FINITE ELEMENT SIMULATION OF MACHINING METAL MATRIX COMPOSITE AlSiC

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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DECLARATION

I hereby, declared this report entitled ‘Finite Element Simulation of Machining Metal Matrix Composite AlSiC’ is the results of my own research except as cited in references.

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Date : 2 September 2021

APPROVAL

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

R Izamshah

Signature :……………………………………………………….
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ABSTRAK

Selama bertahun-tahun, komposit matriks logam (MMC) telah menjadi bahan komposit yang penting. Oleh kerana ciri-ciri yang sangat baik, MMC aluminium yang ditingkatkan zarah telah mendapat permintaan yang tinggi. Oleh kerana wujudnya partikel penyempitan kasar yang lebih sukar daripada alat pemotong, bahan-bahan ini dianggap sukar untuk diproses. Terdapat banyak kesulitan yang wujud, seperti suhu pemotongan yang tinggi, disebabkan oleh kurangnya pemasaran pemotong khusus untuk pemesinan bahan MMC. Reka bentuk geometri baru untuk pemprosesan komposit matriks logam (MMC) telah dikembangkan untuk mengatasi masalah ini. Objektif kajian ini adalah untuk meningkatkan ciri pemotong geometri, yang dapat menghasilkan MMC dengan cekap. Dalam kajian ini, kesan ciri geometri pemotong seperti sudut heliks, sudut rake, sudut pelepasan dan bilangan seruling pada kekasaran permukaan, keausan alat, suhu dan kekuatan dikaji untuk mengoptimumkan ciri geometri pemotong. Suhu dan tekanan adalah tindak balas pengeluaran yang harus dipertimbangkan. Dengan mengoptimumkan ciri geometri alat pemotong, para penyelidik telah menumpukan perhatian pada pengurangan suhu dan tekanan. Walau bagaimanapun, analisis kajian menggunakan Kaedah Unsur Terhingga (FEM) adalah terhad. Kesan besar pada suhu dan nilai tegangan terletak pada sifat geometri pemotong, terutamanya sudut rake, sudut heliks, sudut pelepasan, dan jumlah seruling. Di samping itu, analisis statistik digunakan untuk mewujudkan hubungan untuk setiap tindak balas, iaitu suhu dan tekanan yang berkaitan dengan geometri pemotong. Pengoptimuman bentuk pemotong yang dapat menghasilkan mesin MMC dengan cekap pada suhu rendah adalah gabungan sudut rake 15º, sudut pelepasan 6º, sudut heliks 40º dan seruling 4. Kombinasi sudut rake 5º, sudut pelepasan 17º, sudut heliks 60º dan seruling nombor 2, sementara itu, telah dipilih untuk mengoptimumkan pemotongbentuk yang mewujudkan nilai tekanan terendah.

ABSTRACT

Over the years, composites of the metal matrix (MMCs) have become important composite materials. Due to their excellent characteristics, the particle enhanced aluminium MMCs have acquired great demand. Due to the existence of harder abrasive refinement particles that are harder than the cutting tools, these materials are regarded as difficult to process. There are many inherent difficulties, such as high cutting temperature, caused by the lack of marketing of a specialised cutter for machining MMC materials. A novel geometrical design for the processing of metal matrix composites (MMCs) materials has been developed to address this issue. The objective of this study is to improve geometric cutter characteristics, which can manufacture MMCs efficiently. In this study, effects of cutter geometric characteristics such as helix angle, rake angle, clearance angle and flute number on surface roughness, tool wear, temperature and strength were studied to optimise cutter geometric features. Temperature and stress are the output response to be considered. By optimising the geometrical characteristics of the cutting tool, the researchers have concentrated on temperature and stress reduction. However, the analysis of studies using the Finite Element Method (FEM) is restricted. A major impact on temperature and stress values lies in the cutter geometrical properties, particularly rake angle, helix angle, clearance angle, and number of flutes. In addition, statistical analysis was used to establish the connection for each reaction, i.e., temperature and stress associated with cutter geometry. The optimization of the cutter shape that can efficiently machine MMC at low temperature are the combination of 15º rake angles, 6º clearance angles, 40º helix angles and 4 flutes. The combination of rake angle 5º, clearance angle 17º, helix angle 60º and flute number 2 has, meanwhile, been selected to optimize cutter shape that creates the lowest stress value.

DEDICATION

I would like to dedicate this project to
My beloved father, Manan bin Mohd Saad
My appreciated mother, Habibah binti Hanafi
My adored brothers Amirrul Hazwan bin Manan and Abdul Hannan bin Manan
Respected supervisor, Profesor Madya Dr. Raja Izamshah bin Raja Abdullah
My beloved friends
All lecturers and staff of FKP UTeM
Universiti Teknikal Malaysia Melaka (UTeM)

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“In the name of Allah, Most Gracious, Most Merciful”

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On the other hand, I also need to thank my family members, especially my father, Manan Bin Mohd Saad, and my mother, Habibah Binti Hanafi, for giving me motivation and support. These motivations have always driven me through a lot of hardship.

Finally, I would like to say thank you to all who contributed to this final year project paper, and I apologise for not being able to name each one of you individually.

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LIST OF ABBREVIATIONS

FEA	-	Finite Element Analysis
FEM	-	Finite Element Model
MMC	-	Metal Matrix Composites
PMMC	-	Particulate Metal Matrix Composites
HSS	-	High-Speed Steel
OAL	-	Overall Length
LOC	-	Length of Cut
LBS	-	Length Below Shank
DOE	-	Design of Experiment
Al	-	Aluminium
SiC	-	Silicon Carbide
FE	-	Finite Element
MRR	-	Metal Removal Rate
RPM	-	Revolutions Per Minuteµ

LIST OF SYMBOLS

% - Percentage
mm - Millimetre
min - Minute
rev - Revolution
rad - Radian
ºC - Degree Celsius
s - Second
µm - Micrometre
° - Degree
GPa - Gigapascal
J - Joule
λ - Lambda

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter provides an overview of the underlying project, which is based on a finite element modelling of the AlSiC composite metal matrix. Additionally, this chapter discusses the issue description, the study's goals and objectives, the planning and execution process, as well as the thesis organisation.

1.2 Project Background

In many applications, composites (MMCs), for example in aerospace and automotive sectors, have replaced conventional materials because of their benefits such as better characteristics. For the aerospace sector, its strength is beyond mild steel, which is the most important feature of aluminium-silicon carbide. In addition, SiC and Al composites (Aluminium) have a larger modulus, tightness, resistance to impact, superior thermal conductivity, reduced weight and overall load capacity for many other material characteristics. (Raheem & Ali, 2018)

MMCs are categorised as one of the materials science classes with high strength and rigidity, improved heat resistance and impact resistance compared to their mechanical features. Three basic components, namely matrix, enhancement, and matrix, and strengthening interfaces, are accessible in these materials. MMC reinforcements may be utilised as particle matter, whiskers, or long-lasting fibres. The mechanical and physical properties of these components and the molecular weight of the matrix and strengthening phase, because of the comparably low densities, aluminium, and alloys used in all MMCs to achieve high basic rigidity, improve the composition of the MMCs whilst ceramic reinforcements also improve the thermo-mechanical characteristics of the metal matrix. Compared to MMC continuous fibre composites, PMMCs exhibit a higher compression strength and reduced anisotropy.

They were also cheaper and easier to process. After its development, net shape and excellent surface finishing of PMMCs is essential. Consequently, the machining process must also be completed. However, PMMCs have poor machinability, since their hardened ceramic reinforcements react to the very abrasive tool life. Studies on the machinability of MMCs in the respective literature focus primarily to turning processes. Studies have connected, on the other hand, to the milling of these materials. It examined the facial friction of SiC strengthened composite aluminium materials using a range of equipment. They concluded that flank wear on tools declined at a low spindle speed and that the coated tools exhibited better flank wear rigidity than that on a non-coated tool. (Übeyli et al., 2008)

There are a range of valuable physical and chemical properties for aluminium oxides and related hydrates, such as high hardness, high solubility to solvents and inertness in certain chemical compounds. Today, many additional businesses provide aluminium oxide in a range of shapes, for example particle powder, nanoform microscopy and whiskers. Highly solid corundum is the most frequent allotropic form of crystalline aluminium. (Raheem & Ali, 2018)

1.3 Problem Statement

Metal Matrix Composites (MMCs) became the viewpoint in composites and MMCs generally have attracted substantial materials with high mechanical properties and reinforced particles of aluminium. Due to the hardness and aggressive character of the stimulating element, like Alumina, these particles are classed as hard to process materials. MMC machining is the excessive wear of tool which mostly leads to an inefficient and costly manufacturing process or makes the operation unsustainable. Therefore, the machining of composites mainly demands geometry and fracture toughness of the tool wear. Microscopic homogeneity of composites of the strengthened metal matrix of particles such as Al/SiCp is related to the varied elastic – plastic behaviour. The machining process deformation capacity may be surpassed, and local material damages and even macroscopic failures can occur. In order to solve the difficulties, this project will investigate the optimum geometry for cutting aluminium silicon carbide (Al-SiC) composites in the metal matrix (MMCs). Furthermore, the failure to market specialised cutters for MMC materials is causing numerous inherent issues such as high cutting temperature and strength.

1.4 Research Aim and Objectives

Metal machine tools have suffered considerable stress during the friction process owing to the effort required to remove and friction from the contact between the instrument and workpiece. It is essential thus in the process of milling that influence the basics of milling. Moreover, by monitoring the strength of the tools, it would be necessary to assess the process using a software simulation. The aim of the research is the combined study and discussion of both components and the performance of the potentials in the mill as well as comparisons with other metal machine tools.

The research objectives of this study are as follows:

1. To create a Finite Element Analysis (FEA) model of AlSiC Metal Matrix Composites (MMC).
2. To conduct a simulation study to determine the impact of cutter shape on the machining of AlSiC metal matrix composites (MMC).
3. To optimize the geometrical characteristics such as helix angle, rake angle, clearance angle and flute number of cutters capable of efficiently cutting MMCs (low temperature and low stress).

This research will take the stages of model creation, FEA, data collection and final analysis. The aim is to maximise science in the progress of the milling process.

1.5 Scope

Basically, in the following chapter, the project activities, progress, and outcomes will be clearly described. In addition, the purpose of this research is to develop a novel cutter shape which can efficiently process MMC materials. The thesis or study in this project focused on only one kind of milling cutter, the Tungsten Carbide flat lower mill. Four major geometric characteristics of the cutter will be analysed: helix, rake angle, clearance angle and flute number. In addition, the labour part of this project consists of aluminium silicon carbide (Al-SiC) composites of metal matrix (MMCs). In addition, temperature and stress are the output answers in this project. Finally, the research concentrated on ANSYS software, since this simulation offers a range of model parameters and equation solutions for a number of mechanical design issues compared to other software that are relevant to the contextual finite elements.

1.6 Significant of Study

This research will cover the basis for the development of metal matrix composites machining technology (MMC). This research is now very crucial for the sector, because the manufacturing industries, regardless of their strength, hardness, design sophistication, microstructure and electrical conductivity, are very interested in the production of advanced composite materials such as AlSiC-MMC, which are producing high quality products for different production requirements. This report will offer more comprehensive information on the geometric characteristics of the end mill. This information is extremely useful to determine the optimal geometric functions of the cutter, which can efficiently process MMCs. This study is anticipated to enhance the performance of the machined surface on MMCs.

1.7 Organization of The Thesis

This final year project is comprised of further five chapters as follows:

- Chapter I. Introduction: This chapter covers the backdrop of research and the presentation of problems. This also includes the aims, project scope, research importance, thesis structure and summary of this project.

- Chapter II. Literature Review: This section presents theories relating to research and examines material from the books, journals, articles, and other sources utilised in this study. It illustrates the introduction of Metal Matrix Composites (MMC), methodologies necessary for the production of metal matrix composites, liquid state processes, solid state processes and deposition processes. The interfaces in Metal Matrix Composite, Aluminium silicon carbide (Al-SiC) and Metal Matrix Composites (MMC) machinability problems are also illustrated. In addition, cutting equipment, cutter geometry and FEA analysis are specified.

- Chapter III. Experimental procedure: This chapter consists of the technique utilised to meet all the goals of this study. The step towards achieving all the goals was clearly explained in this chapter. It includes how to analyse the software technique. This chapter focuses on the design and development of software simulation since this study utilises simulation methods.

- Chapter IV. Result and Discussion: All results obtained from the target are shown in this chapter. This chapter describes the setup, considerations, and precision results test. The results of the simulation, optimisation and explanation of the technique and the geometric effect of the cutter on the workpiece are also included.

- Chapter V. Conclusion and Recommendation: The parts which will include the overall project results and discussions and the suggestion for future work are outlined in this research.

1.8 Summary

The objective of this research is to enhance the technology for machining of metal matrix composites (MMCs). There will be several difficulties with the machining of composites in metal matrix (MMC), such as rough machined surface and fast tool wear, leading to high machining costs. The impact of tool geometry on the quality of the generated surface is remarkable, according to the MMCs machining research. Therefore, geometrical characteristics of the tool should be incorporated to estimate the effectiveness of end milling. The research aimed to investigate the impact on the surface roughness, tool usage, temperature, and force of cutter geometrical characteristics, e.g., helix angle, clearance angle, rake angle and flute number. Finally, the optimum cutter geometric characteristics were studied which can efficiently machine MMCs.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter briefly describes the idea and study that several researchers described and carried out years ago. Relevant data from past research are gathered and reviewed based on their work on Metal Matrix Composites (MMC), the techniques needed for the production of the metal matrix composites, interfaces in the metal matrix, alumina silicon carbide (Al-SiC).

Composites for metal matrix have lately been very interesting in many applications due to their characteristics. In this research, composites strengthened by the aluminium metal matrix with such various aluminium and silicon carbide weight percentages were arranged. The simulation of aluminium metal matrix composites is based on the finite element modelling of ANSYS software. The image processing and image interpretation on a software basis have been utilised to convert the picture into the technical geometry used in the finite element modelling of composites in metal matrix. Static and thermo-mechanical research was performed on each model to study the response of mechanical loads and thermal residual stresses to composites produced. (Raheem & Ali, 2018)

Any previous results in this research will be discussed in this chapter. The next part will include discussions on theoretical studies on the milling processes. Next is the experimental technique and setup parameters part of the tool, rotation speed and feed rate. The following section provides background details on the surface consistency of composite materials. The next part provides a brief introduction to machine modelling, simulation and techniques utilised for this study.

