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MACHINABILITY STUDY OF ROUGHING MACHINING STRATEGIES FOR POCKETING FEATURES OF AN AEROSPACE

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A thesis submitted in fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering Technology (Product Design) with Honours



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

DECLARATION

I declare that this Choose an item. entitled "Machinability Study of Roughing Machining Strategies For Pocketing Features of an Aerospace "is the result of my research except as cited in the references. The chosen item has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.



APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology (Product Design) with Honours.



DEDICATION

This report is the

outcome of many long and

difficult journy. Those people who represent

an encouragement thanks to the

NLAY researchers' efforts are gratefully and

proudly acknowledged in

this work. For *parents*

and families to colleagues

and friendship circles who stood in

toaid when problems emerged during

this project. To my devoted parents and relatives,

who was always my closest companions

and who have educated me on this

level. This endeavor

would not have been

possible if it hadn't been for their

love and support.

ABSTRACT

Computer-aided manufacturing (CAM) is the efficient application of computer technology in manufacturing planning and control. Aerospace, biomedical engineering, optics, and MEMS all require the fabrication of parts with high dimensional precision and surface profile, making production difficult. The main aim of this research is to evaluate the effect of roughing strategies namely concentric and helical (multipass mode) on the surface roughness and tool wear in machining pocketing profiles of an example aero structural component. and to determine pand ropose the most optimum roughing strategy to machine pocketing profiles of an example aero structural part using an actual aerospace standard material (Aluminum 6061 series) with respect to the surface roughness and tool wear analysis utilizing roughing operation offered by CATIA V5. Surface roughness is an important property that indicates workpiece quality during the milling process. Meanwhile, dimensional accuracy is a crucial aspect that determines the acceptance of each machined part. The type of cutting tool used in the milling machining process, tool geometry selection, and cutting parameters are all important factors in achieving good surface finishing and meeting part tolerances. In this research, there are two main machining strategies that will be focused on: multipass and helical. In Catia V5, users could choose the direction of the tool path. There were some elements that required the tool path to be carefully considered during the machining process. As a result, selecting the proper cutting or machining strategy is critical to ensuring the end result of machining. This project will utilize a CNC milling machine with a 3-axis to perform the physical machining. In this project, there are two types of measurement involved, which are surface roughness and tool wear. The tool wear was studied using microscopy analysis on a rough image of the tool that was obtained via a Nikon MM-800 optical microscope. Measurement is a method of measuring something using additional equipment. Ra, Ry, and Rz are the three parameters derived by surface roughness testing. The value of Ra was investigated as a parameter for surface roughness. However, because Ra is utilized as a global measurement of the roughness amplitude on a profile, only it was studied. Ra is the mean roughness of a piece of standard length sampled from the roughness chart's mean line. Aside from that, the pieces were divided into two halves, one circular and the other rectangular.

ABSTRAK

Pembuatan bantuan komputer (CAM) ialah aplikasi teknologi komputer yang cekap dalam perancangan dan kawalan pembuatan. Aeroangkasa, kejuruteraan bioperubatan, optik dan MEMS semuanya memerlukan fabrikasi bahagian dengan ketepatan dimensi tinggi dan profil permukaan, menjadikan pengeluaran sukar. Matlamat utama penyelidikan ini adalah untuk menilai kesan strategi pengasaran iaitu sepusat dan heliks (mod berbilang laluan) ke atas kekasaran permukaan dan haus alatan dalam pemesinan profil poket contoh komponen struktur aero. dan untuk menentukan pand ropose strategi roughing yang paling optimum untuk profil poket mesin contoh bahagian struktur aero menggunakan bahan standard aeroangkasa sebenar (siri Aluminium 6061) berkenaan dengan kekasaran permukaan dan analisis haus alatan menggunakan operasi roughing yang ditawarkan oleh CATIA V5. Kekasaran permukaan adalah sifat penting yang menunjukkan kualiti bahan kerja semasa proses pengilangan. Sementara itu, ketepatan dimensi adalah aspek penting yang menentukan penerimaan setiap bahagian mesin. Jenis alat pemotong yang digunakan dalam proses pemesinan pengilangan, pemilihan geometri alat, dan parameter pemotongan adalah semua faktor penting dalam mencapai kemasan permukaan yang baik dan memenuhi toleransi bahagian. Dalam penyelidikan ini, terdapat dua strategi pemesinan utama yang akan difokuskan: multipass dan helical. Dalam Catia V5, pengguna boleh memilih arah laluan alat. Terdapat beberapa elemen yang memerlukan laluan alat untuk dipertimbangkan dengan teliti semasa proses pemesinan. Akibatnya, memilih strategi pemotongan atau pemesinan yang betul adalah penting untuk memastikan hasil akhir pemesinan. Projek ini akan menggunakan mesin pengilangan CNC dengan 3 paksi untuk melaksanakan pemesinan fizikal. Dalam projek ini, terdapat dua jenis ukuran yang terlibat, iaitu kekasaran permukaan dan haus alatan. Haus alat dikaji menggunakan analisis mikroskopi pada imej kasar alat yang diperolehi melalui mikroskop optik Nikon MM-800. Pengukuran ialah kaedah mengukur sesuatu menggunakan peralatan tambahan. Ra, Ry, dan Rz ialah tiga parameter yang diperolehi oleh ujian kekasaran permukaan. Nilai Ra telah disiasat sebagai parameter untuk kekasaran permukaan. Walau bagaimanapun, kerana Ra digunakan sebagai ukuran global amplitud kekasaran pada profil, hanya ia dikaji. Ra ialah min kekasaran bagi sekeping panjang standard yang diambil daripada garis min carta kekasaran. Selain itu, kepingan itu dibahagikan kepada dua bahagian, satu bulatan dan satu lagi segi empat tepat.

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LIST OF ABBREVIATIONS AND SYMBOLS

D,d	-	Diameter
mm	-	Milimeter
CAM	-	Computer aided manufacturing
CAD	-	Computer aided design
Al	-	Aluminum
CMM	-	Coordinate Measuring Machine



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CHAPTER 1

INTRODUCTION

1.1 Background

This chapter will detail the project's goals and objectives history as well as the problem statement for the process machinability on roughing and pocketing features of an aerospace part. The project's objective, scope, and limitations are also included in this chapter.

Mechanical milling is a frequently utilized technology in the industrial sector because to its adaptability and precision in product manufacture. (Edem & Balogun, 2018). Over the last thirty years, machining processes that can form a wide range of work, part shapes, and special geometry features have made increasingly rapid advances. Machining is an important process in the manufacturing process. It is defined as the removal of material in the form of chips from a workpiece. Manufacturing components with high dimensional precision and surface profile is tough in aircraft, biomedical engineering, lasers, and MEMS.(Ahmed et al., 2021).

Milling is an important step in the manufacturing industry since it ensures high productivity and quality are constantly in demand. In their research, Reddy and Prajina looked into the cutting process. (Titu et al., 2021). The surface roughness for mechanical components has a considerable influence on their performance and cost. For creating the needed part for the final assembly while keeping required geometrical forms and dimensional tolerances, the machining variables and methods for composites are crucial. (Nurhaniza et al., 2016). The type of cutting tool used in the milling machining process, tool geometries selection, and cutting parameters are all important factors in achieving good surface finishing and meeting part tolerances.

In the current context, the manufacturing industry is being forced to adopt modern technologies in order to maintain item quality while lowering production costs and increasing production volume. Pocket milling is a common machining technique used in the production of dies and moulds. The roughness of the pocket's surface determines its quality. Characteristic of the product's functioning qualities. (Rajyalakshmi & Rao, 2021). Pocket milling, which involves removing all material within a closed boundary, employs CAM-generated tool paths to remove material to a predetermined depth. Because of their ability to machine complex geometries with high dimensional accuracy, computer numerical control (CNC) machines have grown in popularity in modern manufacturing. These days, the trend in now's, the goal of computer-aided manufacturing (CAM) development of the system is to build a variety of CAM systems that can identify the precise elements that make up a part's 3D model and then generate the most significant machining method and parameters based on geometric form recognition.(Kariuki et al., 2014).

The CADCAM is a hybrid of CAD and CAM. From idea through documentation, computer-aided design (CAD) generally described as use of computers or graphical software to help or enhance product design. This efficient use of computer technology in industrial planning and control is known as computer-aided manufacturing (CAM). This combination allows information to be transferred from the designing phase to the planning step for product manufacture without need to physically reenter part geometry data. CATIA V5 is a CADCAM software package. This software would be used to both alter and prepare the CAM programmed for the component.

In both the literature and industry, 3-axis roughing remains the dominant approach due to easy programming and collision control, and also a generally faster implementation. (Jousselin et al., 2019). For milling freeform surfaces, parallel contour and orientation courses are the most popular. The regular and parallel pathways of the borders are ideal for cleaning machining processes.

A direction parallel route has parts that are parallel to a designated line (Figure 1.1). This line might be perpendicular to or equal to the surface's border, or perpendicular to the coordinate system's axis. The length of the resulting trajectory is directly influenced by the reference line's selection. The zigzag route is a form of path that runs parallel to the axis and is widely used for roughing in commercial CAM systems.(Vila et al., 2019). The contour parallel route is created using the surface's limit curves. Each path represents a shift of the surface border towards the center or away from it (Figure 1.1b). The symbol f stands for the distance between two successive Cutting Contact (CC) sites, whereas the letter w stands for the separation between two adjacent pathways (Figure 1.1c).



