UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MACHINING SIMULATION OF COMPOSITE MATERIALS USING ENGINEERING SIMULATION SOFTWARE

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

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Design) (Hons.). The member of the supervisory is as follow:

………………………………

(Project Supervisor)

ABSTRACT

Proses pengisaran merupakan salah satu alat yang paling penting dalam proses memotong bahan komposit dengan alat geometri operasi pengisaran yang kompleks. Bahan komposit digunakan secara meluas dalam pelbagai sektor pembuatan termasuk aeroangkasa, marin dan automotif. Terdapat kekurangan penyelidikan tentang simulasi logam matriks komposit yang menggunakan Kaedah Unsur Terhingga 3D (FEM) dalam proses pengisaran dan kaedah unsur terhingga 2D tidak boleh mensimulasikan proses pengisaran yang kompleks. Oleh itu, kajian simulasi bermaklumat dengan lebih realistik 3D Model Unsur Terhingga (FEMs) dan juga model pemotongan ortogon untuk proses pengisaran yang kompleks CFRP/AL2024 telah dibangunkan untuk meramalkan mata alat dan bahan kerja menggunakan 3D Analisis Unsur Terhingga (FEA) dengan menggunakan ABAQUS/EXPLICIT. Akhirnya keputusan agihan tegasan, suhu pengisaran, daya pemotongan dan pembentukan cip diperolehi. Model ini mengambil kira kesan yang dinamik, undang-undang kerosakan bahan dan kriteria kenalan. Projek ini juga membangunkan Model 3D dalam pemesinan Realiti Maya (VR) yang memberikan satu penyelesaian yang optimum penjanaan laluan mata alat dengan bantuan simulasi menggunakan VERICUT. Simulasi dan pemodelan proses pemotongan mempunyai potensi untuk mengoptimumkan parameter pemesinan dan meningkatkan reka bentuk alat pemotong, terutamanya dalam pengisaran termaju yang berkelajuan tinggi.

ABSTRACT

The milling process is one of the most important tool for cutting process in milling operation of composite material with the complex tool geometry. Composite materials are widely used in a variety of manufacturing sectors including the aerospace, marine and automotive industries. There is a lack of research on simulating the metal matrix composites using 3D Finite Element Methods (FEM) in the milling process and the 2D finite element methods cannot simulate the complex milling process. Therefore, an informative simulation study with more realistic 3D Finite Element Models (FEMs) as well as an orthogonal cutting model for the complex milling process of CFRP/AL2024 was developed to predict tool and workpiece using 3D Finite Element Analysis (FEA) with ABAQUS/EXPLICIT. Finally the results of stress distribution, milling temperatures, cutting force and chip formation are obtained. This model takes into account the dynamic effect, material damage law and contact criteria. This project also develops the 3D Model in Virtual Reality (VR) machining that to give an optimal solution of the tool path generation with the help of simulation using the VERICUT. Simulation and modelling of cutting processes have the potential for optimizing machining parameters and improving the cutting tool design, especially in advanced high-speed milling.

DEDICATION

Special Dedication to my beloved parents and family,

My fellow colleague, My friends,

and all faculty members,

Who have support and guidance me.

Who is always there for me and always prays for me,

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Thank you.

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AL2024	-	Aluminum
Al_2O_3	-	Alumina
Ti6A14V	-	Titanium alloy
ALE	-	Arbitrary Lagrangian Eulerian
ASTM	-	American Society for Testing and Materials Standards
BC's	-	Boundary Conditions
CAD	-	Computer Aided Drafting
CAE	-	Computer Aided Engineering
CAM	-	Computer Aided Machining
CBN	-	Cubic Boron Nitride
CDM	-	Continuum Damage Modelling
CFRP	-	Carbon Fiber Reinforcement Polymer
CM	-	Composite Modeler
CMA	-	Composite Modeler for ABAQUS
CNC	-	Computer Numerical Control
DoE	-	Design of Experiments
DoF	-	Degree of Freedom
FE	-	Finite Element
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
FEMs	-	Finite Element Models
FRP	-	Fibre Reinforced Plastics
FYP	-	Final Year Project
GFRP	-	Glass Fibre Reinforced Plastics
HSM	-	High Speed Machining
NC	-	Numerical Control
PCD	-	Polycrystalline Coated Diamond
PSM	-	Projek Sarjana Muda