2.2 Theoretical Analysis on Manufacturing Machining

Best versatile and dependable of any technique such as machining where different geometry and geometric component characteristics are produced. Milling is one of the process machining methods. Detailed investigation was performed using the milling technique utilised as a material removal procedure in composite machining. The cutting procedure is carried out in composite materials for contour shape accuracy. The creation of complex forms and a high surface quality is achievable during the milling process. Composite surfaces rely on variables such as feed rate, cutting speed, tool radius and tool wear. The increase in feed rates and the increase in cutting speed reduce the material's surface quality.

Delamination and burrs are developed during the milling process. The main source of the material degradation is the dynamic contact between the mill ends and the laminate composite during machining. The accurate projection of thrust force and axial cutting force are the key variables that may minimise the above-mentioned damage to the material. During the study, the surface damage produced by carbide particles enhanced by composites of aluminium alloy was smaller in the terminal milling phase than the surface damage caused when comprised of aluminium alloy-reinforced carbide. Cuts, depth, and feed rate were evaluated as the cut-off parameters for the final milling operation. In contrast to cutting speed, the feed rate was affected by the roughness of the compound during machining (Shetty et al., 2017).

Researcher (Scallan, 2003) offers a highly efficient cutting speed modelling for workmanship refers to the speed that travels across the workpiece surface with a tool cutting edge. The surface speed is nearly always mentioned. The maximum relative speed from tool to workpiece is frequently considered. The coolant mode and air temperature in the coolant mode are distinct variables in the calculation, as the air is cooled in the cooling mode and the atmosphere temperature in the dry cutting mode. (Hou, 2013)

2.3 Theoretical on Metal Matrix Composites (MMC)

A composite metal matrix (MMC) is a composite material consisting of at least two components, one portion of a metal and a different metal or a distinct substance. Three kinds of metal matrix composites (MMCs) are particle-built MMCs, short fibres or whisker-built MMCs and continuous fibres or sheet-enhanced MMCs. Balaji et al. (2015) said the wear resistance, rigidity, strength-to-weight ratios, high module, fatigue life, resilient thermal expansion coefficient, and many more are the remarkable materials. The inclusion of reinforcement elements that are typically harder and stiffer than the matrix made machining considerably more complex than traditional materials (Muthukrishnan & Davim, 2009). Machining as stated by Manna & Bhattacharyya (2002) is the most important component for the production of composite aluminium metal matrix components. The rates for tool wear during conventional processing were significant owing to the high abrasiveness and hardness of ceramic reinforcing elements.

2.3.1 Interfaces in metal matrix composites

The interface of the composite in question is very important for determining the final characteristics of the composite. The interface is a dimensional area that exists in one or more parameters of the material. In reality, the interface region involves a certain volume, in which the material parameter is gradually changed. As mentioned by K.K. Chawla, (2012) two major reasons are the importance of the contact area of composites. The reasons are that the interface in composites spans a wide region and that strengthening, and matrix must create a structure not thermodynamically balanced.

2.3.1.1 Aluminium-silicon carbide (al-sic) metal matrix composites (mmcs)

Aluminium alloys or composite materials are combinations between two or more components in a manner that has specific structural features or improvements in the resultant materials. The physical and mechanical characteristics of AlSiC MMC include high strength, longevity, low density, little corrosion, wear resistance, slight thermal shock and strong electric and thermal conductivity, excellent thermal properties, good damping efficiency. Composite materials may replace widely used aluminium and steel, with often better performance amongst all components. (Krishnaraj et al., 2012)

2.3.2 Machinability issues in metal matrix composites (MMC)

Machinability is a challenging word owing to the huge amount and complexity of the factors required to define and assess. Numerous machinability measures are usually regarded as cutting forces, power consumption, tool life, surface finish etc. The issue is the effect of these parameters on numerous variables such as work material, tool design, cutting circumstances, stiffness of machine tools and many more. MMCs are very difficult to use with conventional methods because of high wear of tools (Alakesh Manna & Bhattacharayya, 2005). This issue is caused by a hard enhanced SiC particle in the composite matrix of Al/SiC-metal.

Nevertheless, contemporary manufacturers have increased demand for the machining of advanced composite materials, such as Al/SiC-MMC, for highly sophisticated goods to meet various demands for such items, such as wear resistance, light weight, high-precision, high speed, etc. A. Manna & Bhattacharayya, (2003) noted that the tool wear is very minimal in typical Al/SiC/MMC rotating tests when using carbide tip instruments. Sometimes raw SiC particles of Al/SiC-MMC come up against the hard surface resulting in a poor surface finish when turning.

2.3.3 Application of Al-sic metal matrix composites (MMC)

It is well-known that aluminium metal composites are considered by many to be the most revolutionary material for their practical applications and are flexible in industry because of their unique characteristics, including industrial, aerospace, automotive and thermal control, sport, and entertainment. Al-SiC MMCs are utilised in a broad variety of applications, such as aircraft, fuselage, marine, motor vehicles, electrical grounds, golf clubs, turbine blades, rotors. Figure 2.1 shows some of the implementations for Al MMCs.

Figure 2.1: Application of metal matrix composites (MMC) (a) piston, (b) engine with cylinder barrel, (c) piston connecting rod, (d) brake 3system (Verma & Khvan, 2019)

2.4 Machining

Manufacturing is an area where a product may be utilised or sold using machinery, equipment, and manpower. It may relate to a range of human activities from basic items to complex and state-of-the-art products. Manufacturing is mostly employed in manufacturing that transforms raw resources into products that may be utilised by customers. Manufacturers need to create high-quality goods to achieve consumer happiness. Manufacturing procedures must be structured properly to obtain high quality goods. The raw material must be processed, and goods of high quality may be created. Machining of the material is one of the key elements in the handling of the material. The process must be regulated in order to guarantee that the quality product can be produced in a timely and economical way.

2.4.1 Cutting forces

There are reports that the employment of cutting force models for cutting has not made accurate predictions owing to their inability to take into account the impacts of the tool rim, the negative ratcheting angle and the phenomena in the spring. The subharmonic response of the passing tooth frequency beneath the minimum thickness of the chip also affects cuts. Researchers discover that the trimming pressures change when the instrument exceeds the grain limit for microstructures of the workpiece material. Because of these factors, the effectiveness of the frying is variable. This affects the life and consistency of the instruments. The model showed that ferrite's power was more sensitive than perlite machining. The increased ductility of the ferrite phase enhances ploughing forces. (Mian, 2011)

2.4.2 Tool run-out

The inclination of the tool axis, the tool holder and the spindle shaft cause the tool to leave. Run-off is not visible with regular CNC milling, but the final measures of the micro-part and the life of the tool may be greatly affected by the micro-machining. Special tool retention and spindle speed systems are employed to deal with this disadvantage. (Krimpenis et al., 2014) The execution of the tool is characterised as an error or eccentricity between the spindle axis and the tool symmetry axis. A little run-out may have a negligible effect on the milling process, but it may lead to unstable intermittent changes in milling charges and strengths. The operation of the tool does not usually lead to uneven wear on the cuts of one edge while the other does not. As an example, as shown in Figure 2.2. (Li, 2009)

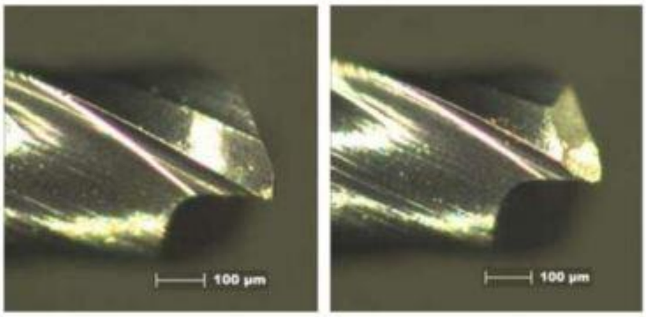


Figure 2.2: Unfair cutting-edge wear arising from the first and second wear of the tool. (Li, 2009)

It is apparent that one edge is wearing more intensely than another for the two-flute cutter. This leads to high forces, chatter, red surface profiles and the risk of tool loss. The cutter is readily dull in this scenario. The triggers of tool run include asymmetric instrument geometry, improper tool holder orientation, malfunction between tool holder and machining spindles, mass malfunction, spindle bearings excentricious and machine friction. However, tool run-off significantly impacts formation of micro burring. A combination of error causes is the execution of a micro tool tip. It is essential to monitor and minimise tool execution to improve tool life and work accuracy. In order to minimise the implementation of the micro-tool it is necessary to not only developed and produced instruments, but also to correct tool holder and spindle. The complicated execution of the procedure with modern equipment and methods is very difficult to assess, mainly due to tiny measurements of micro instruments. Therefore, in order to categorise, monitor and minimise the micro-tool process, the development of micro-milling machines is essential to produce favourable cutting outcomes. (Wu, 2012)

2.4.3 Tool wear and life

In conventional tool cutting, precise measurement and efficiency of machined components are the usual requirements for tool life. These criteria for the tool life cannot be utilised since early tool failures frequently occur as a result of reduced structural stiffness and power of micro tools. The sharp edges of the thumbnails wear extremely quickly under typical conditions, causing in large intensity variations and significant deterioration of the instrument output (Bao & Tansel, 2000). Figure 2.3 illustrates instances of burr shaping cuts and variations utilising new and worn tools. As the phenomena lasts for a long period, the increased wear forces and pressure may help to shatter micro-tools with fatigue. During harsh settings, premature tool breakdowns occur. The tool breakage for a properly designed and manufactured micro tool may be explained twofold. One is that process parameters are not selected properly, resulting in cuts that exceed the critical intensity of the instrument. Chip blockage in only a few revolutions in the tool flutes leads to significant cuts, strains, and temperatures.

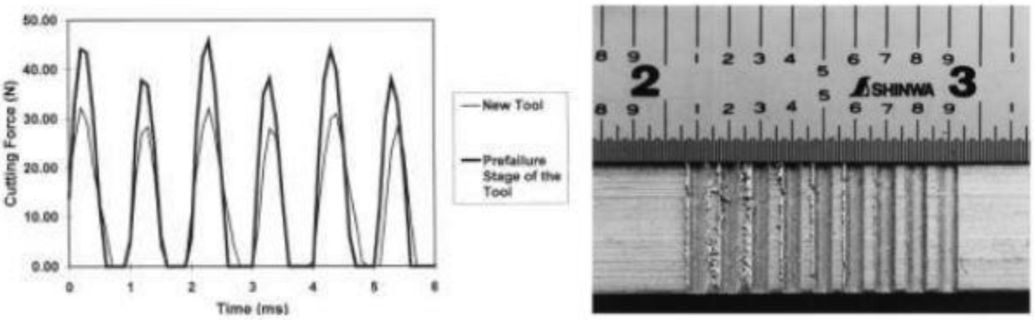


Figure 2.3: Changes in strength and burr development with new and used tools (Bao & Tansel, 2000)

Deviations in tool rotation, partial breakage of cutting edges and shaking contaminants of the work products may contribute to breakdowns in the tool. Unpredictable tool life and early tool failures are essential for researchers to postpone additional cuts and prolong micro tool life. Excellent complex efficiency of the micro-milling devices, optimal design and production of micro tools, standard cutting and acceptable circumstances are generally helpful for minimising needless usage and improved tool life. (Wu, 2012)

Like micro drills, micromachining is nothing but a miniaturisation of the conventional mill cutting technology. In micro milling cutters, two trim edges are typically specified. A robust micro-tool body is similar to the shape and proportions of the tools used for milling. The difference is that the cutting edges of micro-cutters are found when the conical characteristic from the end of the tool body is followed by the figure. The geometric accuracy of micro-tools between ±5 and ±10 μm is a crucial technological constraint. During manufacturing, thermal procedures on micro tools should also be carried out, increasing the efficiency of micro tool cutting.

In addition, various grain sizes may be utilised to enhance process uniformity in contrast with macro friction instruments. Because of the small tool tip size, wear detection at tool cutting edges and tool fractures is difficult to recognise and predict as sensor technology is limited at a micro-scale. Minor deterioration on the cutting edge of the usual instrument may lead to worse surface quality. However, in a micro instrument, such disturbances induce cutting edge destruction and thus significantly enhance the intensity of the cutting force on the opposite edge. The whole microtool failure ends with the phenomenon. Just before the whole cutting-edge damage is done, the micro-tool form is rounded up. Increased cutting forces produce unintentional deflections of tools that may seriously alter the geometry of micro components. In instrument wear, there are two significant occurrences. The first is the blocking of the chip and the second is tooling. Performance also affects the life of the micro tool. (Krimpenis et al., 2014)

2.4.4 End mill cutter

For machining, the technique utilised to remove the material through shear deformation from the workpiece is a cutting tool (or cutter). The cutter must be constructed of a material that is more difficult than the workpiece. However, throughout the cutting operation, the tool must be able to resist the temperature. Actually, the tool needs a geometry with clearance angles that enable the cutting edge to contact the piece without pulling the remainder of the tool to the workpiece surface. The tool is usually constructed of HSS, which makes it cut into metals such as mild steel and 13 aluminium. When selecting a milling cutter, there are numerous variables, viewpoints, and principles (S. Krar et al., 1994). End mill is a multifunctional device having perimeter and end neck cut-off locations. Only one tool is possible for side friction, curved surface grinding and boiling. There are numerous kinds of finishing mills. Square end mill, ball end mill, red end millet, radius corner end mill, exhaust mill and tapered end mill, for instance. The functions and geometry of each end mill are distinct.