Figure 1.1 (a) Direction parallel. (b) Contour parallel. (c) Adaptive Curvilinear spacefilling curve. (Vila et al., 2019)

Finally, In the aerospace industry, tool wear can be a significant concern due to the demanding nature of the machining processes used to produce aerospace parts. These parts are often made from high-strength, high-performance materials that are difficult to machine and can cause rapid tool wear. In addition, the tight tolerances and high-quality requirements of the aerospace industry make it critical to maintain the accuracy and performance of the cutting tools throughout the machining process. There are several approaches that can be

taken to manage tool wear in the aerospace industry, including the selection of appropriate tool materials and coatings, the use of advanced cutting technologies such as cryogenic machining or high-speed machining, and the implementation of tool wear monitoring and control systems.

By understanding the factors that contribute to tool wear and implementing strategies to mitigate its effects, it is possible to optimize the machining process and improve the efficiency and quality of the finished parts in the aerospace industry.

1.2 Problem Statement

Nowadays, the mass-produce of material in the matching industry brought strategies that can optimize the surface finish of the material that important. Whenever it relates to pocketing profiles, the cutting strategy is crucial in determining the machining outcomes. Nowadays, there is a high demand for high-quality pocketing features for surface roughness because appearance, function, and reliability are all important in any product. With these considerations, surface finish and tool wear are critically maintained in the production of industry. For Aero-structural parts, pocketing profile is the main design in rib and spar sections due to its ability in improving the strength of the overall aircraft wing structure. Rapid tool wear is a significant issue in our manufacturing process, leading to increased tooling costs and reduced efficiency. It is important to identify the root causes of tool wear and implement strategies to mitigate its effects in order to optimize the machining process and improve the quality of the finished parts.

1.3 Research Objective

The primary objectives of this study are stated below:

- To evaluate the effect of roughing strategies namely concentric and helical (multipass mode) on the surface roughness and tool wear in machining pocketing profiles of an example aero structural component.
- To determine propose the most optimum roughing strategy to machine pocketing profiles of an example aero structural part using an actual aerospace standard material (Aluminum 6061 series) with respect to the surface roughness and tool wear analysis utilizing roughing operation offered by CATIA V5.

1.4 Scope of Research

The following was a list of the project's focus areas:

- Using CATIA V5 mainly focusing on roughing operation by applying two machining strategies namely concentric and helical motion which both strategies were in multipass mode.
- The types of the pocketing profiles involved in this work were divided into two types namely; circular & rectangular shapes.
- A completed CAM program with the cutting strategies in placed then post-processed by using integrated post processor which compatible with Siemens 840D controller.
- DMGMORI DMU 60 Evo, a CNC Milling Machine 3-Axis was used to perform the physical machining for both mentioned cutting strategies.
- Cutting parameters for all parts remain constant and include the length of the tool reach, depth of cut, feed rate, and spindle speed.
- Aluminium A6061, a 6000-Serie-Aluminum, was to be applied in this machining process.
 - Surface roughness evaluation was carried out using Mitutoyo Surf test.
 - Visual inspection was involves in simply looking at the tool to see if there are any visible signs of wear, such as chipping or excessive dullness
 - Final analysis have be done via doing an analysis through all the data from the surface roughness and microscopic image have acquired to determine the most optimum cutting or machining strategy during machining pocketing profiles of an aero-structural part sample.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

ملاك

This chapter performs and summarizes a literature study to define the idea of machinability, as well as the numerous roughing machining procedures enabling pocketing features of either an aircraft component or the process factors that influence machinability. Regarding machinability in aspects of the whole cutting system, not just certain work material characteristics, results from the assimilation of workpiece metallurgy factors, tool design requirements, and cutting conditions, despite the workpiece's develop more effective in the machining process. Thus, the notion of machinability as well as its assessment techniques, as well as the elements impacting the process in past metal research, will be examined in this chapter. اونيۇم سيتي تيڪنيڪل مليسي

MachinabilityRSITI TEKNIKAL MALAYSIA MELAKA 2.2

Machinability may be described as the simplicity at which a metal could be machined or machined in a material removal process under circumstances. However, the phrase was difficult to define because of the multi-variable and non-qualitative assessment that incorporates the machining variables. Astakhov distinguishes between two forms of machinability: work material machinability and process machinability. The ultimate objective of machining optimization was to make the work material machinable. Machinability was a quality of the work material related to its physico-mechanical properties.

Process machinability, on the other hand, was linked to machining conditions and refers to the deviation of current machining conditions from the optimum. On the other side, process developers, manufacturing engineers, and machine shop operators may have some reasonable questions: why do we need to grasp and comprehend the idea of machinability? What precisely can we take away from this data? These are legitimate issues since no one has yet created a methodology for calculating machinability and illustrating the benefits that may be derived utilizing the computed result (s). 2014 (Astakhov).

One of the most popular machining procedures in industry was aluminum alloy machining. Aluminum, in compared to steel, offers lower cutting forces and may be machined at greater cutting speeds. The influence of metallurgical characteristics, heat treatment, and cutting circumstances on essential machinability parameters such as tool wear, surface quality, cutting forces, and chip formation will be shown in a brief overview of the literature on the machinability of aluminum alloys. The key variables impacting the machining process and, as a result, the machining outcomes are summarized in Figure 2.1. Several experimental tests were devised to try to offer numerical conceptions of the relative ease of machining of a certain material by utilizing these tests to characterize qualitative the relative ease of machining.



Figure 2.1 Machining Operation. (Barakat, 2019)

According to Barakat et al, 2019, these tests may be separated between machining and non-machining testing methods. There are two types of assessment tests in the first category: actual and ranking rating tests. Absolute evaluation machining tests include the taper turning test, variable-rate machining test, and HSS tool wear-rate test, whereas ranking evaluation machining tests include the quick facing test, constant pressure test, and deteriorated tool test.

Absolute evaluation machining tests include the taper turning test, variable rate machining test, and HSS tool wear-rate test, whereas ranking evaluation machining tests include the quick facing test, constant pressure test, and deteriorated tool test. Non-machining testing, on the other hand, consists of measurements of parameters that have a substantial impact on machinability, such as chemical composition, microstructure, and physical qualities. (2019, Barakat)

Additionally, international organizations standardize various tests to evaluate machinability in accordance with various norms, such as the ISO test based on ISO 3685,

which 15 tests tool-life with single-point turning tools, and the ASTM test based on ASTM E618-07 for ferrous metals using an automatic screw machine. (Zajac and colleagues, 2020).

2.2.1 Material Machinability Evaluation Criteria

In the aircraft sector, the usage of innovative materials is tied to commercial and market reasons, as well as weight reduction and enhanced performance. Harder materials, cheaper prices, larger and more complicated constructions, and environmental considerations are all needed for new materials. The graphic below depicts how various materials are utilized in a Boeing 787 and how they compare to materials used in prior Boeing 777 generations. (Pedroh2m, 2014a).



Figure 2.2 Use of different materials in a Boeing 787. (Pedroh, 2014)

Engineers are presently highly worried about picking materials for the aircraft sector, according to reports. This is due to the fact that aircraft are a medium of transportation that need both high levels of security and maximum performance. Titanium, steel, and aluminum make up the majority of the aircraft's construction.

New lightweight materials based on polymers and carbon fiber, on the other hand, are quite likely to be employed in the future. Composite materials are lightweight and robust, as they are made up of polymers and carbon fiber. New alloys are being created to satisfy current demands. Even so-called composite Aeroplan's are just around 50% composite, suggesting that the other 50% is still metallic.



Figure 2.3 Evolution in use in the use of materials in the aerospace industry. (Pedroh, 2014)

Because evaluating machinability is difficult, numerous criteria have been created to help translate the idea of machinability into something usable. The following are some of the most prominent of these:

UNIVERSITI TEKNIKAL MALAYSIA MELAKA • cutting forces

- chip formation, and
- surface roughness.

Temperature rise, tool wear level, specific power consumption, dimensional tolerance, and total cost are all elements to consider. Although these four basic assessment criteria make the study of machinability easier, they are not all equally easy to quantify. Chip formation comprises chip breakability, chip shape-, and built-up edge, while tool life and cutting forces may be easily measured using particular tool wear criteria and dynamometry.

Surface roughness study also includes wear and stress concentration, as well as other elements of surface integrity. (2019, Barakat)

The sole book on the machinability of a wide range of work materials was written by Mills and Redford. In this book, there is no commonly recognized criterion for measuring machinability as a quality of the work material. As a result, the phrase "machinability" still denotes "all things to all men." Mills and Redford, on the other hand, advocated that cutting energy be eliminated from the definition of machinability, and that the word be regarded as a measure of how a material wears down a cutting tool during machining. As a result, the machinability of the workpiece material is presented in table 2.1.(Astakhov, 2014).

Nickel-base alloys	Machin ability (%)		Nickel-base alloys	Machin ability (%)
Astroloy	14		Ti (pure)-(tube)	60
Hastelloy B-2	20	20 Ti (pure)-(plate, bar, forge, ring)		45
Hastelloy C (plate)	25		Ti 17	18
Hastelloy C (cast)	20	•	Ti2Cu and and	30
Hastelloy C-22 20			Ti3Al-2.5V (bar, forge)	25
Hastelloy C-276 VERSITI TEK 18			Ti3Al-2.5V (annealed tube)	60
Hastelloy C-4	18		Ti4Al-4Ma-2Sn-Si	30
Hastelloy G	18	18 Ti5Al-2.5 Sn (annealed)		35
Hastelloy G-3	18		Ti5Al-2.5 Sn (ELI)	40
Hastelloy N(bar, forge, ring)	20		Ti5Al-2.5 Sn	35
Hastelloy N (cast)			Ti5Al-2.5 Fe	30
Hastelloy S 2			Ti6-2-4-2 (precipitation hardened)	25
Hastelloy W 18			Ti6-2-4-2 (annealed)	30
Hastelloy X 18			Ti6-2-4-6 (precipitation hardened)	25

Table 2.1 Workpiece Materials-Machinability. (Astakhov, 2014).