R&D	-	Research And Development
RSM	-	Response Surface Model
SFTC	-	Scientific Forming Technologies Company
SOW	-	Scope of Works
SHPB	-	Split Hopkinson Pressure Bar
VR	-	Virtual Reality
exp	-	Exponential
D	-	Diameter
F	-	Feed Rate
Gpa	-	Giga Pascal
Kg	-	Kilogram
L	-	Length
m	-	Melting
min	-	Minute
mm	-	Millimetre
Mpa	-	Mega Pascal
N	-	Value of cutter
P	-	Parameters
Q	-	Misses Stress
Ra	-	Surface roughness
rpm	-	Revolution per minute
s	-	Second
T	-	Temperature
T_m	-	Melting Temperature
T_r	-	Room Temperature
V	-	Cutting Speed
W	-	Weight
Z	-	Number of teeth

CHAPTER 1
INTRODUCTION

This chapter contains the introduction and project background. This project is carried out based on the simulation and analysis of the milling process of carbon fibre composites CFRP/Al2024. Problem statements, objectives and scopes of this project are also discussed. There is also a chapter organization that explains about the overall subject in this report.

1.1 Overview

Composite is a superior material that is preferred in aerospace, marine and automotive industries. It is made up of a matrix material completely surrounding the reinforcement material to form unique properties and characteristics which do not exist in the matrix material naturally (R. Rusinek, et al., 2011). When the two phases unite to form a composite, it has properties or features that are not available in the original constituents of the composite materials formed (Alwarsamy et al., 2012). Recently, composite became the most preferred material in the aerospace industry due to the many benefits it provides, such as superior strength to weight ratio, stiffness, good fatigue as well as corrosion resistance and low manufacturing cost (NorKhairusshima M.K et al., 2011). Despite its excellent characteristics, machining of composite is difficult to conduct due to its high abrasiveness, non-homogenous and anisotropic structure (Klinkova et al., 2011). Research of composite machining mostly concentrates on drilling and turning. Rahman et al., (1999) developed feasible techniques for turning on Carbon Fibre Reinforced Plastics (CFRP).

According to Ferreira et al., (1999) focused on tool wear and illustrated the performance of different tool materials and supports that only Polycrystalline Coated Diamond (PCD) tool are suitable for used in finish turning. Palanikumar et al., (2004) presented an investigation on optimization of machining parameters for surface roughness using Design of Experiments (DoE) on different types of Glass Fibre Reinforced Plastics (GFRP). Hariharan et al., (2012) the influence of tool wear in a drilling process of CFRP composites is very high. Phadnis et al., (2012) developed 3D Finite Element Model (FEM) of drilling CFRP/A2024. However, there are few researchers dealing with machining of composite material using a CNC milling machine (NorKhairusshima M.K et al., 2011, Alwarsamy et al., 2012). To improve the manufacturing quality, performance of the tool, optimum cutting conditions and cost reduction are the key area need to be considered. On the other hand, the academicians are continually looking for alternatives that help of a better understanding of the metal cutting process.

Generally, there are two most common methods of conducting experiments associated with the machining process. First is by preparing some sample, set-up on the machine with predefined machining parameters and finally some data will be collected depending on the purpose of the experiments. However, this method has proved to be more expensive, especially dealing with composite materials. The second method is called simulation. Simulation models are very important in the machining process as comprehension and for the reduction of experimental tests. Results obtained from the simulation provides better understanding of system behaviour and in turn help in the process of optimization of tool geometries, cutting conditions and other parameters like the choice of the tool material and coating. Simulation eventually enables good predictions in the cutting force, stress and strain distribution. This will contribute to cost reductions for the machining process optimization that are still experimentally done and thus expensive (Madalina C. et al., 2008). Therefore, there are few researchers are focusing on modelling and simulation techniques to predict and optimize certain machining parameters such as the cutting force, surface roughness, stress–strain analysis etcetera. These techniques do not need to perform many experimental tests that will cost a lot of money and are time consuming (Hamed S. et al., 2007).