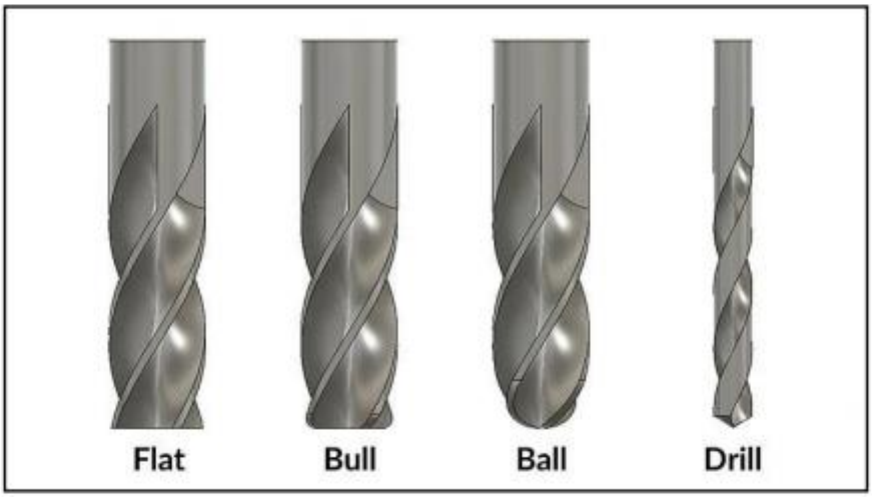


Figure 2.4: Different types of end mill (Lapthorne, 2020)

2.4.4.1 The anatomy of end mill

The finishing mill may be specified in many distinct dimensions in the tool specifications. It is essential to understand how every aspect affects the selection of tools and how even little decisions may have an effect when the tool works. There are four key geometries of the end mill which may influence cutting efficiency, such as helix angle, rake angle, clearance angle and flute (Chatelain & Zaghbani, 2011). Figure 2.5 shows the layout and shape of the finish mill.

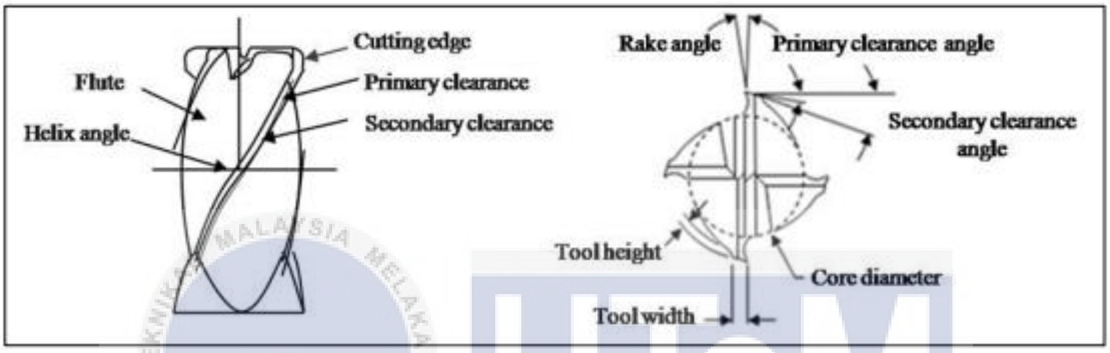


Figure 2.5: Structure and terminology of end mill (Chatelain & Zaghbani, 2011)

Firstly, flutes are the most easily recognised component of the end mill. The grooves in the tool make it possible to produce and expel the chip. Furthermore, the flutes cut the end mill at its tip. The number of flutes is an issue that must be addressed during instrument purchase. The lower the number of the flute, the larger the valley of the flute. The flute valley is the empty area between the edges. This gap lowers the blade's 16 powers but also produces large chips with high cut distances that are suited for fragile or sensitive materials like aluminium. Low flute counts are often utilised for cutting hard materials such as steel. Kivanc & Budak (2004), who began to model the flexibility of the structural end mills, realised that the 2-flute end mill had a good normal machining frequency and was less flexible than the 4-flute end mill. However, the 2-flute terminal mill has been shown to be less demanding in terms of cutting power compared to the 4-flute terminal mill. The machining efficiency may be affected by the variation in the quantity of finishing mill flutes. The effect of the number of flute geometries should thus be studied further in the machining of various materials. The first thing to look at when selecting a cutting tool is the diameter of the cutter. This diameter is the imaginary sphere generated when the machine spins by the cutting edge.

Figure 2.6: Flutes of end mill (H.P.Company, 2017)

The diameter of the shank is the breadth of the shank. Shank is the end of the holder’s tool. When selecting the tool, it is essential to ensure that the holder uses the shank in the appropriate size. It is easy to identify the total length is calculated between the two ends of the instrument. It distinguishes itself from the cutting length (LOC), which is a measure of the cut breadth in the axial direction. The length below the shank (LBS) is really a metric that represents the tools neck length.

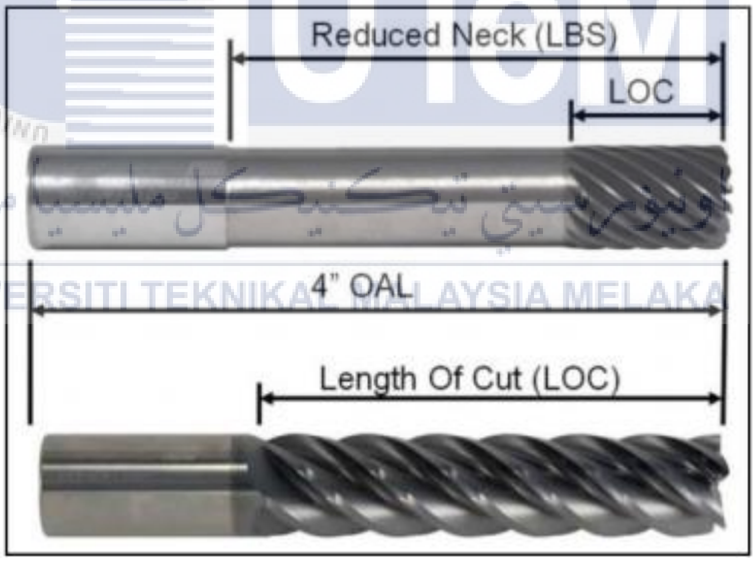


Figure 2.7: Characteristics of tool, The Overall Length (OAL), Length of Cut (LOC) and Length Below Shank (LBS) of end mill (H.P.Company, 2017)

Pitch is the angle of insulation between the edges of the thread, which can most be seen at the end of the mill. For example, each flute is separated by 90° using 4 flutes with the same pitch. Changing pitch devices feature a non-constant range of flutes that assist to break down harmonics and minimise talk. Even with a restricted space, the gadget may nevertheless achieve the intended effect. The helix angle of the tool is defined by the distance between the centre line and the tangent on the cutting edge. The finish utilises a 45° greater helix angle for red cutting. The 35° lower helix angle is smoother and has a sharp edge suited for the toughest tasks. A medium helix angle of 40° enables the tool to do basic roughing, slotting, and completion with incredible performances. Improves the helix angle provides a more effective rake angle which increases machining and accuracy (Izamshah et al., 2013).

Imani et al. (2008) reported that the helical cutter, which had a high helix angle at 30°, produced a smoother surface and less cutting force distribution compared with the helix at zero grade. The cutting power, the tool’s stability and the excellent surface quality of the machined material may be achieved. The cutting force generated both by the helix angles of 30° and 0°. The rake angle is the angle between the front of the tooth and the centre of the cutter. The angle of the rake defines the edge of the cut and provides a method for splitting chips. Lo (2000) is one of the scholars who has analysed the effect of rake angle variation on machining efficiency using the FEM technique.

This research was conducted by modelling five different angles, 5º, 10º, 15º and 20º, of the rake to cut the workpiece, while studying its effect on the form of the chip and the workpiece. The research shows that the larger angles of the rake reduce the cutting force and produce a smoother chip shape. In support of the result, Soukatzidis, Demosthenous & Lontos (2008) said that better cutting may be achieved utilising a wider angle rather than a low rake angle that translates the cutting activity into pressing and gripping forces that create a lower smoothness of the chip. The rake does not have a wider angle to prolong its life, as stated by Chatelain & Zaghbani (2011), since the finer cutter lowers the edge pressure due to the distribution of tense and machining of the machined item. The proper selection of the angle of the rake must thus be determined according to the qualities of the material to be machined. The clearance angle is split into three main angles of clearance, secondary and tertiary angles.

The main clearance angle is the angle of the base of each tooth calculated from the tangent line to the middle line of the cutter. This angle prevents every tooth from brushing the materials. This angle defines the ground of each tooth, which provides further clarification for chip and oil flow. The machine damping angle decreased as the quantity of indentation and the severity of the vibration increased, Tunç & Budak (2012). The danger of a very tiny clearance angle may nonetheless cause the device to buckle against the system's surface and create an excess heat in thermoplastic polymer. The heat causes polymer gumming and affects the characteristics of the material life and the surface quality. The optimal clearance angle value is thus necessary to provide the machine tool sufficient stability and enhance the surface quality.

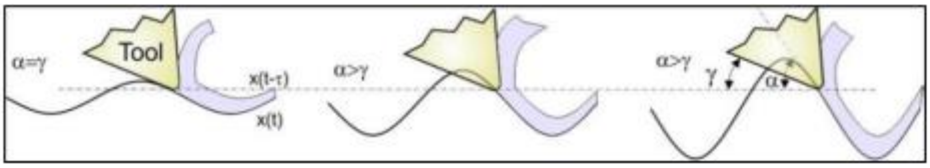


Figure 2.8: Mechanism of indentation between tool and workpiece (Tunc and Budak, 2012)

2.5 Cutting Parameters

Cutting factors such as depth of cut, speed and feed rate contribute to significant process outcomes. In most instances, the depth of cutting is determined by workpiece type and operating sequence. The cutting depth should be used in one pass to save time and costs. Another cutting parameter, such as cutting speed, is required throughout the machining process as the cutting strength, shear stress and surface quality for the processed material are significantly impacted. The machining cutting speed is shown in revolution per minute (RPM) and the spindle rotation is regulated. Palanikumar & Karthikeyan (2007) reported that Al–SiC machining surface roughness affects feed size, cutting speed and SiC volume percentage. Meanwhile, the feed rate is measured by millimetres (mm/rev) or millimetres per minute (mm/min) and is necessary to push the tool into machined component or manufactured part. Lin, Bhattacharyya, & Lane (1995) reported that the removal of aluminium composite material looks high when the feed rate is greater, and the cutting speed is lower.

The tool was typically worn on flanks and rake surfaces, the most apparent wear on the flanks. Value for cutting speed and process feed rate, depending on the required surface finish, capacity of the machine, and total cutting force permitted by tool stiffness. In reality, the workpiece hardness dictated the speed and the feed rate utilised in the process of machining. With an increase in material hardness during machining, the cutting speed and feed rate often decrease. (Tomadi et al., 2017) concludes that, during end-milling processes AlSi/AlN MMC with 15% volume fraction of particular strengthening under dry cutting condition, the optimum combination of cutting parameter levels to the surface ruggedness and tool life with uncoated carbide insert is a 240m/min, 0.4mm/tooth and axial depth 0.3mm. In turn, Rajeswari & Sivasakthivel, (2018) discovered that the optimum combination of cutting speed 90m/min, feed rate 0.04mm/rev and cutting depth 1.5mm produce lowest surface roughness and wear while milling Al 356/SiC metal matrix composites (MMCs).

2.6 Surface Quality in Milling Composite

Surface uniformity is one of the most important workmanship problems. The uniformity of the machined surface is characterised by the precise development of the designer's metrics. Each machining method produces its own appropriate evidence on the machined surface. This evidence comes in the form of a newly separated micro irregularity left by the cutting instrument on the workpiece. The unique patterns may thus be determined for each kind of cutting instrument. This tendency is known as surface finishing or surface robustness.

Surface robustness is an assessment of the material response to the machining process. The machined surface consistency is directly proportional to the equipment. The word machinability refers to the surface quality of an item that is easily utilised. The manufacturing material needs minimal machine strength, is quickly machined, and provides a good surface quality. Engineers and technocrats are pushed to discover methods to increase process capacity while manufacturing components cheaply without compromising efficiency. Wear, cutting force and surface finish for machining are usually analysed. There is still a nice user interface with a reasonable polish on the surface. A nice composite surface is extremely difficult to produce because the material response differs from plain metal. Under ideal circumstances, the surface robustness profile consists of repeated tool profiles at feed intervals per workpiece rotation. Many factors affect the quality of the surface in the processing of composites.

The product to be produced, its size, kind, machine tool, machine factors such as accurate machinery, diaphragm straightness, temperature tolerance, friction, tool design, tool quality and instrument materials all influence the quality of the surface of the composite materials. The physical and chemical characteristics of the material employed, and the short-term precision of the product often affect the surface finishing of the product. While many factors impact the surface condition of a machined component, the ruggedness of the surface is affected by characteristics such as cutting speed, workpiece condition, feed and cutting depth. (Palanikumar, 2012)

(Palanikumar, 2012) stated that the most significant factors influencing machining surface roughness are:

- Rigidity and precision of power tools (vibrations on machine tool, spindle run out, etc.).
- Work material used.
- Method of chip removal (type of machining).
- Cutting tool geometry and condition of the cutting tool.
- Cutting conditions such as cutting speed, feed, and depth of cut.
- Type of cutting fluid used.
- Finishing required on the workpiece material.

2.6.1 Mechanisms of composite delamination

The delamination is a ply separation produced by friction in composite-fiber reinforced polymer laminates. This is a major issue in the use of composite materials as it affects its specific solidity. The measuring delamination in the milling process is different from boiling. (John & Kumaran, 2019) Many lab tests showed that the use of blunt instruments in contour framing damages the top layers due to delamination and fibre on the border of the fabricated component. High-speed films show that the tool is being resisted again and again when the feed is moving in fibre and fibre, Figure 2.9 simplifies this process when the laminate is either twisted in or changed to the laminate in severe circumstances. The explanation of the fibre is that its transverse tension is not fulfilled. (Hintze & Hartmann, 2013)

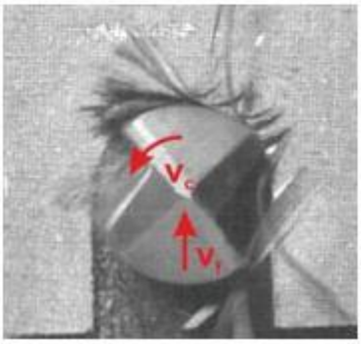


Figure 2.9: High-speed video of contour milling showing deflected fibre bundles (Hintze & Hartmann, 2013)

2.6.2 Damage criteria on composite delamination

While the axial cutting force is extremely little during a slot frame inspection, uncoated and peeled up carbon fibres in particular areas are frequently observed on the top of the laminate plate. Fluffing occurs in 0° fibre direction on the right hand and in 90° fibre direction on the left (to the left) and in the milling direction, as shown in the Figure 2.10. Fluffing happens on both sides with the fibres concentrating at 135° and fluffing occurs immediately before the direction of the tool feed for inclination at 45°.