From the various available machinability criteria, the most appropriate machinability criteria for a certain work material should be picked. First and foremost, it must be directly

tied to the ease with which it may be machined, as defined by the original definition of machinability.

Metal cutting is a deforming method in which the cutting system's components are designed in such a manner that the external energy provided to the cutting system causes the layer being removed to be purposefully fractured. As a result, the amount of energy (mechanical effort) necessary to fracture a unit volume of work material was recommended as a criterion for machinability. As a result, because machinability is described in terms of energy, it has units of energy (J) and can be determined via mechanical testing.(Astakhov, 2014).

2.2.2 Material Characteristic (Aluminium 6061 series)

This alloy is part of the 6000 series of alloys. As a result, magnesium and silicon are the primary alloying elements. Magnesium is used to boost strength, whereas silicon is used to lower the melting temperature of the metal. The rules for the chemical composition of 6061 aluminum can be found here.

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Table 2.2 Shows properties of 6061 Aluminium Alloy.(Gabrian International LTD, 2020). General Characteristics

Characteristic	Appraisal
Strength	Medium to High
Corrosion Resistance	Good
Weldability & Brazability	Good
Workability	Good
Machinability	Good

Chemical Composition				
Element	Minimum %	Maximum %		
Magnesium	0.8	1.2		
Silicon	0.4	0.8		
Iron	No Min	0.7		
Copper	0.15	0.4		
Manganese	No Min	0.15		
Chromium	0.04	0.35		
Zinc	No Min	0.25		
Titanium	No Min	0.15		
Other Elements	No Min	0.05 each, 0.15 in total		

Physical Properties ALAYSIA				
Property	6061-T4	6061-T6		
Density S	2.70 g/cc 0.0975 lb/in3	2.70 g/cc 0.0975 lb/in3		
A CONTRACTOR	>			
Mechanical Properties				
Property	6061-T4	6061-T6		
Tensile Strength	241 MPa 35000 psi	310 MPa 45000 psi		
Yield Strength	145 MPa 21000 psi	276 MPa 40000 psi		
Modulus of Elasticity	68.9 GPa 10000 ksi	68.9 GPa 10000 ksi		
Juni all'	ة, تحتكره	اونية مرسب		
Properties	COCO TA	6061 TC		
Property	6061-14	6061-16		
Coefficient of Thermal	23.6 µm/m_°C 13.1 LAYS	23.6 μm/m-°C 13.1		
Expansion @ 20.0 - 100 °C	µin/in-°F	µin/in-°F		
Temp				
Thermal Conductivity	154 W/m-K 1070 BTU-	167 W/m-K 1160 BTU-		
	in/hr-ft²-°F	in/hr-ft ² -°F		

Al 6061 is widely used in a range of technical applications, including transportation and construction, where strong mechanical properties such as tensile strength and hardness are required. The chemical composition of Al 6061 is shown in Table 2. Because of its high corrosion resistance, it's an ideal contender for maritime structural applications. The quest for less weight, cost-effective, and high-performance materials for 6061 aluminum usage in a number of structural and non-structural applications has led to the development of metal matrix composites (MMCs) in various forms.(Christy et al., 2010).

Element	Mg	Fe	Si	Cu	Mn	V	Ti	Al
Weight %	1.08	0.17	0.63	0.32	0.52	0.01	0.02	Remainder

Table 2.3 Chemical composition of Al 6061. (Christy et al., 2010)

2.3 **Pocketing Profiles**

Milling profiles are preferred over pocketing profiles. CNC machining is used to make a wide range of components, and tooling prices have been steadily decreasing. Alternative technologies are appropriate for large production runs with basic designs, whereas CNC machining may fulfil a wide range of manufacturing needs. CNC milling is a great tool for prototyping and short-run manufacture of complicated parts, as well as making one-of-a-kind precision components.

In the machining of mechanical components, dies, and moulds, pocket machining is critical. Pockets might be rectangular, circular, square, or any other complicated form. It may also be worn in a pocket, either open or closed. Basic machining processes are milling sequences with simple geometric properties, such as profile milling, hole-making, pocket milling, and so on. These basic sequences may be completed with a standard 3-axis mill.



Figure 2.4 Profile milling sequence. (Chang, 2015).

However, users must first create 3D solid parts for the design model before using a full-scale CAD/CAM system like Pro/MFG or CAM/Works (and usually the workpiece as well). In software packages with a CAM focus, such as Mastercam, a simple 2D wireframe is typically adequate to handle basic machining processes. Using a basic example in Figure 2.4, we'll go through several aspects of fundamental machining processes in this section. In this example, profile milling, pocket milling, and hole-making are all employed. Figure 2.4 depicts the toolpaths for the three NC sequences.(Chang, 2015).

2.4 CNC History

First and foremost, a shout-out to the machine tool widely considered as the first: The answer to accurately drilling cylinders for steam engines was John Wilkinson's boring machine, which was created in 1775. Watt is credited with inventing the steam engine, which propelled England's Second Industrial Revolution, but he struggled to achieve consistent precision in his steam engine cylinders until Wilkinson developed his engine cylinder boring machine, which was based on his original cannon-boring machine design.(Tools, 2019).



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Figure 2.5 Invention of Matthew Boulton, Watt's business partner, 1776. (Tools, 2019).

The creation and execution of innovative products using sophisticated manufacturing technologies and process combinations is a major challenge in worldwide competitiveness. Today, the advancement of the High-Speed Industry is principally represented by different Additive Manufacturing procedures in the emerging Rapid Technologies category. High-Speed Cutting (HSC) is a unique and vital technique. Machining on a single setup with little clamping is the current trend. With the emergence of computer graphics, a computer can now produce, handle, and check components, reducing final machining time while removing mistakes caused by manual part swapping. The extensive usage of computer-assisted systems offers several advantages. Manufacturing engineering tasks such as process planning, and design are most closely related with CAM. Numerical control part programming (CNC).

2.5 3D CAD System (CATIA)

CAD/CAM systems are extensively employed in everyday engineering activities. The use of computer systems to plan, manage, and control the operations of a manufacturing facility via a direct or indirect computer interface with the plant's production resources is known as computer-assisted manufacturing (CAM). The geometric model developed during the CAD phase provides the foundation for the CAM process. Different forms of CAD process information may be required for different CAM processes. It necessitates the best judgement to choose the greatest software to purchase because it has evolved through time and is extensively utilised. As competitive pressures call for improved product performance and quality, as well as shorter development times, it is becoming increasingly vital in the product design and manufacturing process.

The CAM application is created using Catia V5's Advanced Machining workstation. "Sweeping" is a surface machining operation available in Catia V5. In Catia V5, users could
pick the tool path's direction. Machining parameters were also computed automatically from the library, based on the user-specified range, which is unusual for Catia V5. At every level, Catia V5 emphasizes the importance of details.(Azwan et al., 2016).

2.5.1 Milling Simulation (CATIA V5)

The function Generative CNC code in the CATIA CAD/CAM system is used to implement the code. The CNC program will construct the active machining process that was designed in the previous phases when this symbol is engaged. The correct data on the machining process, tool, and specifying its holder must be decided before the CNC code can be generated. The resultant code can then be modified on a computer or delivered straight to a CNC machining center; the latter option is less efficient. Because these data are established in CNC machining centers and the eradication of numbering lines, the deletion of produced CNC code is a necessary first step. The file must be changed to CNC program without an extension before it can be read by CNC machining centers. The next step is to save CNC code to portable media and put it into a machining center, which runs programs straight from portable media due to its lack of internal memory.(Dubovska et al., 2014a).



Figure 2.6 Virtual simulation of milling process in CATIA V5. (Dubovska et al., 2014).



Figure 2.7 Strategy of milling process and dialog panel for the settings of machining simulation. (Dubovska et al., 2014b).

2.6 Machining Strategies

The pathways that a cutting tool follows to remove material and build a shape are known as machining techniques. It's made up of a sequence of coordinate coordinates that dictate how a tool travels during machining. The tool path must be taken into account while machining since it has a direct influence on the machining performance and qualities of the workpiece. There were various aspects of the machining process that need careful consideration of the tool path.

The Concentric cutting approach, which is popular due to its ease of programming, generates the toolpath using offsets from the area profile that will be cut.



Figure 2.8 The generated toolpaths concentric. (Zoghipour et al., 2021).

Helical motion can be inward, outward, or both. The way the tool starts from a point within the zone and follows the boundary is called inward helical, whereas outward helical moves outward lines parallel to the border is called outward helical. The motion of inward and outward helical spirals is seen in Figure 2.9. UNIVERSITI TEKNIKAL MALAYSIA MELAKA



Figure 2.9 Inword helical motion and outward helical motion.

2.6.1 Helical

In Helical mode, the management of the Non-Cutting Diameter (Dnc) has been enhanced, especially in the computation of ramping techniques. Inward, outward, or both helical motions are possible. Outward helical refers to how the tool travers's outward pathways parallel to the border, whereas inward helical refers to how the tool starts from a point inside the zone and follows the boundary. The helical toolpath tool, on the other hand, begins inside the geometry and parallel to the border for both.