1.2 Problem Statement

CFRPs are an expensive material that fast gaining ground as the preferred material to replace the traditional material used for construction of aircraft and spacecraft (W. N. F. Mohamad et al., 2013). In recent years, the combinations of CFRP/metals to form a composite material have also gained popularity (Klinkova et al., 2011; R. Rusinek, et al., 2011). Literature reviews relevant to the field of composite material machining most often focus on analysis of cutting tools wear and methods of optimization for surface roughness. Most of the research conducted by performing actual machining operation which actually very expensive and time consuming. Another method of experiment which is less costly as described previously is simulation. Generally, most of the machining simulation only provides limited information such as tool path generations and errors/collision detection, Output like surface roughness, tool wear, cutting forces etcetera are not readily available on request.

Therefore, in this project, the simulation of the machining process of CFRP/AL2024 is conducted using the engineering simulation software. However, complex milling process cannot be simulated by 2D finite element methods (H. B. Wu. S. J. Zhang, 2013). Therefore, an informative simulation study with more realistic 3D Finite Element Model (FEM) and orthogonal cutting model for the complex milling process of CFRP/AL2024 is developed. This model takes into account the dynamic effect, material damage law and contact criteria. Also the 3D Model developed in virtual machining would give an optimal solution of the tool path generation with the help of simulation. Simulation and modelling of cutting processes have the potential for optimizing machining parameters and improving the cutting tool designs, especially in advanced high-speed milling.

1.3 Objectives

The overall aim of the Final Year Project (FYP) is to study and develop a methodology for simulating the machining process of CFRP/Al 2024 using a milling machine. The aim can be resolved into the following specific objectives:-

- To develop 3D Finite Element Model (FEM) for milling process using 3D Finite Element Analysis (FEA) with ABAQUS/EXPLICIT software.
- To simulate machining tool path, under the selected cutting conditions (speed, feed rate and depth of cut) using the VERICUT software.

1.4 Scope of Work

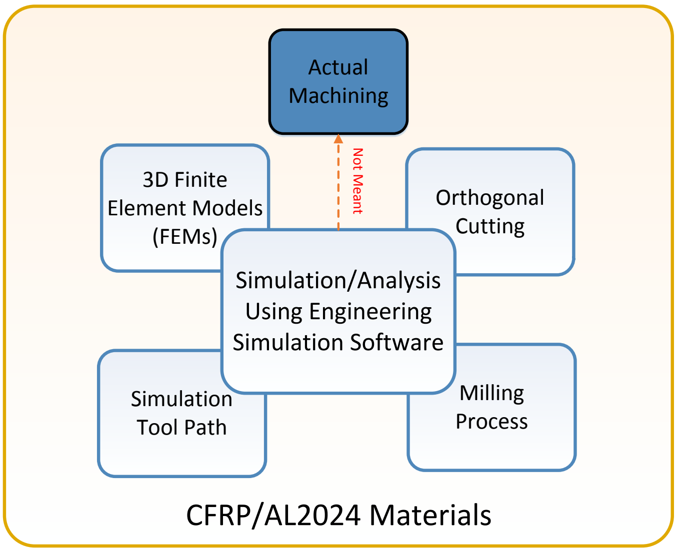

Figure 1.0: Scope of works (SOW)

Figure 1.0 shows the Scope of Works (SOW) in this Final Year Project (FYP). The scopes of the project are mainly focused on studying about analysis and simulation in the milling process of CFRP/Al2024. In this project, an informative simulation study with a more realistic 3D Finite Element Models (FEMs) as well as an orthogonal cutting model has been developed to simulate the complex milling process of CFRP/AL2024 using the engineering simulation software.