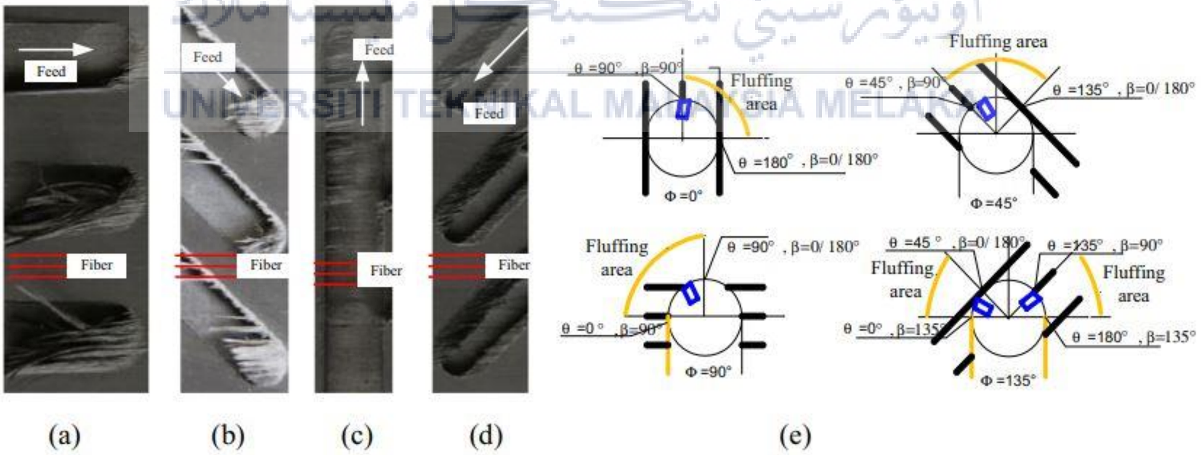


Figure 2.10: The milling damage in different fiber orientation angles. (a) 0°. (b) 45°. (c) 90°. (d) 135°. (e) Damage sketch (He et al., 2017)

Careful looking shows that the fluffing is linked closely to a fibre cutting angle. A heavily frozen angle surpasses 90° and more than 180° until you reach the fibre cutting angle. When the corner of the fibre is from 0° to 90°, the left corner tends to fluff. By chip formation, the fluffing pattern in different fibre cutting angles is explained. Table 2.11 The top layer laminate shows different cutting rates. The pushing action of the tip is broken down in a fibre direction if the fibre angle is between 0° and 90°. The fibre is subjected to axial tension, which enables the brittle fibres to crush and rapidly remove fibres with a little potential for fluffing. This is shown by the experimental finding. (He et al., 2017)

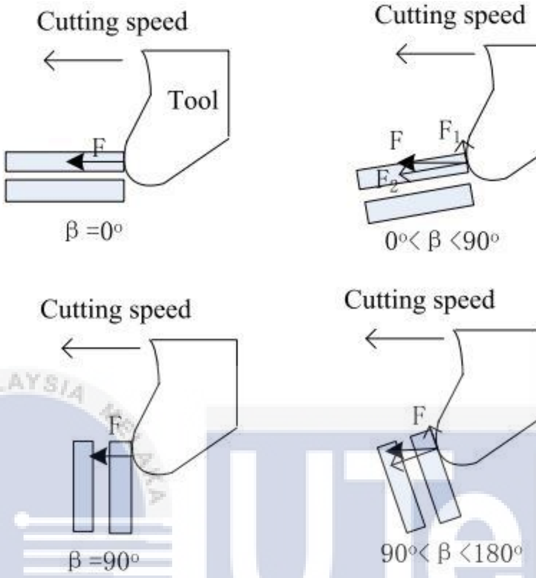


Figure 2.11: The fluffing mechanism (He et al., 2017)

2.7 Modelling and Simulation

Simulation modelling shows how the operating condition of the models evolves over time in every setting. Simulation is a simple method of assessing the design. The aim is to be inspected more quickly so that a computer understands the architectural characteristics correctly and is divided by dissection into a smaller technique. This research demonstrates why or what a system does or doesn't, and a model indicates what it really does. Modelling simulation plays a vital part in contemporary design techniques. The models must comply with physical principles and rules in order to successfully build them. The interpretation of semantics should be apparent if the model simulation is intuitive and analyzable.

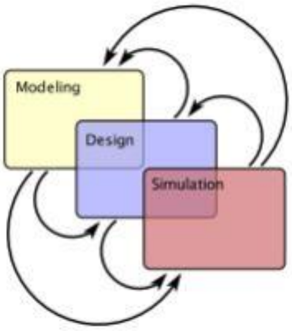


Figure 2.12: Simulation analysis process (Cheng, 2017)

Many computer architectures contain a definition of time. This clearly shows that there is a logical chronology between the actors and the actors' computations. In particular, this implies that two actions, communication or measurement, are arranged in advance or occur simultaneously, on time. There may also be a time specification with a metric value to determine the time difference between two actions. Computer simulation software includes more than 50 types of finite-element simulation software in today's industry expansion. For example: ANSYS, HyperSizer, COMSEL, Quickfield, etc. For example.(Cheng, 2017)

2.7.1 Solidworks

Solidworks is used from start to finish to design mechatronic systems. Initially, the programme is used to plan, visually determine, model, evaluate feasibility, prototype, and manage projects. The programme is then utilised for mechanical, electrical and software element design and construction. Finally, the software may be used to manage devices, analytics, data automation and cloud services.

2.7.2 FEA simulation in ANSYS

ANSYS Mechanical is a technique for analysis of finite elements for linear, nonlinear, and dynamic structural analysis research. This software provides end-to-end modelling components and enables material simulations and equation solvers to face a wide range of problems in mechanical design. ANSYS is not only utilised in academia and business via the use of clean, transparent settings and extensive automated databases; the user interface is widely used. This thesis thus utilises the finite elements ANSYS software. The ANSYS Workbench User's Guide (2009) reveals that the ANSYS Workbench comprises three levels of cells accessible which is:

a. Pre-processing: defining the problem
  - Define dimensions
  - Define element type and material properties
  - Define mesh

b. Solutions: assigning loads, constraints and solving
c. Post-processing: viewing and results

For finite element analysis of model structure, ANSYS is utilised to simulate the structure operational state. In this research, ANSYS can assist address the issue of model analysis and the micro-milling technique. (Cheng, 2017) The normal way to evaluate the actual composite application requires considerable testing and actual structural component scale. Computer simulations known as 'virtual mechanical tests' also play a major role in improving dependability and minimising the number of significant tests in order to guarantee that such possible situations may be created in the structural part's real service life.

Finite Element Modeling (FEM) as an alternative to numerical techniques is used to forecast various outputs and features of metal cutting processes as specified variables, according to Kurt, Yalçin, & Yilmaz, (2015). FEM also reduces experimental expenses. FEM was created based on the Eulerian and the modified Lagrangian formulations to assess the machining process. The sophisticated computer technology and code development have brought FEM numerical models to academics attention in recent years. The Eulerian formula in the number of FEM models in the literature was utilised for the modelling of orthogonal metal cutting. Due to the ability of Lagrangian formulation method to mimic chip formation in the first phases, it was utilised more often in metal cutting.

2.8 Summary

In this chapter, many essential background materials on milling are provided. The relevance of these variables is evident while there has been little information and research in mathematical milling models, processing equipment, tool setup and parameter effects. Although milling is generally a well-known industrial activity, most study and technical details have been focused on concrete application and post operation physical measures. The FEA lacks the capacity to predict and model the milling process, but valuable information and insights are provided, which may be significantly enhanced with FEA. When contemplating improved production, especially with respect to size, precision and precision requirements, the necessity to combine knowledge acquired via conventional milling with mathematical modelling is even higher. As the milling process advances from traditional, millimetres and micrometres, it has now become necessary to have a comprehensive but scalable mathematical model that can describe the drilling method on this size. The research will therefore focus on verifying friction force data to represent the framing phases by means of FEA simulation, mathematical modelling, and experimental measurements in the following chapters. Different criteria and operating circumstances such as the frame size, diameter and speed and feed rate will be examined. To improve conceptual feasibility, these findings are further cross-examined with other working component materials, such as silicon carbide particulate aluminium matrix (AlSiC). In order to properly analyse the impact of the various variables, the connections and linkages between each parameter may also be assessed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The method may be used to get an overview of the main procedures, legislation, and ideas of a subject. The details of the techniques utilised for the analysis would be described in this chapter. In this chapter, the processes for the analysis start with structural modelling, utilising Finite Element Analysis to apply material characteristics (ANSYS). The study will be placed in a diagram in which each section of the study is described so that the protocol is followed, and the test procedures are done adequately at this time.

3.2 Project Planning

Many literature evaluations have been carried out on the substance. They are available from many websites including newspapers, a connected library guide and the Internet. In addition, throughout the gathering of information via collection evidence a focus group discussion, monitoring and brainstorming were carried out. Some actions have been done to complete this job and the steps below are shown. The projects are split into two stages, the planning, the experiment, and the analysis phases. This project begins with the experimental design (DOE) until the optimum cutter geometric characteristics are achieved which can efficiently process MMCs.

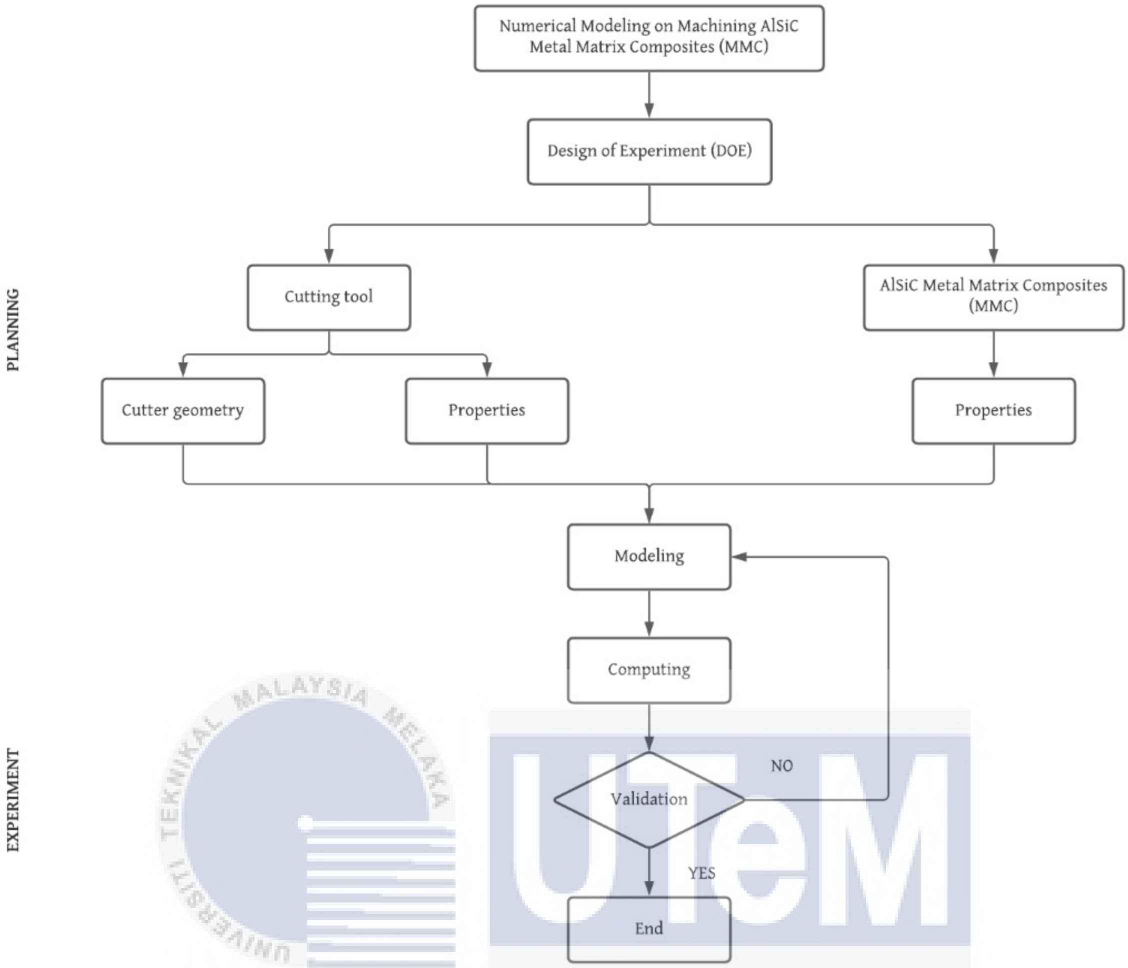


Figure 3.1: Project flow chart

3.2.1 Planning Phase

The planning phase outlined at the beginning of this project begins with the issue description, the goals, and the literature review of 3 main studies in this research, including cutting tools such as cutter geometry, Al SiC Metal Matrix Composites (MMCs) and finite element simulation analysis. In this step, the cutter geometrical characteristics are designed on the basis of the Design of Experiment (DOE) which is created using Taguchi L9 orthogonal array 3^4 from the MINITAB programme. The first chapter dealt with issue definition, research goals and scope. The second chapter deals with the literature review of three major simulation studies. Design of experiment (DOE)

Taguchi offers a systematic technology that improves production at a minimum cost and time. These standard arrays provide the method to run the minimum number of tests, which may provide complete information on all the variables affecting the performance parameter. To evaluate experimental findings the orthogonal array and the S/N ratio are required. Table 3.1 and Table 3.2 offer a four variables and three-phase orthogonal array, including nine experiments. The 'smaller is better' S/N ratio is utilized in the meantime to determine the outcomes achieved via minimum temperature and stress.