Figure 2.10 Tool path strategies (a)Inward Helical (b)Outward helical (c) Both Inward and outward helical

When utilizing the inward helical, the finest surface roughness was recorded when the tool path ratio was 30 percent. However, because this approach takes a long time, mould inset firms may face increased production expenses. This experimental study may be utilized to pick the optimum surface finish with the kind of tool path strategy employed since the surface finish of the cavity and core insert of the mould is the most significant parameter in the moulding business.(Mebrahitom et al., 2016).

2.6.2 Concentric

The Concentric cutting approach, which is popular due to its ease of programming, generates the toolpath using offsets from the area profile that will be cut.



Figure 2.11 Concentric toolpath. (Bagci & Yüncüoğlu, 2017).

"Concentric Roughing" is a CATIA machining technique that provides cornering capabilities and allows customers to produce tool paths that are optimized for their HSM machines. Other Catia techniques included not entirely burying the tool in the materials, rounded internal corners, and loops added to exterior corners akin to zigzag machining. (Ding et al, 2010).

The rounding method is used extensively in several of Esprit's machining operations, including "Z-Level Finishing," "Z Plane Concentrical Roughing," and "Concentrical Milling with a Constant Stepover." "Z Level Finishing" can employ smooth circular approach movement and fluent stopovers to maintain consistent chip loads throughout transitions between vertical walls and horizontal floors. In addition to the rounding approach in "Z Plane Concentrical Roughing," the results of the dynamic in-process stock model may be used to optimize step over with polite feed (considering residual materials left over from previous machining cycles).(Ding et al., 2010).

2.6.3 Multipass

The cutter, positioned on a spindle spinning perpendicular to the surface, provides a high material removal due to the cutting action of numerous teeth on its perimeter and face in the face milling operation. Milling can be done in a single pass or in many passes. Multipass milling is always preferred over single pass milling for greater machining economies, and it is used to form workpieces that cannot be machined in a single pass. Face milling with several passes frequently results in low power usage, machining force, machine degradation, and clatter.(Diyaley & Chakraborty, 2019)



Figure 2.12 Roughing and Finishing on multipass face milling operation. (Diyaley & Chakraborty, 2019)

Multiple rough passes and one final pass are used in multipass milling, which has a sophisticated material removal mechanism. During many rough passes, the majority of the material is removed from the workpiece. The single finish pass is primarily responsible for smoothing the surface. A typical multi-pass face milling procedure is shown in Figure 2.13.



Figure 2.13 multi-pass face milling. (Li et al., 2017).

2.7 Profile Milling Process

Profile milling is a milling technique that is typically used to finish or semi-finish vertical or sloped surfaces. Multi-axis milling of convex and concave forms in two or three dimensions is also included. 2.5 axes are used in the profile milling CNC sequence. The strategy for a profile milling operation is crucial, particularly for big workpieces and equipment with complicated designs. (Anonymous, 2022a).

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Turning, milling, facing, and other operations must be performed in the machine shop to meet the basic requirement of CNC machining. Conventional machining processes, which involve two stages or two types of processes, are suitable for high stock removal and good surface quality. The roughing operation is used to quickly produce a part geometry that is close to the shape of the finished product, and the finishing operation is used after roughing to achieve the final geometry and other details.(Anonymous, 2021).

2.7.1 Roughing/Semi-Roughing

In machining, roughing procedures are typically used to remove bulk material and roughly shape the workpiece to the desired shape, making further processing easier and more efficient. Rough machining's purpose is to get rid of the blank allowance as rapidly as feasible. To remove as many chips as feasible in a short period of time, a high feed rate and cutting depth are frequently selected. As a result, rough machined goods have a low degree of precision, a rough surface, and a rapid rate of production. Roughing is a common technique for preparing surfaces for semi-finishing and finishing.

2.7.2 Semi-Finishing/Finishing

After rough machining, semi-finishing and finishing operations are normally conducted; nevertheless, high-speed machining may be necessary for milling the remaining stock or materials, which is widely utilised in super-fishing.

2.7.3 Profile Milling Tools Selection

End mills, face mills, conical mills, and T-slotters are recommended for pocketing. Round inserts and ideas with radius for roughing and semi-roughing, as well as ball nose end mills for finishing and super-finishing, are among the profile milling cutters. For each profile milling procedure, select the right tool. Rough inserts are highly stable, have a medium cutting depth, and are quite productive. The cutting depth of a ball nose indexable is medium, and the steadiness is moderate. The ball nose interchangeable head is sturdy, but its cutting depth is limited. Furthermore, ball nose solid carbide has a limited cutting depth and low stability.(Anonymous, 2022).



Figure 2.14 Shows the tool for roughing and finishing. (MEAD, 2021).

The importance of tool selection stems from the fact that certain geometries, such as the filter, plays a role in it. The radius of a fillet must be at least half the diameter of the end mill. Any smaller, and it becomes more difficult to perform or involves an unnecessary equipment change.(MEAD, 2021).



2.7.4 Machining time

Time spent on the machine / total time spent on the machine is the amount of time a machine spends processing something is known as machining time. When undesired material

is removed, machining time is the phrase used. Machining time, for example, is when the cutting edge moves forward and makes a hole in a drill press. Subtractive manufacturing is the term for this method. The machine cycle time, or the amount of time that the machine must commit to each item after it is set up to run that product, is calculated by adding the machining time to the loading and unloading time.

Monreal and Rodrigues proposed a system for machining time prediction based on a mechanistic approach. However, it only considers the machining time for pocket milling in a zig-zag route based on tool path strategy. (Gusev et al., 2017). Huge NC programs include a large quantity of data that the CNC machine must process quickly. As a result, in order to manage such large volumes of data, the CNC machine's feed rate may need to be lowered. As a result, the milling feed rate and, as a result, the machining time are related to the linear segment length.

2.7.5 Speed and Feed Rate

In today's manufacturing, creating process models and anticipating actual machining process conditions in a computer environment has become critical to increasing efficiency and throughput. For example, during the quoting process, precise machining cycle time forecast is critical to ensure feasible and profitable contracts. The feed rates for approach, retract, machining, and finishing, as well as a machining spindle speed, on the Feeds and Speeds tab page can be set. Feed rates and spindle speeds can be expressed in both linear and angular units. The output of the SPINDLE instruction in the resulting NC data file may be controlled using the Spindle output checkbox. The instruction is generated if the checkbox is selected. It is not created if this is not the case. The operation's feeds and speeds can be changed automatically based on tooling data and the operation's Rough or Finish quality. Update of Feeds and Speeds on Machining Operation explains how to do this. As a result, in order to build realistic digital twins for machining operations, the feed rate profile formed by a machine tool's NC system must be properly anticipated. Thus, in current NC systems, this is for modelling and forecasting interpolator dynamics so that machining cycle durations and cutting forces may be accurately anticipated over complicated sections.

To forecast a machine's actual feed rate profile, a detailed model of the NC system's real-time interpolation behavior is necessary. Figure 2.14 depicts a typical feed rate profile for continuous motion, which includes the motion transition between CL blocks. The acceleration and jerk constraints determine the machine tool's performance and behavior during the first linear motion from zero to the desired feed rate. When the tool approaches the end of the first CL line (corner transition 1 in Figure 2.14) to change the feed direction, it decelerates to a minimum cornering feed rate before accelerating to the prescribed feed rate. Throughout the cornering transition, the machine tool satisfies both the tool canter point (TCP) error tolerance requirements and the machine tool kinematic constraints, resulting in a drop-in feed rate around the CL line junction point. The TCP fault may be seen at corner transition 2, where the TCP is at maximum displacement between the CL line and the TCP point. The TCP error restriction placed on the toolpath limits the maximum feed rate during cornering transitions, which has a significant influence on the overall machining cycle time.(Ward et al., 2021).



Figure 2.15 Example of kinematic profiles of NC program. (Ward et al., 2021).

2.8 Surface roughness

During the milling process, surface roughness is an essential feature that reflects workpiece quality. Munoz-Escalona and Maropoulo devised multiple regression approaches, **UNVERSITIEKNIKAL MALAYSIA MELAKA** fuzzy set-based methodology, and artificial neural networks prediction of surface roughness (Ra) values in Al alloy 7075-T7351 in the face milling machining process for various ANNs. (Eser et al., 2021).

Surface roughness has a big influence on microscopy evaluation, mechanical item performance, and manufacturing costs. The manufacturer adjusts the cutting condition to obtain the appropriate surface roughness for these reasons. The desire for high-quality, completely automated manufacturing focuses on the product's surface condition, particularly the roughness of the machined surface, because it impacts product look, function, and dependability, as well as the relevance of tolerance and surface finish consistency. Reduced surface quality may signal workpiece material non-homogeneity, progressive tool wear, cutting tool chatter, and other issues, which can impair machining process stability diagnostics.



Figure 2.17 Graph of Ry surface roughnes.



Figure 2.18 Graph of Rz surface rougnes. (Hizzuanna & Hazizan, 2015).

Based on Ra, Ry, and Rz, surface roughness is used to determine surface quality. The mean roughness of a standard-length segment sampled from the roughness chart's mean line is Ra. The mean line is represented on a Cartesian coordinate system, with the x-axis representing the mean line and the y-axis representing magnification. When Ry is the greatest peak, the distance between the peaks and valleys of the sampled line is measured in the y-direction. The distance between the peaks and valleys of the sampled line in the y-direction is measured by Rz, a ten-point mean roughness. The average peak (Yp) is then calculated from the five highest peaks, while the average valley is calculated from the five lowest valleys (Yv). Micrometers are used to measure the product of these two values. The graph below is an example of what the Surface Roughness machine may create.

