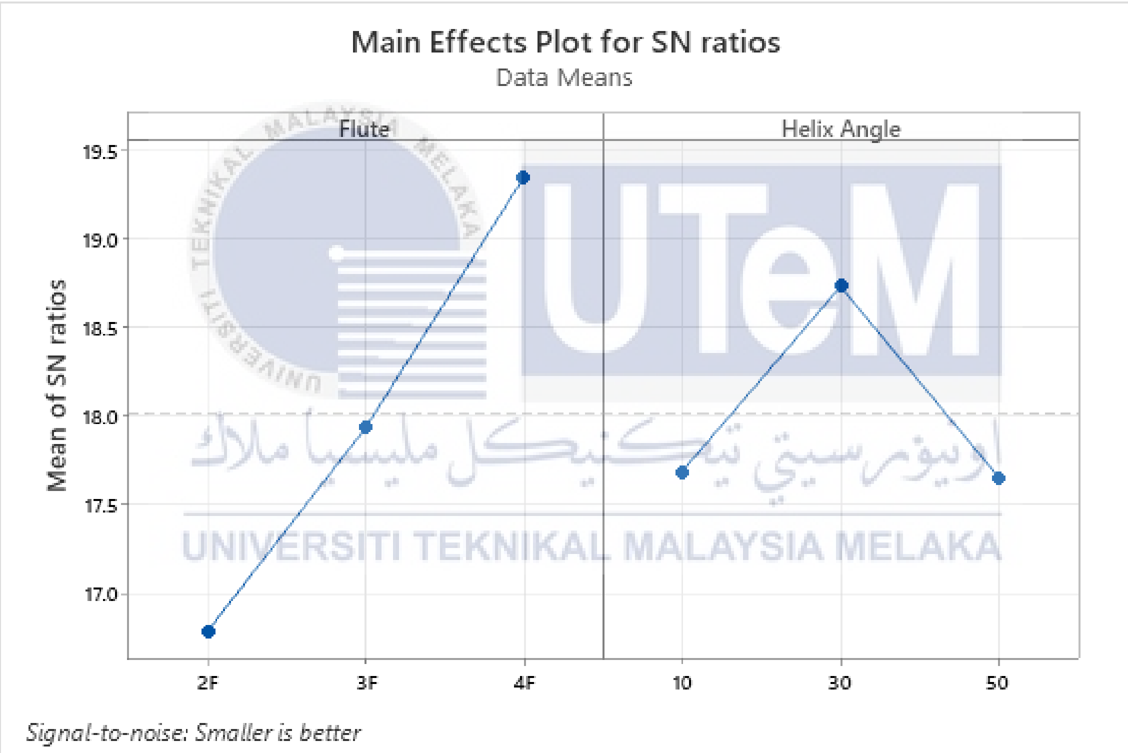


Figure 4.18: Mean of SN ratios for flute and helix angle ***open pocket.***

Analyzing the main effects plot presented in Figure 4.19, specifically crafted to investigate how flute and helix angle impact chip thickness in closed pocket machining, the graph's slope suggests a more substantial effect from the helix angle when compared to the flute. Furthermore, identifying the optimal tool geometry based on the highest mean SN values indicates that a tool setup with 4 flutes and a 30° helix angle is considered optimum for achieving the desired machining outcome.