Table 3.1: Factors and levels

Factors	Levels		
	-1	0	1
Rake angle $(^{0})$	5	10	15
Clearance angle $(^{0})$	6	10	17
Helix angle $(^{0})$	30	40	60
Number of flutes	2	3	4

The above rake angle was utilised in Lo, (2000) tests with 5°, 10°, 15° and 20° using the finite element model (FEM) technique for cutting the workpiece. Tunç & Budak (2012) showed that the clearance angle decreased to improve process damping with increasing indentation volume and amplitude of vibration. The stability of surfaces and the workpiece cutting tool are governed by the tool’s clearance angle. To ensure a good tool life, a high clearance angle value is recommended. However, a too high clearance angle, which is overheated by inadequate transmission of heat from the cutting edge, seems to damage the cutting edge. Imani et al. (2009) found that a helical trimmer with a broad helix angle of 30° provides smoother surfaces and a lower distribution of cutting force compared with 0° helix. Kivanc & Budak (2004) showed that the 2-flute end mill was less analytical than the 4-flute end mill. It has been shown that the machining performance may be influenced by flute variation of the end mill.

Table 3.2: Taguchi L9 designs

Tools	Rake angle $(^{0})$	Clearance angle $(^{0})$	Helix angle $(^{0})$	Flute number
1	5	6	30	2
2	5	10	40	3
3	5	17	60	4
4	10	6	40	4
5	10	10	60	2
6	10	17	30	3
7	15	6	60	3
8	15	10	30	4
9	15	17	40	2

3.3 Geometry Creation

The initial stage of the simulation during a complicated simulation of the milling process is the creation of the geometry model. All geometry solids are modelled according to the experimental size utilised in the test to adapt the intended simulation results to the current circumstances during the development of geometry. Solid geometry was initially created using solidworks programme and then imported via IGES (.stp) file format into ANSYS Workbench 2019 R3. Rappoport (2003) says that IGES helped sketches and wireframes and was later extended to support surfaces and solids. Figure 3.2 shows the requirements for the cutting device for rake angle, clearance angle, helix angle and flute number. The end mill has a diameter, length, and depth of 15mm, 80mm and 5mm correspondingly.

a) Tool solid geometry: Procedure to developed model of cutting tool started by a 2D sketch of a circle with diameter 15mm. Then, the 2D sketch was extruded to 80mm. The helix angle was developed by using the helix and spiral features and defined by pitch and revolution and the flute number is produced by using the circular pattern feature in the Solidworks software. On the top of the model was sketched the geometries of the cutting edge such as rake angle and clearance angle. Table 3.3 Shows the entire end mill design that have been done in Solidworks software.

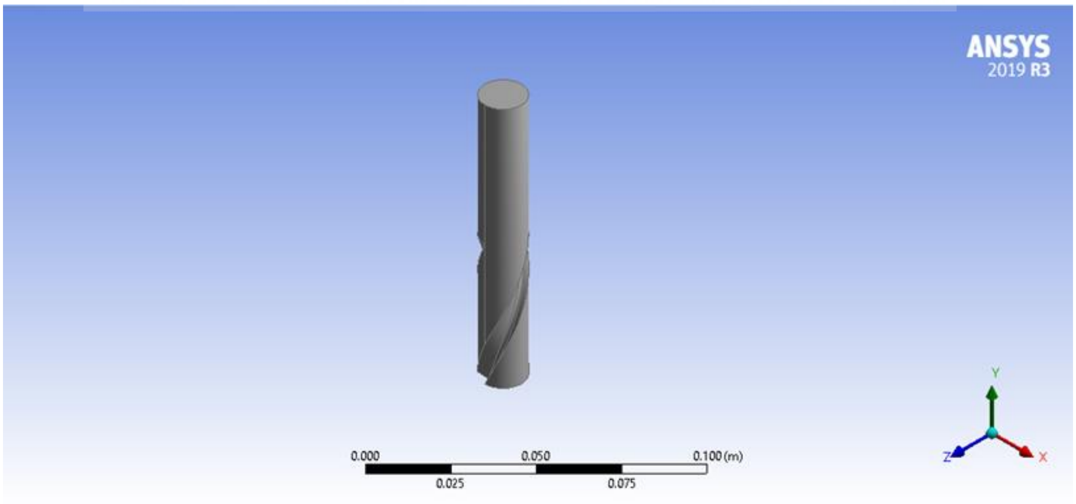
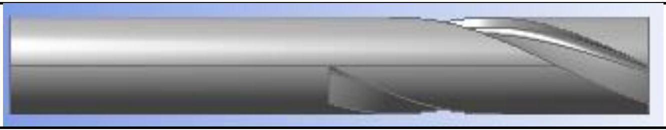
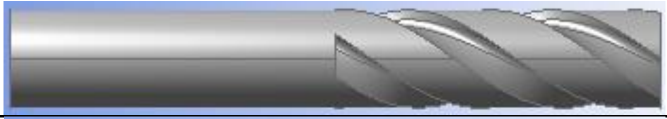
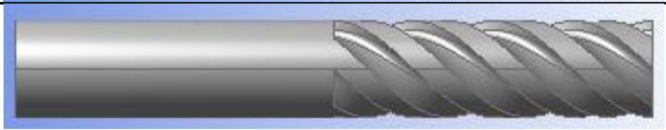
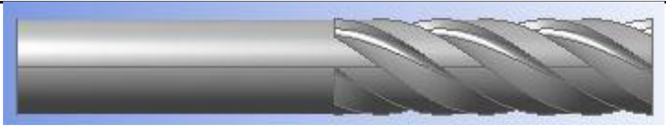
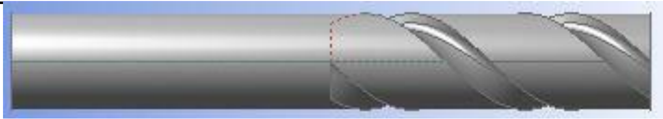
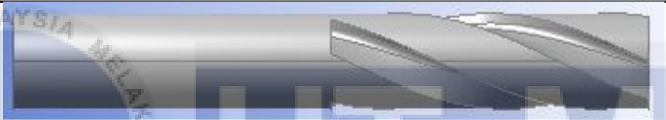
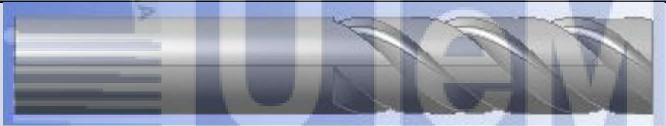


Figure 3.2: Tool geometry creation

Table 3.3: The entire end mill designs

No	End mill design
1	
2	
3	
4	
5	
6	
7	
8	
9	

b) Workpiece solid geometry: workpiece model has been created from the 30mm long, 10mm wide and 10mm thick Solidwork programme as illustrated in Figure 3.3. The model was initially created using a 2D rectangle drawing, then extruded into required proportions.

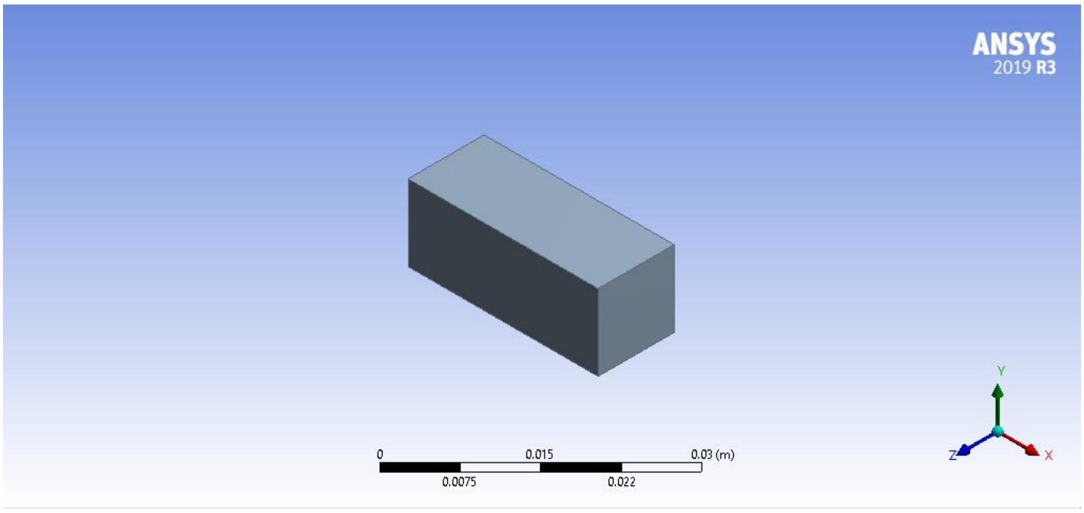


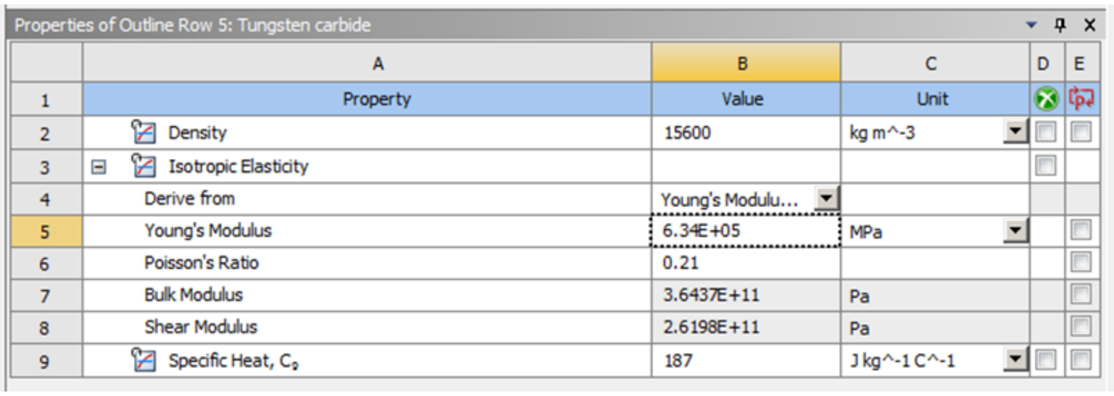
Figure 3.3: Workpiece geometry creation

3.4 Materials Properties

ANSYS software initial step is to specify the materials and material characteristics from the data tab of engineering. Al SiC metal matrix composites are the workpiece material for this study (MMC). This content must be added as new material since it is not included in the main material. The following Table 3.4 illustrates the general features of the cutting tool and workpiece material.

Table 3.4: The material properties of the cutting tool and the workpiece (*JAPAN FINE CERAMICS HOMEPAGE*, 2017)

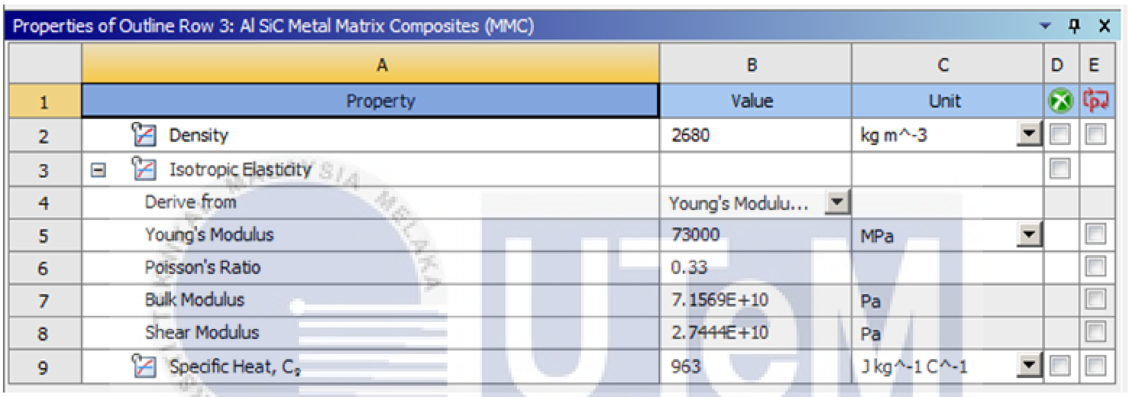
	Density (kg/m^3)	Young's Modulus (MPa)	Poisson's Ratio (-)	Specific Heat (J/kg.C)
Tool (Tungsten Carbide)	15600	634000	0.21	187
Workpiece (Al SiC MMC)	2680	73000	0.33	963



Properties of Outline Row 5: Tungsten carbide

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	15600	kg m^-3	☐	☐
3	⊟ Isotropic Elasticity			☐	
4	Derive from	Young's Modulu...			
5	Young's Modulus	6.34E+05	MPa		☐
6	Poisson's Ratio	0.21			☐
7	Bulk Modulus	3.6437E+11	Pa		☐
8	Shear Modulus	2.6198E+11	Pa		☐
9	Specific Heat, C_p	187	J kg^-1 C^-1	☐	☐

Figure 3.4: The Engineering data input for cutting tool material in ANSYS software



Properties of Outline Row 3: Al SiC Metal Matrix Composites (MMC)

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2680	kg m^-3	☐	☐
3	⊟ Isotropic Elasticity			☐	
4	Derive from	Young's Modulu...			
5	Young's Modulus	73000	MPa		☐
6	Poisson's Ratio	0.33			☐
7	Bulk Modulus	7.1569E+10	Pa		☐
8	Shear Modulus	2.7444E+10	Pa		☐
9	Specific Heat, C_p	963	J kg^-1 C^-1	☐	☐

Figure 3.5: The Engineering data input for workpiece material in ANSYS software

3.5 Mesh Generation

As demonstrated, mesh development is an essential activity of the ANSYS component. The objective of meshing is to incorporate computational physical simulation components such as finite simple analysis. In general, mesh creation in ANSYS provides pure hex mesh for the following highly detailed hybrid meshes. In short, a suitable mesh-generating setup will improve both physical model representation and simulation performance accuracy. The lower element size, on the other hand, increases the amount of mesh components and the simulation duration. The mesh boundary selection therefore not only impacts simulation speed, but also performance accuracy, convergence, and solution speed.