2.9 Microscopic Images

A microscopic picture in an aerospace part inquiry refers to a photograph or digital image of a tiny piece of an aeronautical component that has been enlarged using a microscope. This sort of imaging is often used to inspect the surface characteristics or internal structure of an aircraft item in order to discover flaws or anomalies. Microscopic pictures may be employed in a range of various aircraft part examinations, including quality control inspections, failure analysis, and material characterization studies. In rare circumstances, microscopic pictures may be utilized to discover minute fractures, surface flaws, or other abnormalities that are not visible to the human eye. In other circumstances, microscopic pictures may be used to investigate the microstructure of a substance to evaluate its qualities or performance.

There are various types of microscopes that may be used to create microscopic pictures in aircraft component examinations, including optical microscopes, electron microscopes, and scanning probe microscopes. The choice of microscope will depend on the size and type of the features being studied, as well as the resolution and contrast necessary for the research.



Figure 2.19 Nikon MM-800 optical microscope

CHAPTER 3

METHODOLOGY

3.1 Introduction

The aerospace industry has expanded rapidly in Asia, particularly in Malaysia. Most aerospace components are manufactured in Asian countries. This is because Asian countries offer lower manufacturing and labor costs. As a result, many efforts are made by industries to compete with market demand. One of the current methods thought and used by industries was to simplify the machining approach from five-axis to three-axis machining. This method can only be applied to parts with specific shapes or geometries.



Figure 3.1 Internal structure of a wing

The proposed research began with a literature review and the search for reading materials to gain some ideas and methods to be used while conducting the research. Discussions had taken place with the relevant industries to brainstorm and gather input for the best aerospace sample part that corresponded as shown above (figure 3.1) to the desired requirement for the intended research. After the part was finalized, CATIAV5 was used to

create the modeling. All modeling processes in CATIAV5 were completed using Sketcher, Part Modeling and Assembly workbench, and Advanced Machining workbench, which allows users to create machining programming by integrating Computer-Aided Design and Computer-Aided Manufacturing (CADCAM).



Overall, the operation setup, surface roughness, and microscope analysis are all essential machining factors that help guarantee that the end product satisfies the required criteria and is of a high caliber. (Shows in figure 3.2)

3.2 Visions of Development



Figure 3.3 Flow Chart.

3.2.1 First phase

The project began with searching the existing CAD part and finding the best strategies in roughing and pocketing which are helical path, and concentric path (with both multipass). The pocketing shapes that have been determined were circular and rectangular. For the first phase, the CAD model was modified to preserve the concept of the product for machine and model suitability. The process continues with tool geometry, and machining parameters. Cutting parameters for all parts remain constant and include the length of the tool reach, depth of cut, feed rate, and spindle speed. Lastly, finishing the program to proceed to the next phase after determining the machining strategies for roughing and pocketing.



3.2.2 Second phase

The 3-Axis CNC milling machine was chosen for the project because of the simple part. Aluminum 6000 series have been used in this research by selecting accordingly to the material used in the aerospace or aircraft industry. When there is no error on CAD file or CAD part that have been modified, the process will have continued with setup the material, WPC, and physical machining process. After program end, surface roughness will be tested, and tool wear evaluation will be measured and analyzed.



evaluation, all the documentation will be reviewed by supervisor than will be submit for calculation of final year project marks.



Figure 3.6 Screenshot of Phase 3

3.3 Computer-Aided Design (CAD)

A part model was created using CATIA V5. Although the actual part modelling is done via the internet, it is critical to ensure that the part chosen can be opened in CATIA.

3.3.1 Modifying Process

To preserve the Intellectual Property (IP) of the actual part, a modification process was required. Cutting off the best portion to study was the first step, followed by scaling, stock preparation, axis system, plane system, and finally assembly of the entire part. All of the changes to the original CAD model are shown in Figure 3.7.





Figure 3.7 Modification operation

3.3.2 Modifying Existing Part

- i) Cutting Off The right and middle sides of the aircraft rib were removed by cutting off. It's because the right of the portion already has a pocketing profile. As a result, the part shrinks to a fraction of its original size.
- i) Scaling The scaling process was carried out to ensure that the part was compatible with the size of cutting tools available. For each axis, a scaling process was prepared. Scaling processes were prepared for all three axis which are x = 0.45, y = 0.50 and z = 0.50.
- ii) Stock The size of the stock are 110mm x 130mm x 25mm.
- iii) Axis System WPC-----01 (Axis System) created at the stock
- iv) Plane System The approach (20 mm) plane has green color, and the approach (100 mm) plane has a red color. It also includes one point in the plane approach's center and a new axis system.
 - v) Assembly In assembly design, a new file was created to combine the part with the stock, axis system, and plane system. The two axis systems happened to be updated at the same time. For a better understanding, see Figure 3.7.

3.4 Computer-Aided Machining (CAM)

The CAM method is limited to rectangular and round-shaped pocketing profiles. Because of the various tool path tactics used, there are three machining processes. Define the part operation was a required method in the CAM process. Type of machine, reference axis, product, part, stock, and cutting tools are all included.

3.4.1 Selecting Aided Machining (CAM)

This project made use of a CNC milling machine with 3-axis. This is due to the fact that the pocket profiles were of a simple shape that did not necessitate the use of a 5-axis machine for milling. Figure 3.8 illustrates how to choose a machine type.

3-Axis Machine	
Machine Editor ?	×
اونور سيني ناچا کر لک الح الح الح ا	
Name mori evo60	
Comment NIVERSIT LEKNIKAL MALAYSIA MELAKA	
Spindle Tooling Compensation Numerical Control	
Home point X : Omm	
Home point Y : Omm	
Home point Z: 100mm Named the machi	ne
Orientation I:	i de la composición de la comp
Orientation J:	
Orientation K:	

Figure 3.8 Machine Selection.

Axis is a crucial component in the machining process. It will serve as a process datum as well as a guideline for cutting tool movement and direction. Axis was made on the same standard workstation. Figure 3.9 shows how to choose a reference axis.



The part that needs to be defined is an assembly part, which is a mix of stock, axis, and plane systems. It can also refer to a part that needs to be manufactured. Figure 3.9, the design selection process.

3.4.3 Selecting of Stock

In the CAM process, stock is very important. To get a flat surface, it was necessary. The stock size should be greater than the part's actual size. It's because a facing process is required for the top surface to achieve a better finish. Because the raw material may not be accurate for that component, the sides around the portion must also undergo a profile contouring process. Part Body was clicked to produce stock on the part design workbench. If the part isn't 90 degrees, stock must be put at the bottom and top. The appropriate way to choose the stock is shown in Figure 3.10.



The tool selection is determined by the machining technique as well as the size of the profile to be machined. End Mill is typically used for roughing, pocketing, and profile contouring, but Ball Mill is the most ideal tool for isoperimetric machining.



Figure 3.11 Tool Change.

3.5 CAM Simulation

Cam process shows the process of roughing, semi finish, and finishing step by step to understand the movement of the tool, machined and part. The simulation of CAM process also shows the end of the part when being cut and after the cut before the actual process on actual machined have been process. Moreover, the wrong machining process that have been made on the CAM process can be repaired before proceeding to next process.



Figure 3.12 Machining Simulation 1 (CAM).



Figure 3.13 Machining Simulation 2 (CAM)

3.5.1 Machining Simulation (CAM)

- i) Process 1 Facing The facing technique was utilised to remove surplus material from the stock surface, as seen in figure 3.12 and figure 3.13 Face Mill D63 was used to complete for both machining process.
- ii) Process 2 Roughing To acquire a rough outline of that portion, the roughing procedure was used. It had been completed with the use of exterior roughing. Profile contouring can also be used to eliminate material from the area surrounding the part. The tool End Mill D6 2 flute was used for these two procedures. The figure 3.12 and 3.13 shows the roughing of both strategies for the machining strategies needed in this objective. Setting for the machining strategies Concentric-Multipass and Helical-Multipass were change in this roughing process.

3.6 Machining KAL MALAYSIA MELAKA

The machining process began only after the preceding steps were completed. It took multiple setups to produce a good quality result that could be measured later.

3.6.1 Machining Parameter

Every machining procedure necessitated the use of a parameter. This is due to a technical limitation and the desire to achieve a desired result. The machining performance as well as the properties of the part produced will be affected by this parameter. For all thw types of machining processes in this project, the parameters were kept consistent. The

machining parameter for the total process is depicted in Figure 3.14. The parameters employed were tool reach length, spindle speed, and cut depth. For all processes, the spindle speed is kept constant at 7500turn/min. Approach and machining feed rates are 1200mm/min, and retract is 4500mm/min. Both machining methods employed have a tolerance of 0.05mm.



Figure 3.14 Machining Parameter.









3.6.2 Macro Setting

Macro is necessary to ensure that the tool moves in the correct direction. It also prevents the tool from coming into contact with any unwelcomed surfaces. Moreover, it was utilized to reduce machining time. The macro setting for pocketing profiles is shown in Figure below.







Figure 3.18 Return Between Level Approach and Retract Setting



Figure 3.19 Pre-motion and Post-motion Setting

3.7 Machine Setup

Before beginning a machining process, the machine must be set up. It aids in the avoidance of any unfavorable situation or accident. The item was held in place by a fixture during the machining operation. When force is applied to the part's surface, it stops any movement. The cutting tool should have an offset value, which signifies that the machining operation should be done from the tip's center. The offset should be applied to both the x and y axis.



Figure 3.21 Laser measuring system for tool length masurement (BLUM)

To guarantee that the tool will cut appropriately, it is crucial that the Tool Length Offsets be exact and correct for each tool. In severe circumstances, if the tool length offset is wholly incorrect, this may result in a collision that harms the tool and probably also harms the machine or work holding. A Tool Length Touch Setter will be included with some machines. The machine employs this special purpose probe to automatically measure tool lengths. In other instances, the operator enters tool lengths into the Tool Table after measuring them off-line.