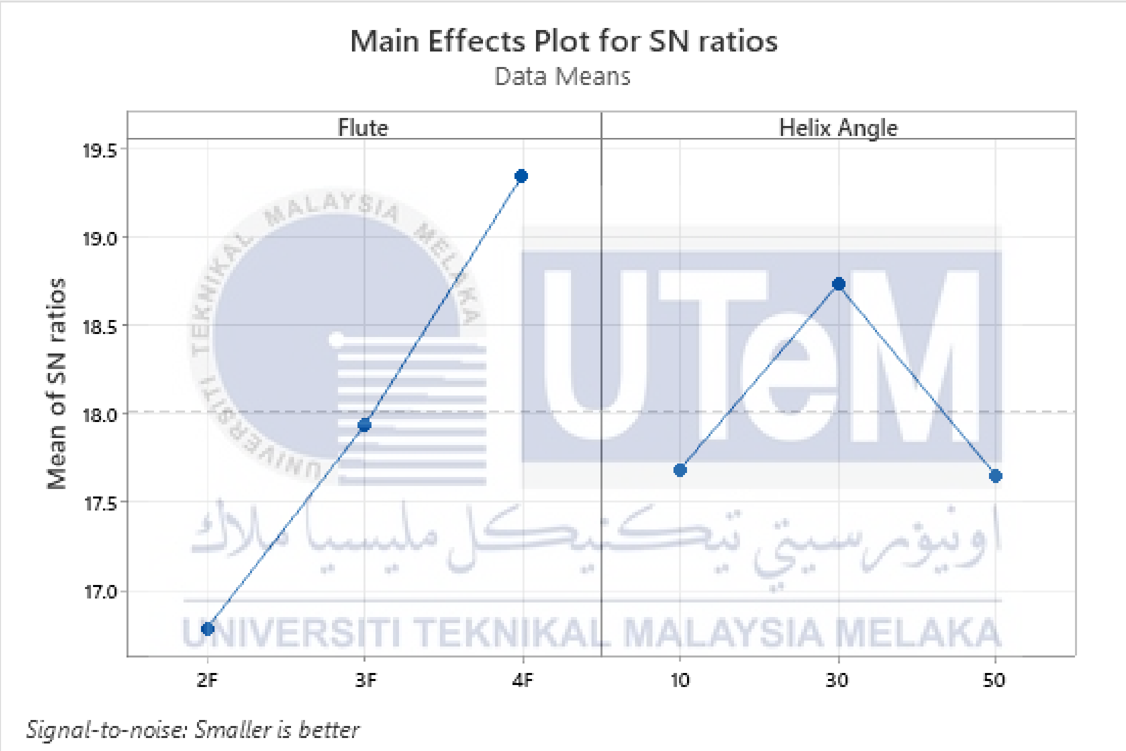


Figure 4.19: Mean of SN ratios for flute and helix angle ***closed pocket.***

4.7 Summary

Table 12: Summary table for optimum tool teometry.

Output		Optimum Tool Geometry	
		No. Flute	Helix Angle (°)
Surface Roughness	Open Pocket	4F	10°
	Closed Pocket	3F	10°
Dimensional Accuracy	Surface	4F	10° & 30°
	Perpendicularity	2F	30°
	Flatness	4F	30°
Chip Observation	Open Pocket	4F	30°
	Closed Pocket	4F	30°

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Introduction

Within the confines of this chapter, we embark on an exhaustive exploration into the conclusions arising from our meticulous investigation into the intricate interplay of machining parameters within closed and open pockets, specifically homing in on aluminum—a pivotal material in the aerospace sector. This narrative not only encapsulates the successful realization of our research objectives but also amplifies the holistic performance achieved throughout the duration of this comprehensive study.

Moving beyond a mere exposition of conclusions, the chapter unfolds as a compass guiding the trajectory of future endeavors. It extends its reach beyond the immediate findings, venturing into a realm of insightful recommendations and forward-looking proposals. The focal point is a commitment to contribute meaningfully to the ongoing evolution and enhancement of productivity within the aerospace industry. As we navigate this narrative, it's not just a reflection on the findings but a contemplation of their broader implications. The discourse dissects the outcomes while envisioning their significance in the wider context of aerospace manufacturing. Recommendations surface as guiding lights, directing future researchers, industry practitioners, and stakeholders toward avenues of refinement and innovation.

5.2 Conclusion

In recapitulation, our study thoroughly examined and evaluated the influence of tool geometry, specifically focusing on the number of flutes and helix angle. We conducted three primary analyses surface roughness, dimensional accuracy, and tool observation. Utilizing Signal to Noise Ratios graphs, we successfully analyzed the impact of the number of flutes and helix angle on machining open pocket and closed pocket surfaces. The analysis of dimensional accuracy revealed significant influences from both the number of flutes and helix angle across surface, perpendicularity, and flatness aspects of the machined part. Optimal tool geometry for achieving the highest surface quality involved a higher number of flutes and a high helix angle, while less favorable cutting conditions were associated with fewer flutes and a high helix angle. The study identified the optimal tool geometry for achieving the best surface roughness in a closed pocket as 4 flutes and a 10° helix angle, and similarly, for an open pocket, it was also 4 flutes and a 10° helix angle. Regarding dimensional accuracy, the ideal tool geometry for precise surface dimensions was identified as 4 flutes and a 30° helix angle. Conversely, for achieving optimal perpendicularity, the recommended tool geometry was 2 flutes and a 30° helix angle, and for flatness, it was 4 flutes and a 30° helix angle. Conversely, when it comes to observing chips for dimensional accuracy, the ideal tool geometry aligns with the same number of flutes and helix angle specifically, 4 flutes and a 30° helix angle.Our study highlights that having more flutes and a specific helix angle leads to better surface quality and accuracy. These insights are crucial for improving how we shape aerospace parts, making the manufacturing process more effective and precise.

5.3 Recommendation and Future Works

Looking ahead, the investigation into the impact of cutting tools geometry on roughing operations for aerospace pocketing profiles suggests compelling directions for future research and practical recommendations. A comprehensive exploration through an in-depth parametric study, focusing on individual cutting tool parameters such as rake angle, clearance angle, and cutting edge geometry, is proposed to unravel their nuanced effects on the roughing process systematically. Advancements in tool materials, considering options like ceramic or composite tools, and the exploration of novel coatings present opportunities to extend tool life and enhance overall performance. Mitigating vibrations during roughing through advanced vibration analysis and effective damping strategies emerges as a critical consideration for improved machining stability. The incorporation of sophisticated simulation tools, adaptive machining strategies driven by real-time feedback, and environmentally sustainable practices involving eco-friendly cutting fluids are vital aspects in shaping the future landscape of aerospace machining. Collaborative efforts with industry stakeholders, educational outreach initiatives, continuous monitoring systems, and the exploration of hybrid machining techniques are all recommended avenues to validate findings, disseminate knowledge, refine process control, and innovate in the dynamic domain of aerospace pocketing profiles production.

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