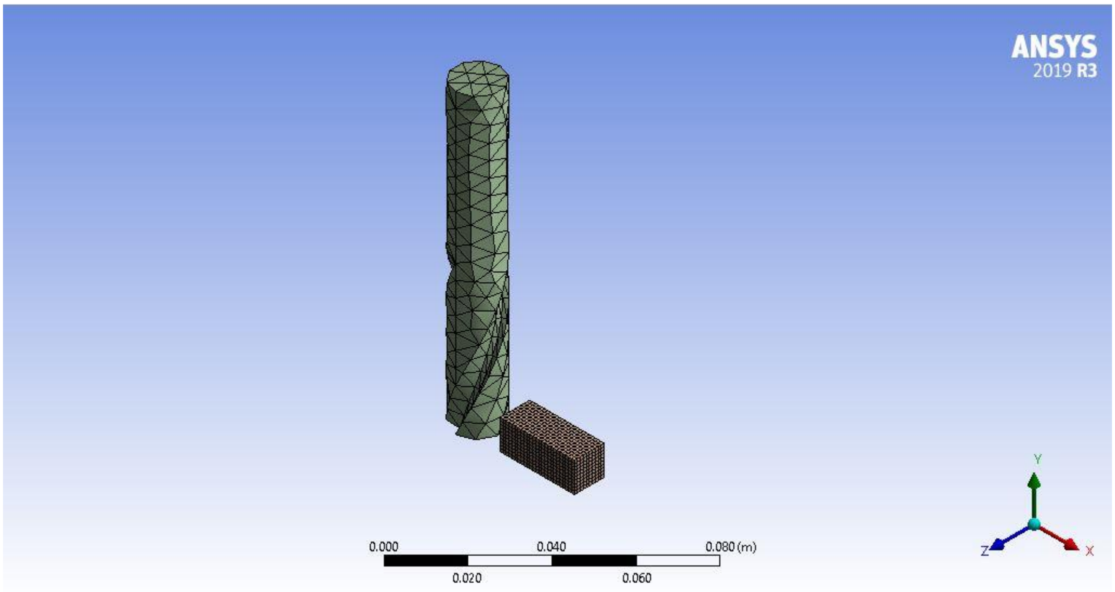
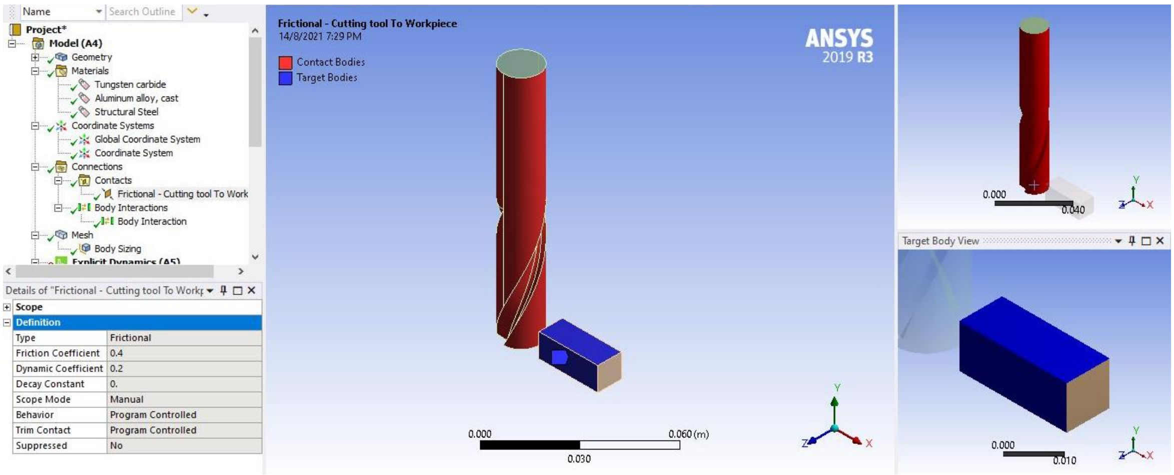


Figure 3.6: Mesh generation

The results of this examination often reflect the workpiece. The workpiece was significantly enhanced in its body size feature to enhance the accuracy, in particular for highly detailed mesh production.

3.6 Tool Friction Model

Friction along the interface tool-chip interface affects chip shape, edge creation and cutting temperature. Therefore, the friction mechanism along the faces and the edge of the tool is essential for correct FEA models. In ANSYS/Explicit the generic contact algorithm accessible defined contacts from the tool to the workpiece. The contact forces based on the ANSYS interaction system as illustrated in Figure 3.7 suggest this approach.



Details of "Frictional - Cutting tool To Workp

Scope

Definition

Type	Frictional
Friction Coefficient	0.4
Dynamic Coefficient	0.2
Decay Constant	0.
Scope Mode	Manual
Behavior	Program Controlled
Trim Contact	Program Controlled
Suppressed	No

Figure 3.7: The ANSYS workbench that shows the connections diagram tree

3.7 Boundary Conditions

After geometry development and mesh production, the boundary conditions for future simulation must be established. Boundary restrictions explain a specific problem in each instance. The data on the dependent variables must be accurate at the domain frontiers. This is successfully achieved via the user interface of the ANSYS workbench. For performing experimental simulation data, the experiment was conducted during AlSi/AlN MMC processing with 240m/min uncoated carbide, feed 0.4mm/tooth, cut depth 0.3mm and 10 percent volume fraction of AlN particle strengthened (Tomadi et al., 2017).

Figure 3.8 illustrates the ANSYS software FEA model interface with the same experimental approach. Displacement was directed to the workpieces that may deflect to any degree of freedom and movement of the x-axis during the cutting process. The pre-set field function has a displacement value of 4000 times as a movement of the speed, to guarantee that the workpiece travels linearly along the X-axis. The tool was then set up using the condition type limit: speed/angular speed (VR3) of -9420 rad/time, which was rotated on the Z-axis.

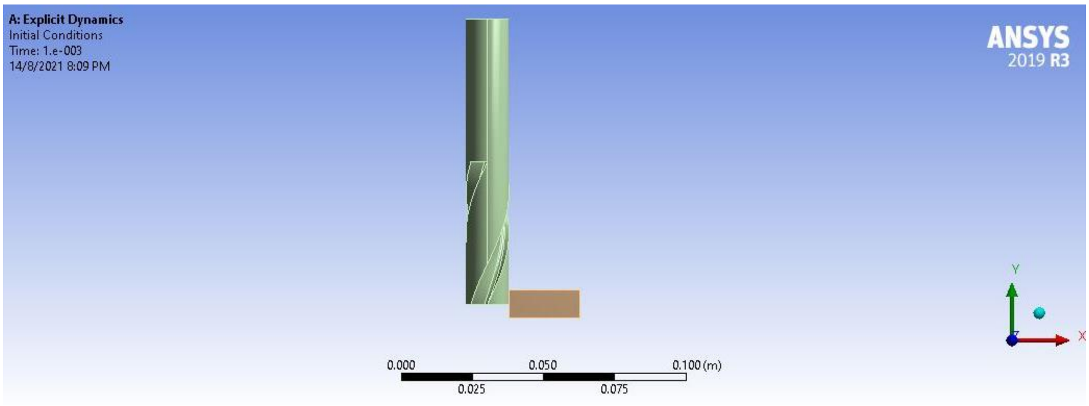


Figure 3.8: Side view of the machining simulation ANSYS interface that showing the cutting tool and the workpiece

3.7.1 Displacement

The idea of border conditions includes displacement assistance and fixed aid as part of a complementary cooperation. With a set aid, motion is not possible due to changes in external force, movement, and geometry. A geometry-level displacement aid needs one or more smooth, curved faces, corners, or vertices to move one element of a displacement vector in relation to its initial location within the global coordination system. The space below the milling tool is open so that the tensile variance of both the tool and the workpiece are not obstructed. The simulation of the displacement was used for the bottom surface of a piece where Y and Z axes are not moving, and the X axis is freely moving as shown in Figure 3.9. This setting also serves to communicate the tension difference in the frying tip as it moves across the X-axis, the technique by which the workpiece is milled from first contact.

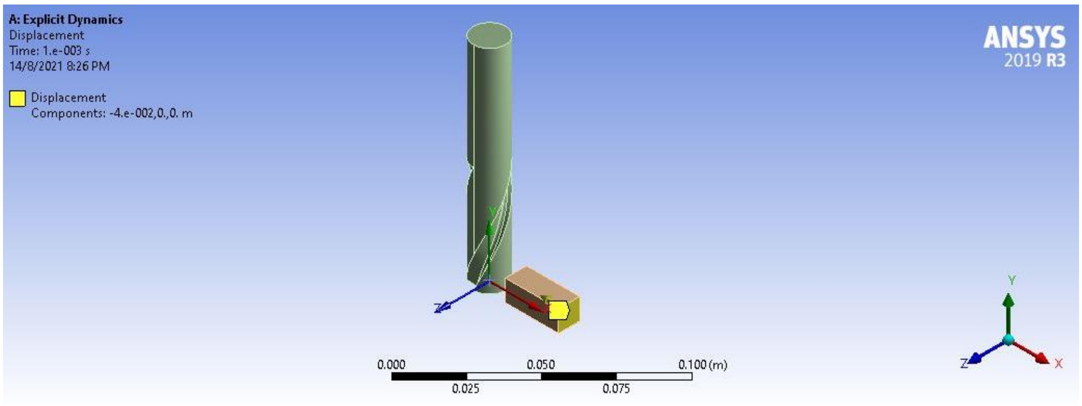


Figure 3.9: Displacement

3.8 Optimization

The optimization phase uses the Taguchi technique. The Taguchi method is an excellent engineering approach for enhancing productivity in research and development. The Taguchi technique is not only suitable to optimize cutting parameters in friction but can also be applied for other processes (Tomadi et al., 2017). In ANOVA and Gray Relation Analysis, Singh et al. (2014) determined this optimum cutting value for converting Al-SiC(10p) MMC. They found that the performance parameters of Al-SiC (10p) MMC machining processes, for example surface raw material and specific strength, are improved using the Taguchi technique.

CHAPTER 4

RESULTS AND DISCUSSIONS

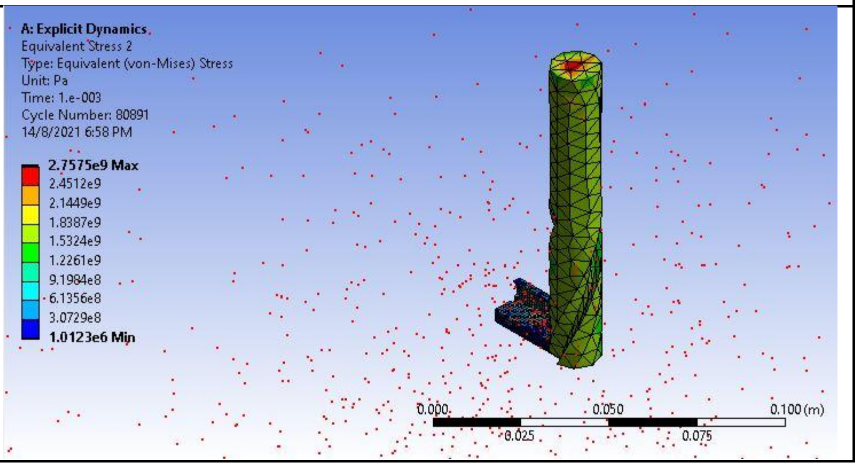
4.1 Introduction

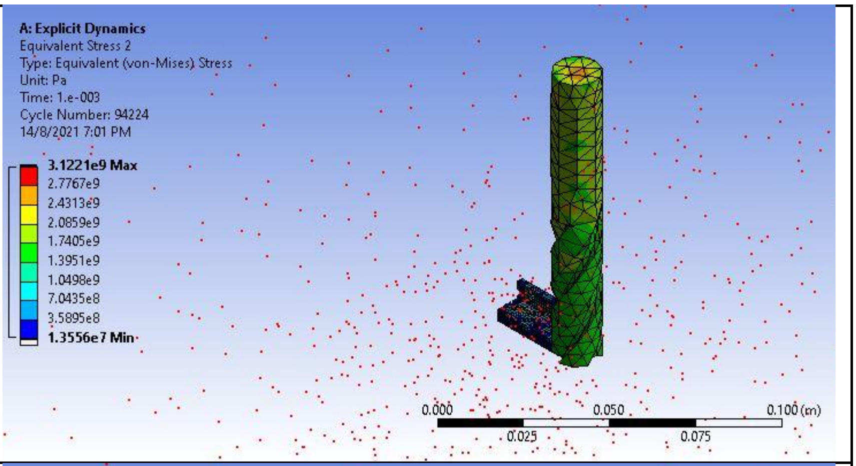
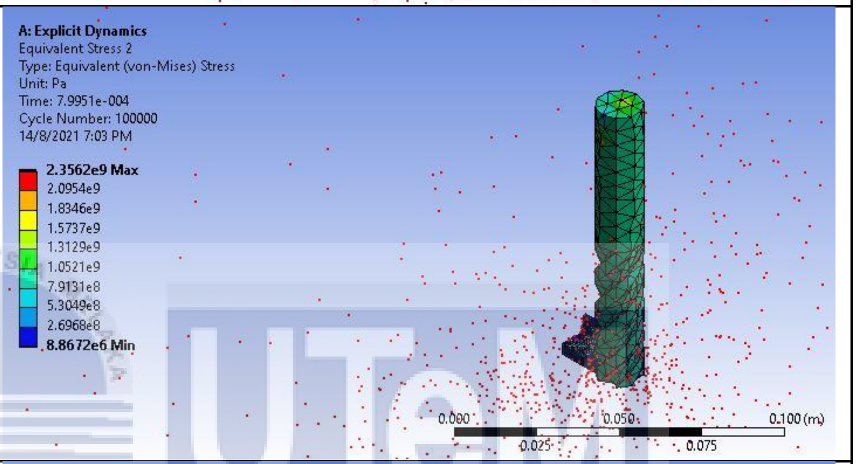
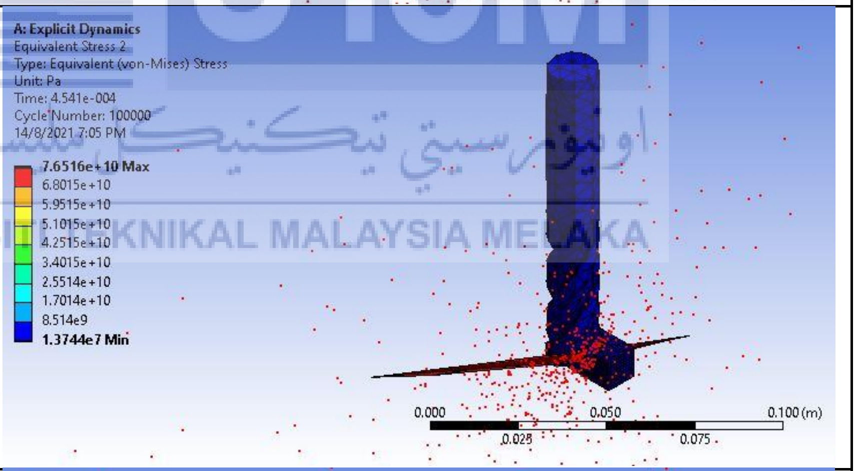
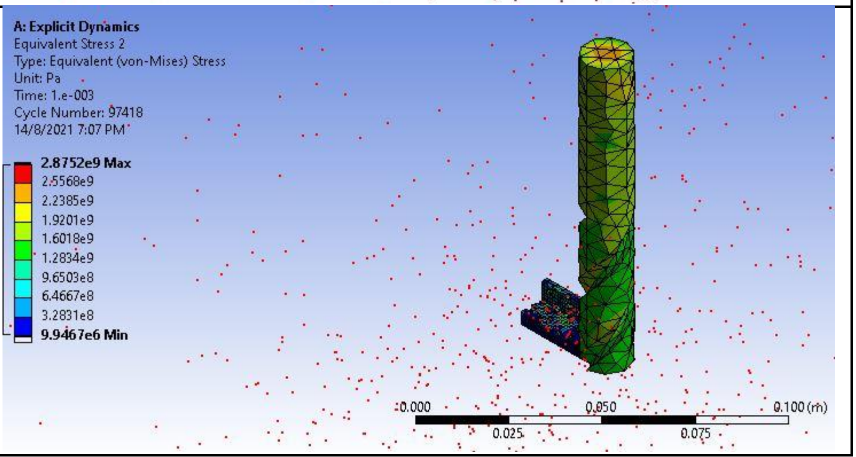
This chapter shows the outcome of optimizing cutter geometry for Al SiC Metal Matrix Composites after finishing the Finite Element Analysis (FEA). The Taguchi S/N ratio analysis was used to assess the deviation of quality properties from the intended value for the ‘smaller is better’ attributes. Additionally, the rationale for the rejected cutter geometry from the screening process is explained