In this phase, we place any work holding that will hold the pieces during the machining process. There are several work holding options accessible. Another crucial function of the CNC Setup Sheet is to specify precisely what is required for a certain work (as shows in figure above).

Part Zero's physical location has to be communicated to the CNC machine. There are several approaches to doing this task. Work Offsets are designed to enable the existence of multiple component zeros. This is helpful, for instance, if you have several parts, each of which wants its own part zero. Or perhaps you wish to instal various fittings, each of which has a unique part zero.


Figure 3.23 Transfer the post processed NC code to machines controller

In order to configure the machine to execute the component, the NC code must be loaded onto it. Depending on the system, there are many ways to accomplish this.



Figure 3.24 Machining process

After carefully prepare the preparation needed before machining the machine can run the machine to cut the workpiece and produce the cutting finish.



Figure 3.25 Final product after machining in Mori60 Evo

3.8 Surface Roughness Test

Surface roughness test was made to collect data that can be analyzed for the best surface between both machining strategies Concentric-Multipass and Helical-Multipass. Before starting the surface roughness test, the workpiece must be setup carefully with a flat surface to make an accurate data measurement on both workpieces. The point must be at the same place on both workpieces surface area which is round surface, internal wall, and external wall.



Figure 3.26 Area of point testing

3.8.1 Setup Operation Roughness

In this operation, surface roughness plays a significant role in defining the surface quality of the machined Aluminum 6061 material. Surface quality may be created via machining processes, changing the mechanical properties of the surface texture. The machining techniques, spindle speed/cutting speed, feed rate, cutting pressures, and tool shape, among other aspects, all had a significant effect on the surface quality. The surface finish of the workpiece is evaluated with a surface roughness tester, such as the Mitutoyo Surf test SJ-410. In this study, the term Ra (Arithmetical Mean Deviation) is employed to assess surface roughness. The stylus travel distance is set at 4 mm for each measurement to evaluate longitudinal surface roughness. To determine the conclusion of the surface finish on the two parts' machining, 8 points of measurement were obtained on each machined surface, and a final average Ra was produced. The roughness tester and display unit for the SJ-410 are shown in Figure 3.27.



Figure 3.27 Roughness tester and display

Using a Nikon MM-800 optical microscope (shown in figure 3.28), the surface quality of each cut surface is examined in detail. From one to one hundred times is the

magnification range. As a result, it makes it easier to see tool wear or damage and gives us a clearer picture of what is going on with the cutting surfaces (shows in figure 3.2 below).



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CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The outcome of the machining process and the data collected from surface roughness testing and dimensional measurement for pocketing and circular pockets are shown in this chapter. Two alternative machining techniques were used to machine the two pieces, Concentric-Multipass and Helical-Multipass. To determine which of the two sections generated a better surface, all parts are being tested utilizing surface testing. Due to the stylus's limited functionality in the surface roughness testing equipment, a portion of each pocketing procedure is tested at the wall. The goal of the analysis is to record all data. For comparison between the two pieces.

4.2 Aircraft Rib Sample Machining

Using a DMU60 Evo 5-Axis Machining Center, the part is milled. Face Mill D50 diameter of 50 millimeters, and End Mill D6 diameter of 6 millimeters was used in roughing process of both machining strategies. All pieces are 120mm x 100mm x 50mm in stock size. Each component requires a varying amount of time, and the feed rate and spindle speed are constant to make both of workpiece are valid for analysis. Compared to Concentric-Multipass, which taken approximately 53.41 minutes, Helical-multipass was faster which takes 39.04 minutes which is 14.3 minutes fasters. The machining time are shows in figure 4.1. A CAD drawing-like object is produced from two components. However, each part's surface look varies. Table 4.2 shows the machined part for both machining strategies.

T,F,S	No. Contraction of the		T,F,S				
T ENDMILL_6_MD32 D1 ►► ENDMILL_6_MD32	R 3.000 L 113.443			11ll_6_MD23_ D1 Endmill_6_m	_SM 1D23_SM	R L 12	3.000 4.774
F 0.000 0.000 mm/min	0.0%		F	0.000 0.000	mm/min		100%
S1 0 Master 0	II 🔯 100%	Machining	S1 Master	0 0 50	, 100,	1	100% 140
<u>0 , 50 , 100,</u> Time coupter	140,	Time	Time, cour	nter			
Program	0.53:41b		Program		AND ASTRON	0:3	9:04h
Prog. remainder ca.	0:00:00h		Prog. rema	ainder ca.		0:0	0%
			Count worl	kpieces	Nin series	Yes	
Count workpieces	Yes		Workpiece	s, setpoint			10
Workpieces, setpoint	10		Workpiece	s, actual			7
Workpieces, actual	7						- Alle

Figure 4.1 Machining Time



Figure 4.2 Workpiece of Concentric-Multipass (a) and Helical-Multipass (b)

4.3 Microscopy Evaluation

Following the machining process, a close-up view of the tool and the workpiece demonstrates how the two machining processes differ and affect the tool and parts viewpoint. A microscope is an optical tool used to magnify small objects or characteristics so that they may be examined more carefully. Microscopes are classified into three types: optical microscopes, electron microscopes, and scanning probe microscopes. The most popular form of microscope is an optical microscope, which uses lenses to magnify an object's picture. They are classified into two types: compound microscopes, which magnify the picture with many lenses, and stereo microscopes, which magnify the image with a single lens but offer a three-dimensional perspective of the object. Below was the cutting tool path style that have been taken from the finished part from machining.



Figure 4.3 Differentiation outcome between two machining strategies Helical-Multipass (a) and Concentric-Multipass (b)

4.3.1 Surface Roughness UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Several factors, including the machining process, the material of the workpiece, and the conditions under which the workpiece is being machined, can contribute to the appearance of surface roughness. It's significant because it can have an impact on the final product's performance and functionality and is usually measured in microinches or micrometers. A rough surface, for instance, might be more susceptible to corrosion or might not perform as well in certain contexts as a smooth one. Surface roughness can be enhanced through several machining and finishing techniques.



Figure 4.4 Point Section

In general, the points of a section marking (shown in figure 4.4) for microscopy evaluation are chosen to represent specific features or areas of interest on the surface of the sample. The number and location of these points will depend on the purpose of the evaluation and the characteristics of the surface. It is important to choose a sufficient number of points to ensure that you are getting an accurate representation of the surface roughness. This will depend on the size and complexity of the surface, as well as the resolution of the microscopy system.



Figure 4.5 Viewpoint for Concentric-Multipass Surface Workpiece

Figure 4.5 and figure 4.6 shows the evaluation of surface on both Concentric and Helical machining strategies (with both multipass). It is also important to consider the characteristics of the surface itself, such as its material, texture, and geometry. These factors can all affect the roughness of the surface and will need to be considered when interpreting the results of the microscopy test.



Figure 4.6 Viewpoint for Helical-Multipass Surface Workpiece

4.3.2 Tool Wear

Machining a workpiece result in tool wear, which is the slow erosion of a cutting tool. Depending on the tool material, the workpiece material, the cutting conditions, and the length of time spent milling, this may occur. Below was the tool that have been used in making the aerostructure sample. The operation for both machining strategies used a new tool with the same pattern below. (figure 4.7 And figure 4.8)



Figure 4.8 Point section tool

Abrasive wear, adhesive wear, and fatigue wear are all types of tool wear that can occur. Small particles of the workpiece material embed themselves in the tool surface, generating abrasive wear. When a tool's substance becomes adhered to a workpiece's material, the tool wears away. The repeated pressures of machining can cause the tool material to fatigue and crack or fracture.

Inefficient or ineffective machining might be a direct result of tool wear. Poor surface finishes, higher tooling costs, and slower material removal rates are all possible outcomes. Therefore, it is essential to keep a close eye on tool wear and promptly replace worn tools to guarantee consistent product quality throughout the machining process.



Figure 4.9 Viewpoint for Tool One Endmill-6mm 2 Flute (Concentric-Multipass)

Figure above and below are the evaluation of surface that have caught on the Nikon MM-800 optical microscope. These will help in comparison of the tool wear that have impacted the tool because of the machining strategies between two strategies



Figure 4.10 Viewpoint for Tool Two Endmill-6mm 2 Flute (Helical-Multipass)

4.4 Surface Roughness Data

For surface roughness, the parameter that was investigated in surface roughness was the value of Ra. Ra, Ry, and Rz are the three parameters derived by surface roughness testing. However, because Ra is utilized as a global measurement of the roughness amplitude on a profile, only it was studied. Ra is the mean roughness of a piece of standard length sampled from the roughness chart's mean line. Defects in material surfaces can develop during or after processing, and analysis is required to provide the information needed to improve surface effectiveness, efficiency, and durability.

4.4.1 Roughness Data

The test was carried out on the area that had been selected by rough eye as being crucial in the surface testing, specifically the surface round, wall inner, and wall outer areas. Having said that, there are certain concerns regarding the area that has to be assessed in order to provide more precise data regarding the surface's roughness.