This project also develops the 3D Model in virtual reality machining that to give an optimal solution of the tool path generation with considering speed, feed rates, and depth of cut with the help of simulation. The data from the observation and compilation will be used in simulation, applications of machining for verification. It will then help to analyze more conditions affecting the machinability of CFRP/AL2024. These studies are not meant for actual machining.

1.5 Chapters Organization

This dissertation consists of five chapters which is covered on PSM 1 and PSM 2. The report includes of introduction, literature review, methodology, result and conclusion. The first chapter introduces the background of the project, problem statement, objectives, scopes of the project and the report structure for overview the whole chapters in the report. Then follow by literature review on Chapter 2 which more on the research about the related project and review on the previous research work in composite machining, machining simulation and analysis using engineering simulation software. Chapter 3 focuses on the project planning as well as the methodology used during completing this project to ensure this project is successfully completed on the specified time period. This chapter explains about the flow of process planning, equipment and software application will be conducted. Chapter 4 describes the result and discussion of this project from the simulation and analysis process that has traversed. This project report ends with the conclusion of Chapter 5. Conclusions are made based on the result of simulation and analysis that have been conducted. Finally, suggestion and recommendation for the future work also included in this final chapter to improve this project.

CHAPTER2

LITERATURE REVIEW

The purpose of this chapter is to provide a general overview of past and current research work and placing the FYP project in wider context of simulation. All relevant information related to this project is refined and structurally present in this chapter. This literature review is vital to help in generating ideas to complete the tasks and project. The section of this report will review on previous research work on composite machining, composite materials, and machining simulation using engineering simulation software. Towards the end of this chapter, a summary of the literature is presented.

2.1 Background

Machining operations of composite materials which especially carbon fibre is extensively used in the aerospace industry in order to create smoothness on the desired surface and make a prototype part from a big blank or set of materials. Machining of the materials is very common and easily performed (Klinkova et al., 2011; R. Rusinek et al., 2011). However, the machining of the composite has proved to be more challenging. Machining of the composite material parts generates discontinuity in the fibre and thus affect the performance of the part, the temperature during the cutting process must be considered where it should not exceed the cure temperature or close to the melting temperature of the resin to avoid material disintegration. During machining process the smaller values of feed rate are much better as far as the tool life is concerned (W. N. F. Mohamad et al., 2013; Alwarsamy et al., 2012).

Adversely, this causes the process consuming more time and are very expensive. Machining also exposed the fibre to chemical and moisture and the effect of coolant materials on composites. The machining of composite materials required for dry machining process without using any coolant, or cutting fluid (W. N. F. Mohamad et al., 2013). This is due to the composite materials will expand if using the coolant or any cutting fluid during machining. The mechanical damage will occur faster when the workpiece that manufactured with composites are exposed to moisture and elevated temperature. The presence of water modifies the properties of the matrix and affected the mechanical properties such as strength, stiffness and creep (Rahman et al., 1999). Furthermore, there are several advantages by using dry cutting it will reduce the cost of machining (Premnath et al., 2012).

In the field of cutting process research, the Finite Element Method (FEM) is regarded as a ve1y useful tool to study the cutting process of materials. Many finite element models have been developed, including orthogonal cutting model, oblique cutting model, and 3D FEM. The orthogonal FEM has been more used to investigate the cutting mechanism. Simoneau et al., (2006) studied chip formation of medium carbon steel using 1hc orthogonal cutting model. Jin and Altintas, (2012) predicted micro-milling forces with the orthogonal model.

According to Mohammadpour et al., (2010) investigated the effect of machining parameters on residual stresses in orthogonal cutting. Molinari et al., (2011) studied the link between local variables and global contact characteristics in orthogonal cutting using the finite element method. Shams and Mashayekhi, (2012) established a nonlocal damage model to improve the orthogonal cutting simulation. Deng et al., (2009) used an orthogonal FEM to investigate burr formation. Zhang et al., (2012) investigated the cutting process of Ti6A14V based on crystal plasticity theory and discrete cohesive elements. Afazov et al., (2010) predicted micro-milling, cutting forces through the orthogonal cutting FEM.