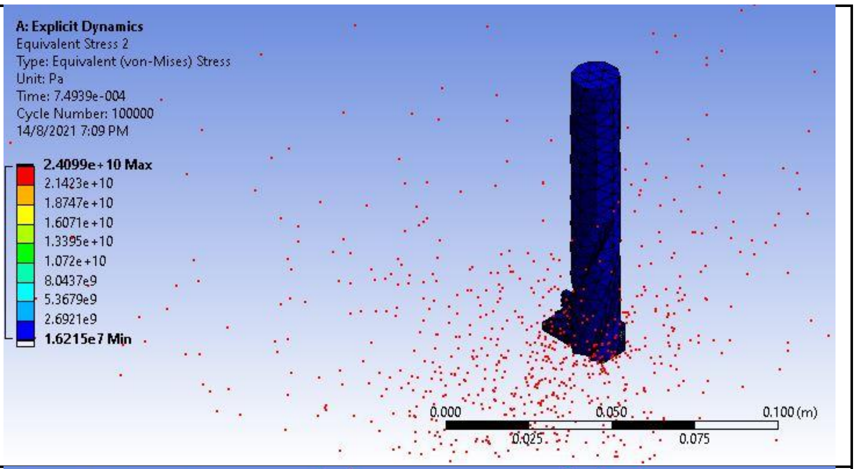
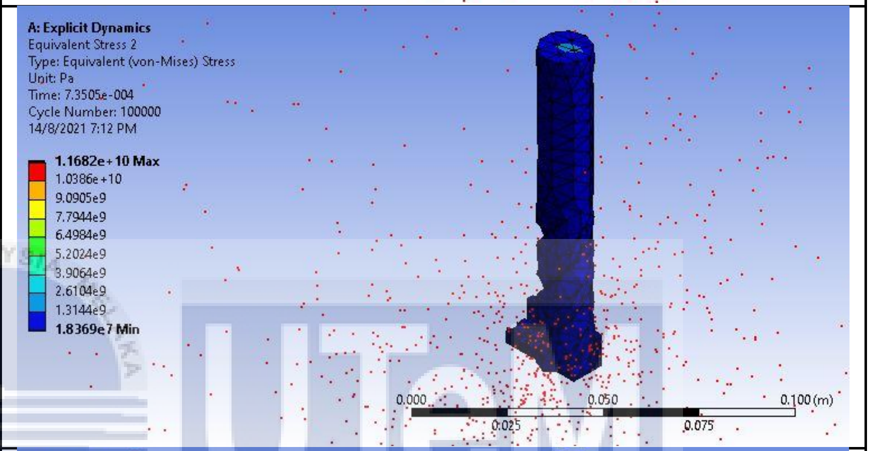
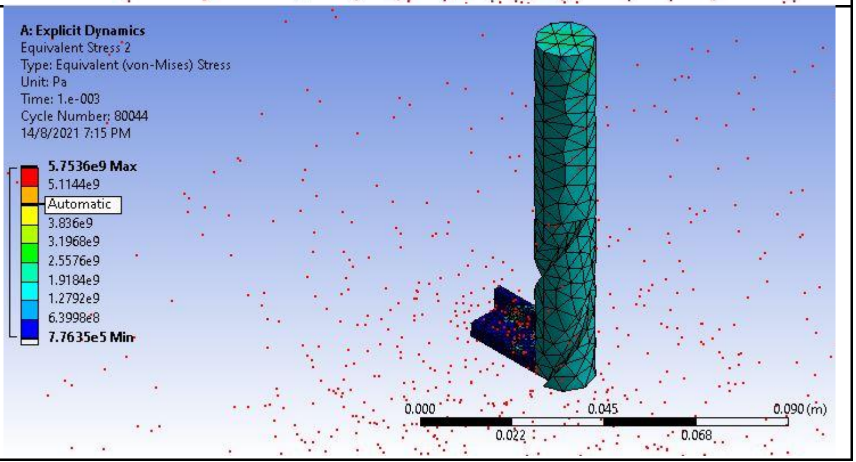
4.2 Simulation Result

This simulation of Finite elements is based on data material models and friction of contact faces. The results presented relate to the Al SiC metal matrix composites (MMC).

Table 4.1: Cutter and FEA results

No	Cutter	FEA result
1		

2		 **A: Explicit Dynamics** Equivalent Stress 2 Type: Equivalent (von-Mises) Stress Unit: Pa Time: 1.e-003 Cycle Number: 94224 14/8/2021 7:01 PM
3		 **A: Explicit Dynamics** Equivalent Stress 2 Type: Equivalent (von-Mises) Stress Unit: Pa Time: 7.9951e-004 Cycle Number: 100000 14/8/2021 7:03 PM
4		 **A: Explicit Dynamics** Equivalent Stress 2 Type: Equivalent (von-Mises) Stress Unit: Pa Time: 4.541e-004 Cycle Number: 100000 14/8/2021 7:05 PM
5		 **A: Explicit Dynamics** Equivalent Stress 2 Type: Equivalent (von-Mises) Stress Unit: Pa Time: 1.e-003 Cycle Number: 97418 14/8/2021 7:07 PM

6		 **A: Explicit Dynamics** Equivalent Stress 2 Type: Equivalent (von-Mises) Stress Unit: Pa Time: 7.4939e-004 Cycle Number: 100000 14/8/2021 7:09 PM **2.4099e+10 Max** 2.1423e+10 1.8747e+10 1.6071e+10 1.3395e+10 1.072e+10 8.0437e9 5.3679e9 2.6921e9 **1.6215e7 Min**
7		 **A: Explicit Dynamics** Equivalent Stress 2 Type: Equivalent (von-Mises) Stress Unit: Pa Time: 7.3505e-004 Cycle Number: 100000 14/8/2021 7:12 PM **1.1682e+10 Max** 1.0386e+10 9.0905e9 7.7944e9 6.4984e9 5.2024e9 3.9064e9 2.6104e9 1.3144e9 **1.8369e7 Min**
8		 **A: Explicit Dynamics** Equivalent Stress 2 Type: Equivalent (von-Mises) Stress Unit: Pa Time: 7.0371e-004 Cycle Number: 100000 14/8/2021 7:14 PM **5.5909e+10 Max** 4.9698e+10 4.3487e+10 3.7276e+10 3.1065e+10 2.4854e+10 1.8643e+10 1.2432e+10 6.2212e9 **1.0224e7 Min**
9		 **A: Explicit Dynamics** Equivalent Stress 2 Type: Equivalent (von-Mises) Stress Unit: Pa Time: 1.e-003 Cycle Number: 80044 14/8/2021 7:15 PM **5.7536e9 Max** 5.1144e9 Automatic 3.836e9 3.1968e9 2.5576e9 1.9184e9 1.2792e9 6.3998e8 **7.7635e5 Min**

4.2.1 Statistical analysis

In essence, statistics are a science that involves data gathering, data interpretation and data validation. The study of statistical data is a technique used to conduct particular statistical operations. It is a kind of quantitative study intended for data measurement and utilises some form of statistical analysis.

4.2.1.1 Temperature

For the whole period of time, the temperature ranges of the workpiece, device and chip may be monitored in simulation. The heat content and distribution in the device, workpiece and chip was monitored using temperature ranges through an autonomous device independent of the Finite Element system. The heat fluxes are based on changes in the heat content. Table 4.2 indicates the temperature and value of the S/N ratio for the simulation of machining.

Table 4.2: The temperature and S/N ratio value of FEA simulation

Tool	Rake angle	Clearance angle	Helix angle	Flute Number	Temperature (ºC)	S/N ratio
1	5	6	30	2	39.10917	-31.8456
2	5	10	40	3	43.77955	-32.8254
3	5	17	60	4	39.53228	-31.939
4	10	6	40	4	32.1997	-30.157
5	10	10	60	2	51.94462	-34.3108
6	10	17	30	3	43.38803	-32.7474
7	15	6	60	3	43.98695	-32.8665
8	15	10	30	4	36.16872	-31.1667
9	15	17	40	2	36.4703	-31.2388

The values indicate the impact of geometrical cutter characteristics on the answer from the table above (temperature). The combination of Tool no.4 (10° rake angle, 60° clearance angle, 40° helix angle, 4 flute number) produces an average 32.2°C lower temperature. The simulated findings indicate that the optimal combination of cutting geometrical characteristics may enhance the process of machining in this instance, which can provide better shearing action that reduces cutting force and heat generation. In addition, the maximum temperature with an average of 51.9°C can be shown in Tool No.5 (10° rake angles, 10° clearance angles, 60° helix angles, 2 Flute Numbers). One of the major reasons for the high temperature values achieved by this tool's combination was the smaller number of flutes on the cutting tool. The temperature distribution has a significant effect on the manufacture of tool wear, which leads to high-temperature wear rates and makes it easy to wear and dull the cutting edge especially at tip spots. Therefore, high wear in a two-flute end mill concentrates mainly on two cutting point tips. To this extent, the high helix angle and positive rake angle may not be suitable for heavy-duty activities in order and reduce tool wear to extend the tool life (Wu et al., 2012).

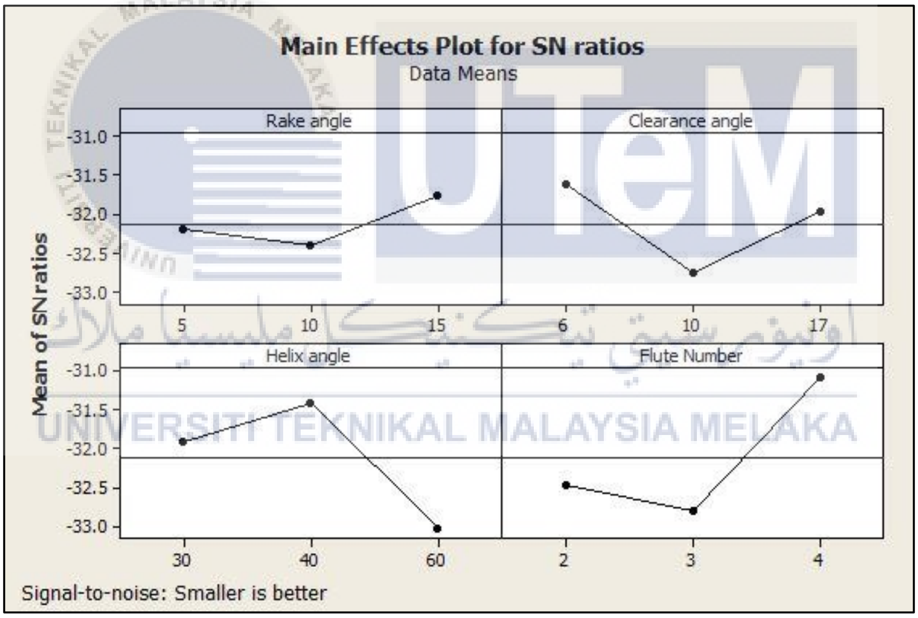


Figure 4.1: Main effects plot for S/N ratio of temperature

Figure 4.1 demonstrates that the S/N ratio graph is preferable for lesser temperatures. The effect on temperature of all cutter geometry parameters may be demonstrated. As shown in the graph, the number of flutes most contributes to the temperature value compared to the other factors, as seen in the steepest graph. The flute offers the route for chip removal while cutting. The more flutes, the lower the cutting force, which reduces heat production. The S/N ratio for the helix angle shows that the 40° helix angle gives the lowest temperature in comparison to two other values. The shearing behavior may be explained throughout the cutting process. The successful shearing action therefore lowers the cutting forces and heat generated by any increase of the helix angle during the milling operation. The high temperature zones and the rising helix angles seem to be decreasing from the tool interface to the cutting tip regions (Wu et al., 2012). Therefore, an optimal value for the helix angle may be seen, which needs further study to enhance machining performance.