	Surface roughness test, Ra (µm)														
Surface Test	Concentric-Multipass					Helical-Multipass									
Surface Round	1	2	3	4	Averange	1	2	3	4	Averange					
P1	0.641	0.643	0.643	0.642	0.642	1.39	1.394	1.394	1.39	1.392					
P2	0.322	0.316	0.3	0.32	0.3145	0.416	0.402	0.393	0.398	0.402					
P3	0.633	0.612	0.57	0.62	0.609	0.508	0.502	0.502	0.504	0.504					
P4	0.464	0.414	0.432	0.44	0.438	0.763	0.644	0.61	0.65	0.667					
Wall Inner	1	2	3	4	Averange	1	2	3	4	Averange					
P5	0.667	0.665	0.666	0.655	0.663	0.655	0.658	0.657	0.65	0.655					
P6	0.644	0.644	0.645	0.643	0.644	0.634	0.636	0.628	0.643	0.635					
Wall Outer	1	2	3	4	Averange	1	2	3	4	Averange					
P7	0.325	0.329	0.331	0.323	0.327	0.75	0.683	0.749	0.69	0.718					
P8	0.36	0.366	0.364	0.36	0.363	0.88	0.974	0.969	0.9	0.931					

Table 4.1 Surface roughness data

4.4.2 Surface Round

The point that corresponds to this region can be found at the top of the pocket area, which refers to the surface area of the spherical pocket. Four measurements of the surface's roughness have been collected at these spots so that they can be compared to the results of the two different milling processes.







The machining methods for Helical-Multipass are beyond the critical value because they consistently produce the same result for four tests in a row. The value of this area is 1.39 μ m, which is greater than the value for Concentric-Multipass, which is 0.641 μ m, as shown in table 4.2 and figure 4.13. Both readings follow a chronological order with one another. Therefore, the costs of operating a Helical-Multipass system are 46% higher than those of a Concentric-Multipass unit.

Dorte	Reading	Reading, Ra (µm) P1									
Parts	1	2	3	4							
Concentric-Multipass	0.641	0.643	0.643	0.642							
Helical-Multipass	1.39	1.394	1.394	1.39							

Table 4.2 Ra value point 1



Figure 4.13 Graph Ra value for point 1

4.4.2.2 Ra value point 2

The Ra value for further information on point two's roundness surface area is displayed in the table and figure below. When compared to Concentric-Multipass, Helical-Multipass achieved a greater value of reading continuously than its counterpart. The best reading area has a reading of three, which places it at 0.3 μ m and 0.393 μ m for both the concentric and helical multipass. Due of these factors, the Concentric-Multipass surface was found to be the most successful during the point two surface testing. According to the reading that follows, the Concentric-Multipass Cutting Strategy produced the best finish surface area, which was 26.8% less than what was achieved with the Helical-Multipass Cutting Strategy (reading 3).

Douto		Reading, Ra (µm) P2									
Parts	1	2	3	4							
Concentric-Multipass	0.322	0.316	0.3	0.32							
Helical-Multipass	0.416	0.402	0.393	0.398							

Table 4.3 Ra value point 2



Figure 4.14 Graph Ra value for point 2

4.4.2.3 Ra value point 3

The results of table 4.4 and figure 4.15 indicate that the Concentric-Multipass method obtained the highest reading, and the best reading out of the four reading is number 3 with a value of 0.57μ m. When compared to Concentric-Multipass, which had linear readings in the range of 0.508μ m to 0.504μ m, Helical-Multipass achieved superior results. According to reading 3, the reading for the Helical-Multipass was 12.7% lower than the reading for the Concentric-Multipass.

Parts		Reading, Ra (µm) P3									
	1	2	3	4							
Concentric-Multipass	0.633	0.612	0.57	0.62							
Helical-Multipass	0.508	0.502	0.502	0.504							

Table 4.4 Ra value point 3



Figure 4.15 Graph Ra value for point 3

4.4.2.4 Ra value point 4

Last point section for round surface have declare based on table 4.5 and figure 4.16 of graph that the best machining strategies was Concentric-Multipass because the table and graph shows that the roughing test got consistence with reading of 0.4 μ m that make it is a linear graph and compare to Helical-Multipass that got higher value that range from 0.763 μ m to 0.61 μ m that make it an exponential graph and According to these findings, the proportion of Concentric-Multipass is 48.7% lower than the percentage of Helical-Multipass for the first reading. As a result, the surface area at Concentric-Multipass was the greatest possible option for this particular sector of the area.

Douto		Reading, Ra (µm) P4									
Parts	1	2	3	4							
Concentric-Multipass	0.464	0.414	0.432	0.44							
Helical-Multipass	0.763	0.644	0.61	0.65							

Table 4.5 Ra value point 4



4.4.3 Wall Inner

Wall Inner is the measurement that was taken of the side area of the workpiece or item being machined that is located on the inside of the pocket. This measurement was taken during the surface roughing tests. Workpieces produced using the two different machining processes have been compared in order to determine which of the two workpieces is superior. The selection areas are determined by the regions that have not suffered any defects as a result of the machining process, and the points at which the surface area is tested are fixed in place with both work pieces.



Figure 4.17 Section point 5 and 6 for Concentric-Multipass



Figure 4.18 Section point 5 and 6 for Helical-Multipass

4.4.3.1 Ra value point 5

The initial point, which was located at the innermost part of the wall, reveals that both of the surfaces have almost the same value, although the Concentric-Multipass value is somewhat more than the Helical-Multipass value. The critical reading for the Concentric-Multipass was at reading one, which is $0.667\mu m$, while the critical reading for the Helical-Multipass is at reading two, which is $0.658\mu m$. This information is based on the graph and table in figure. Both machining techniques have their minimum reading at reading four, which is the value 0.655µm for the Concentric-Multipass strategy and 0.65 for the Helical-Multipass strategy. In these surface roughness tests, Helical-Multipass was shown to be 1.8% better than Concentric-Multipass. These factors contributed to this finding.

Dente		Reading, Ra (µm) P5									
Parts	1	2	3	4							
Concentric-Multipass	0.667	0.665	0.666	0.655							
Helical-Multipass	0.655	0.658	0.657	0.65							

Table 4.6 Ra value point 5



Figure 4.19 Graph Ra value point 6

4.4.3.2 Ra value point 6

The table and the picture both demonstrate that both the Concentric-Multipass and the Helical-Multipass received a linear data reading that contains the value of $0.6\mu m$. Concentric-Multipass displays the greatest value out of all the readings that have been tested, but Helical-Multipass displays a number that is somewhat lower than Concentric-Multipass.

The Concentric-Multipass are 1.4% (minimum reading) of both workpieces, as determined by a comparison between both data collections.

Darts	Reading, Ra (µm) P6									
Parts	1	2	3	4						
Concentric-Multipass	0.644	0.644	0.645	0.643						
Helical-Multipass	0.634	0.636	0.628	0.643						

Table 4.7 Ra value point 6



Figure 4.20 Ra value point 6

4.4.4 Wall Outer

The dimensions of the wall outer, also known as the side face of the outer wall or the profile of the face wall, have been determined. In order to identify which of the two machining processes produced the better product, the workpieces themselves were analyzed and compared. The region that is selected for the purpose of calculating the surface area is based on the region that has not been formed as a result of the machining process, and the point that serves as the basis for the selection is shared by both workpieces.



Figure 4.21 Section point 7 and 8 for Concentric-Multipass



Figure 4.22 Section point 7 and 8 for Concentric-Multipass

4.4.4.1 Ra value point 7

The seventh point section for wall outer that has stated that the best machining strategies were Concentric-Multipass because the table and graph show that the roughing test got consistence with reading of 0.3m that makes it a linear graph and compare to Helical-Multipass that got higher value that range of 0.683μ m to 0.75μ m that makes it an exponential graph. The reason for this is because the table and graph show that the roughing test got

consistency with reading of 0.3µm that makes it a linear and the percentage of concentric multipass in the initial reading is 79.1% lower than the percentage of helical multipass. As a direct consequence of this, the surface area at Concentric-Multipass satisfies all requirements for this particular section of the region.

Parts	Reading, Ra (µm) P7										
	1	2	3	4							
Concentric-Multipass	0.325	0.329	0.331	0.323							
Helical-Multipass	0.75	0.683	0.749	0.69							

Table 4.8 Ra value point 7



Figure 4.23 Graph Ra value point 7

4.4.4.2 Ra value point 8

Tests on the surface's roughness were carried out at point eight, which is situated on the outside wall of both components, in order to determine which of the two was generated by the machining strategies: the smoother or the less rough one. The tables and figures that follow provide the findings of the tests conducted on the trough roughing. Using the HelicalMultipass approach rather than the Concentric-Multipass method is recommended by all four measurements. A statistical analysis revealed that the second measurement for the Helical-Multipass was 0.974µm higher than the second reading for the Concentric-Multipass, which was 0.366µm, and that all readings agreed that the Concentric-Multipass produced the smoothest surface. Additionally, the statistical analysis revealed that the second measurement for the Concentric-Multipass was 0.366µm. According to the findings of reading 4, the Helical-Multipass method was worth 85.7% more than its alternative, the Concentric-Multipass method.



Table 4.9 Ra value point 8

Figure 4.24 Graph Ra value point 8

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4.4.5 Averange Roughness value/data

Following the completion of the data gathering process for the surface roughness data, the average data will be computed in order to get the means of each surface area and point. These will make the data more accurate, allowing for more exact judging of the right surface roughness data gathering, which will allow for the optimum process strategies to be developed. Roughness is the degree to which a surface deviates from a perfectly smooth and level plane as a result of the presence of minute, erratic characteristics. It is common practice to quantify the average roughness of a surface using a metric that is known as the root mean square (RMS) roughness. The average roughness of a surface is a measure of the surface's overall roughness. To get the RMS roughness, take the root mean square of the surface's departures from its mean plane. This will give you the RMS roughness.

It is common practice to report the value of the average roughness in micrometers (μm) or nanometers (nm). The value is very susceptible to change based not just on the substrate but also on the intended use. The roughness of a surface that has been machined, for instance, may be anywhere between 0.1 and 1.0 um, but the roughness of a surface that has been polished could be lower than 0.01 um.

