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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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:

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Supervisor Profesor Madya Dr. Raja Izamshah bin Raja Abdullah

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

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TABLE OF CONTENTS

CHAPTER 3: METHODOLOGY

CHAPTER 4: RESULTS AND DISCUSSIONS

CHAPTER 5: CONCLUSION AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

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