The graph indicates that the lowest temperature with a 10° rake angle is achieved and that the rake angle is measured progressively increasing with a rake angle at 15°. The rake angle may influence chip formation, cutting force and distribution of stress in the cutting zone. Tu et al., (2019) stated that as the rake angles rise, the temperature drops, showing the proper rise in the rake angle the lower the tool's temperature. In addition, the high rake angle for the continual formation of chips improves the smoothness of processed surfaces. Finally, the S/N ratio shows the clearance angle temperature impacts. The highest S/N ratio of the diagram as shown in Figure 4.1 is given by a 10° clearance angle to reduce the temperature as opposed to other clearance angles. In dampening the cycle to improve machining stability, the clearance angle plays an important role (Tunç & Budak, 2012).

4.2.1.2 Stress

In this research, FEM analysis was carried out to forecast stress on cutting tools. Table 4.3 provides the FEA simulation stress and S/N ratio values, and Figure 4.2 illustrates the major S/N plot impacts for stress purposes. As seen in the graph, the angles of the rake most contribute to the stress, as shown in the steepest graph line compared to other factors. 50 indicates the lowest stress value for the rake angle. The forming, the cutting force, and the distribution of stress on a cutting zone may be affected by the angle of the rake. The cutting stresses diminish as the depth of the cut goes up, says Kurt, Yalçin, & Yilmaz, (2015). The reason is that greater cutting depth adds to the contact area of the chip.

Table 4.3: The stress and S/N ratio value of FEA simulation

Tool	Rake angle	Clearance angle	Helix angle	Flute number	Stress (MPa)	S/N ratio
1	5	6	30	2	2757.5	-68.8103
2	5	10	40	3	3122.1	-69.8889
3	5	17	60	4	2356.2	-67.4442
4	10	6	40	4	76516.0	-97.6750
5	10	10	60	2	2875.2	-69.1734
6	10	17	30	3	24099.0	-87.6400
7	15	6	60	3	11682.0	-81.3503
8	15	10	30	4	55909.0	-94.9496
9	15	17	40	2	5753.6	-75.1988

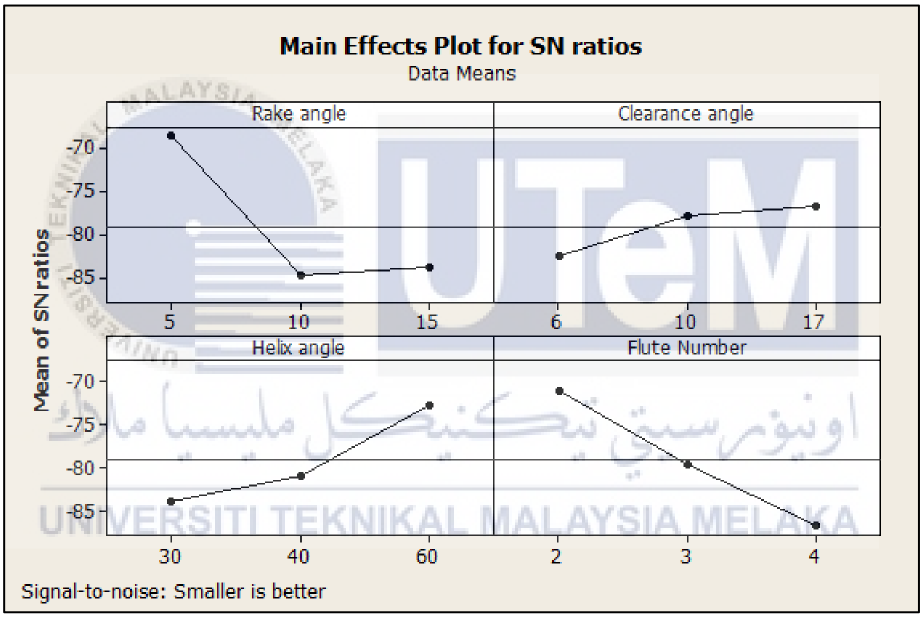


Figure 4. 2: Main effects plot for S/N ratio of stress

For flute number, the S/N ratio plot indicates that flute number 2 is lower than other values. The two-flute end mills Kivanc and Budak (2004) found less analytical than the four-flute end mill. The machining output has been found to be affected by the flute number of the end mill. 60° indicates the lowest stress value in the simulation for the helix angle. In addition, the helix angle removes the chip weight without causing shock and vibrations. Higher helix angle may result in a smoother surface and a low force distribution that generates less heat. Finally, the 17° clearance angle from the S/N ratio shown in the graph shows the lowest stress value. The angle of clearance affects the polish and quality of the surface. Tunç & Budak, (2012) have shown a decrease in the clearance angle to a better damping mechanism with an increasing indentation volume and vibration amplitude.

4.3 Summary of Optimization Analysis

For optimization of the cutter shape that can efficiently machine MMC at low temperature, the results in Figure 4.1 are the combination of 15° rake angles, 6° clearance angles, 40° helix angles and 4 flutes. The combination of rake angle 5°, clearance angle 17°, helix angle 60° and flute number 2 has, meanwhile, been selected to optimize cutter shape that creates the lowest stress value as shown in Figure 4.2.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The aim of this research is to optimize cutter geometry for the machining of Al SiC Metal Matrix Composites (MMC). The following conclusions may be made from the analysis carried out and the findings obtained:

1. The rake angle, helix angle, clearance angle and number of flutes all the geometrical characteristics of cutter have a major impact on temperature and load value. Furthermore, the connection between temperature and stress associated with cutter geometry for each reaction was effectively established via statistical analysis.

2. Flute number is the main factor influencing the lowest temperature as the helix angle, the clearing angle, and the rake angle of the helix value. The rake angle, clearance angle, helix angle and flute number parameters for optimum are 15°, 6º, 40º and 4 correspondingly.

3. 2 flute cutters with a blend of 5º rake angles, 60º helix angles and 17º clearance angles were found as optimum cutter shape which generated the minimum stress during Al SiC Metal Matrix Composites (MMC) workmanship using FEA software.

4. The suggested novel Finite Element Method (FEM) simulation cutter design is successful in improving machining performance for the Al SiC Metal Matrix Composites (MMC) material machining that may significantly reduce cost.

5.2 Recommendation

For potential research work, the following subjects should be explored:

1. Extending optimization to deal with specific machining performance, such as surface roughness, tool life, vibration, and force machining.

2. Expand the optimization model to handle additional tool parameters.

3. Enlarge the optimization model for additional Al SiC composites (MMCs) Metal Matrix.

4. The methods of machining of other composite forms with specific machining operations can be used further in this study, such as turning, grinding, boring, etc.

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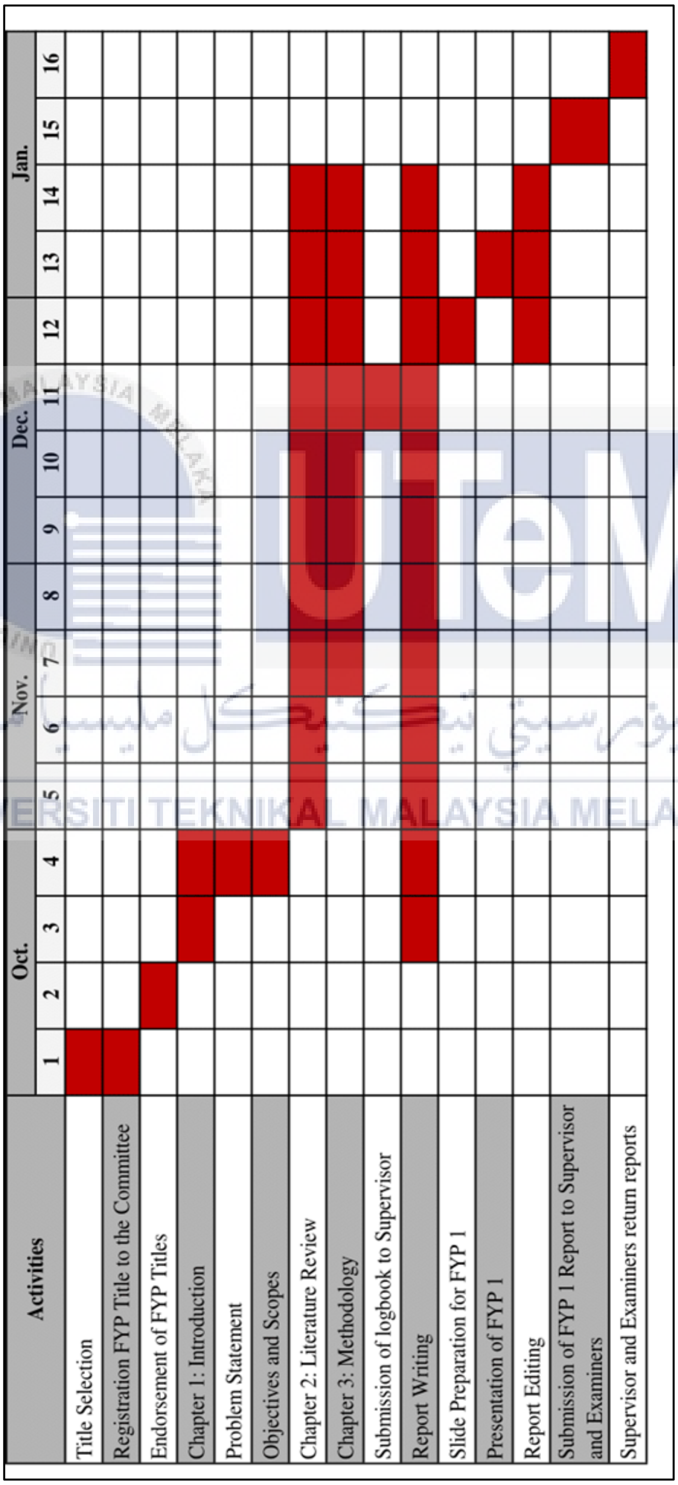
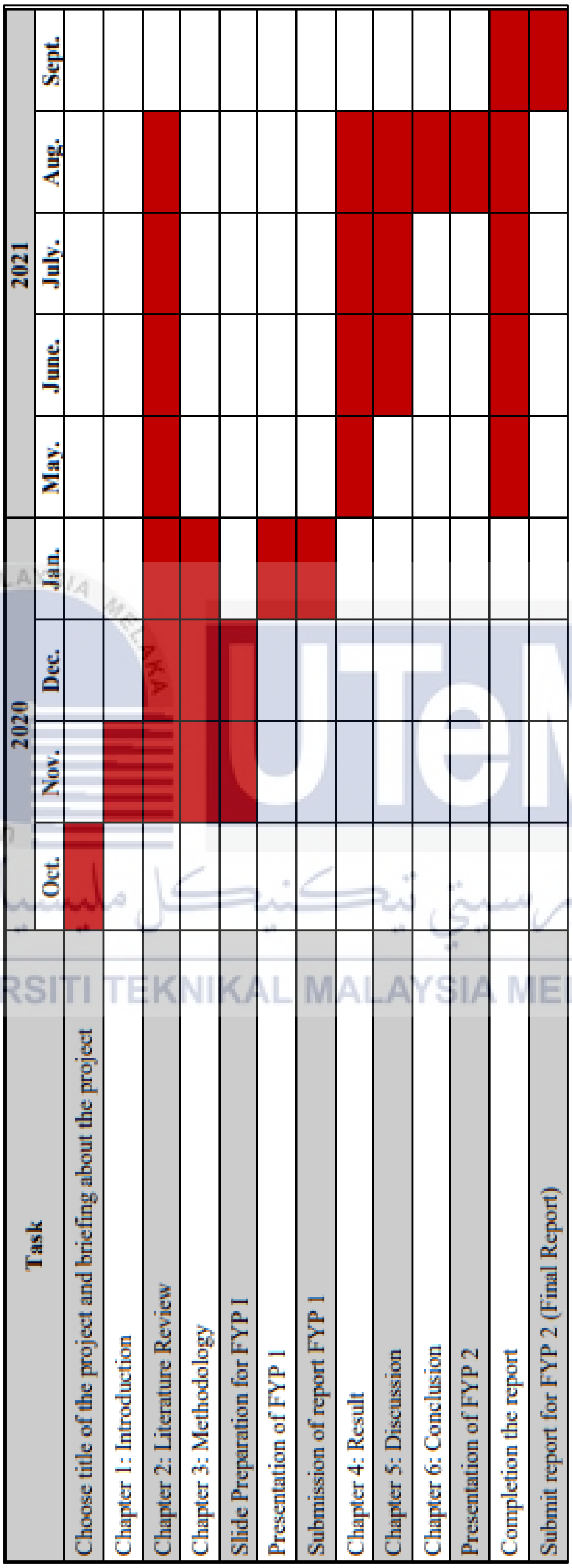
APPENDICES

A. Gantt Chart of FYP I



Activities	Oct.				Nov.				Dec.				Jan.			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Title Selection	🟥															
Registration FYP Title to the Committee	🟥															
Endorsement of FYP Titles		🟥														
Chapter 1: Introduction			🟥	🟥												
Problem Statement				🟥												
Objectives and Scopes				🟥												
Chapter 2: Literature Review					🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		
Chapter 3: Methodology							🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		
Submission of logbook to Supervisor											🟥					
Report Writing			🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		
Slide Preparation for FYP 1												🟥				
Presentation of FYP 1													🟥			
Report Editing												🟥	🟥	🟥		
Submission of FYP 1 Report to Supervisor and Examiners															🟥	
Supervisor and Examiners return reports																🟥

B. Gantt Chart of FYP I and II



Task	2020				2021				
	Oct.	Nov.	Dec.	Jan.	May.	June.	July.	Aug.	Sept.
Choose title of the project and briefing about the project	🟥								
Chapter 1: Introduction		🟥							
Chapter 2: Literature Review		🟥	🟥	🟥	🟥	🟥	🟥	🟥	
Chapter 3: Methodology		🟥	🟥	🟥					
Slide Preparation for FYP I		🟥	🟥						
Presentation of FYP 1				🟥					
Submission of report FYP 1				🟥					
Chapter 4: Result					🟥	🟥	🟥	🟥	
Chapter 5: Discussion						🟥	🟥	🟥	
Chapter 6: Conclusion								🟥	
Presentation of FYP 2								🟥	
Completion the report					🟥	🟥	🟥	🟥	🟥
Submit report for FYP 2 (Final Report)									🟥