Surface test	Point	Concentric-Multipass	Helical-Multipass
Roud face	P1	0.642	1.392
	P2	0.3145	0.402
	P3	0.609	0.504
	P4	0.438	0.667
Wall inner	P5	0.663	0.655
	P6	0.644	0.635
Wall outter	P7	0.327	0.718
	P8	0.363	0.931

Table 4.10 Averange roughness data



Figure 4.25 graph averange value Ra

The average Ra value that was determined from the surface roughness testing is shown here in the accompanying graph. Both the graph and the table show that the highest reading was achieved using the Concentric-Multipass strategy rather than the Helical-Multipass strategy. The most significant value for the Helical-Multipass was found at point 1, which was 1.392μ m, while the most significant value for the Concentric-Multipass was found at point 5, which was 0.655μ m. Table 4.10 of the Concentric-Multipass Method presents the data indicating that the least value at position 2 is 0.3145μ m, whereas flow by the Helical-Multipass Method obtained the lowest value at the same place, which was 0.402m. As a result, the graph in figure 4.25 demonstrates that the Helical-Multipass method produces a spike at the first point, after which it continues to maintain the lowest and most acceptable value for surface polish while remaining below 1.0μ m. We are able to draw the conclusion that the Concentric-Multipass achieved the best surface finish for the roughing operation for the surface roughing test. This means that the Helical-Multipass did not achieve the best surface finish at the workpiece, which prevented it from producing the best rough pocketing profile in this investigation.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

The effectiveness of the suggested machining processes was evaluated with the help of two machined components throughout the course of this chapter. The outcomes of the measurement of the surface roughness are broken down in great detail, with illustrations and citations from prior research serving as supporting evidence. Through the use of surface roughness measurements and microscopic examinations of tool wear and the machined workpiece, this evaluation of two different machining techniques enables us to establish which of the two was the best method. The limitations of the study as well as some recommendations for more research are discussed, and the implications of these limitations as well as their application to the aerospace industry are shown.

5.2 Conclusion

We are able to draw the conclusion that the Concentric-Multipass achieved the best surface finish for the roughing operation for the surface roughing test. This means that the Helical-Multipass did not achieve the best surface finish at the workpiece, which prevented it from producing the best rough pocketing profile in this investigation. Because of the movement of the tool while the pocketing process is being carried out, there is a possibility that the Concentric-Multipass method will provide the highest possible surface quality outcome. It travels down each route and then levels off once it retracts to get closer to the pocketing surface. The microscope analysis of the surface component image that was machined reveals a wide range of images and cutting paths that have been produced as a result of using the machining methods of both helical multipass and concentric multipass. Image of the surface can be decided, which are the best finish through rough eye, and the route of the cutting can be observed, which can be determined for a more un defected cutting path. Image of the surface can also determine which are the best finish via rough eye.

The tool wear that has been obtained through microscopy shows that from performance the cutting strategies of Concentric-Multipass has made the tool wear of first tool more wear than Helical-Multipass, which makes the tool that was used for making the cutting strategies for Concentric-Multipass unsuitable for these strategies. This was shown by the fact that the tool wear of first tool is greater than that of Helical-Multipass. The machining time for Concentric-Multipass is much greater than that of Helical-Multipass, and the cutting technique of Concentric-Multipass is distinct from that of Helical-Multipass. This raises the possibility that Concentric-Multipass was used more often. Because of these possibilities, the tool wear of the Helical-Multipass technique is superior than that of the Concentric-Multipass technique.

5.3 Research Objectives

It is possible to draw the conclusion that the goal of this research, which was to investigate the influence of surface finish at different machining techniques, was accomplished successfully. This may be stated as a conclusion. In addition to that, the findings of this study are able to provide advice about the method of machining that is the most successful in machining, In a nutshell, the objectives, which were to observe the surface roughness and tool wear as a result of applying the roughing operation that was offered by CATIA V5, were accomplished successfully.

5.4 **Recommendations**

In further research of this kind, it may be possible to investigate other milling strategies, such as the concentric-trochoid and helical-trochoid approaches, for example. The more techniques that are taken, the more data that can be reviewed, and the more insights that may be acquired as a result. The aviation industry places a significant emphasis on the use of components with thin walls. Therefore, making the components in question thinner will result in a greater degree of applicability for this research. Circles and rectangles are the most typical forms seen in coated tools, although they may be found in a broad range of other sizes and shapes as well. In reference to their radii, often known as the number of flutes, instruments may be categorized as either 3 flute (Carbide) or 4 flute (Carbide).

In precision applications, coordinate measurement machines (CMMs) are often used for the purpose of evaluating tool wear. Therefore, CMMs may be used in future research for the purpose of precision measuring devices. These instruments make use of a probe to acquire data on the dimensions, shape, and location of a workpiece or tool.

In addition, by cherry-picking components that comprise forms other than squares and circles, this research may be improved upon significantly. The examination of a higher amount of data will be made possible by the use of a more complicated form. For this research to provide findings that are more accurate in terms of measuring roundness, more points are required. This is due to the fact that profiles with a higher point count have a greater propensity to be more accurate.R

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APPENDICES

APPENDICES A Standard Specification for Aluminium and Aluminum-Allov Bars, Rods, Wire, Profiles, and Tubes. (ASTM)



Designation: B221 - 14

Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes¹

This standard is issued under the fixed designation B221; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (a) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense

1. Scope*

1.1 This specification² covers aluminum and aluminumalloy extruded bars, rods, wire, profiles, and tubes in the aluminum alloys (Note 1) and tempers shown in Table 2.

Norn 1-Throughout this specification, the use of the term alloy in the general sense includes aluminum as well as aluminum alloy. Nom 2—For rolled or cold-finished bar and rod refer to Specification

Port 2—Portoiga or cond-mission or and rou reject to Specification B211, for drawn seamless tube used in pressure applications, Specification B210, for structural pipe and tube, Specification B429/B429/M, and for seamless pipe and tube used in pressure applications; Specification B241/B241M.

Norn 3-Pipe and tube products listed in this specification are inter for general purpose applications. This specification may not address the manufacturing processes, integrity testing, and verification required for fluid-carrying applications involving pressure. See Specifications B210 or B241/B241M, or both as appropriate, for seamless pipe and tube used in fluid-carrying applications involving pressure. See Specification B234, as appropriate, for use in surface condensers, evaporators, and heat exchang-

1.2 Alloy and temper designations are in accordance with ANSI H35.1/H35.1M. The equivalent Unified Numbering System alloy designations are those of Table 1 preceded by A9; for example, A91100 for Aluminum 1100 in accordance with Practice E521

1.3 For acceptance criteria for inclusion of new aluminum and aluminum alloys in this specification, see Annex A2

1.4 A complete metric companion to Specification B221 has been developed-Specification B221M; therefore, no metric equivalents are presented in this specification.

2. Referenced Documents

2.1 The following documents of the issue in effect on the date of material purchase, unless otherwise noted, form a part of this specification to the extent referenced herein:

2.2 ASTM Standards:³

- B210 Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes
- B211 Specification for Aluminum and Aluminum-Alloy Rolled or Cold Finished Bar, Rod, and Wire
- B234 Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes for Condensers and Heat Ex-
- B241/B241M Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube
- B429/B429M Specification for Aluminum-Alloy Extruded Structural Pipe and Tube
- B557 Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products
- **B594** Practice for Ultrasonic Inspection of Aluminum-Alloy Wrought Products
- B660 Practices for Packaging/Packing of Aluminum and Magnesium Products
- B666/B666M Practice for Identification Marking of Aluminum and Magnesium Products
- B807/B807M Practice for Extrusion Press Solution Heat Treatment for Afuminum Alloys
- B881 Terminology Relating to Aluminum- and Magnesium-Alloy Products
- B918 Practice for Heat Treatment of Wrought Aluminum Alloys
- B945 Practice for Aluminum Alloy Extrusions Press Cooled from an Elevated Temperature Shaping Process for Production of T1, T2, T5 and T10-Type Tempers
- E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specification
- E34 Test Methods for Chemical Analysis of Aluminum and Aluminum-Base Alloys
- E527 Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)

E607 Test Method for Atomic Emission Spectrometric

*A Summary of Changes section appears at the end of this standard

¹ This specification is under the jurisdiction of ASTM Committee B07 on Light Metals and Alloys and is the direct responsibility of Subcommittee B07.03 or Aluminum Alloy Wrought Products.

Current edition approved Oct. 1, 2014. Published October 2014. Originally proved in 1947. Last previous edition approved in 2013 as B221-13. DOI: 10.1520/B0221-14.

For ASME Boiler and Pressure Vessel Code applications see related Specification SB-221 in Section II of this Code.

³ For referenced ASTM standards, visit the ASTM website, www.astm. contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page or the ASTM website.

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APPENDICES B GANT CHART PSM1

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Supervisor selection and registered	Plan															
title	Actual															
Brief and project explanation by	Plan	1														
supervisor	Actual	4														
Module 1: Research and planning	Plan	8														
	Actual		14													
Discuss problem statement and	Plan		P						- L							
objective for chapter 1	Actual															
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Module 2: final year project literature	Plan					1										
review	Actual															
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APPENDICES C GANT CHART PSM 2

ACTIVITIES	STATU	WEEK														-
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PSM Briefing	Plan															
	Actual															
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Chapter 3: Methodology	Plan				100											
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Chapter 4: Preliminary	Plan				7											
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Formatting and Grammar Improvement	Plan				10											
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Slide Preparation	Plan															
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