UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SURFACE INTEGRITY ANALYSIS IN CNC MILLING OF 6061-T6 ALUMINUM ALLOY

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

by

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ABSTRACT

This study presents the surface integrity analysis and optimization of machining parameters in 3-axis CNC milling of 6061-T6 aluminum alloy. Aluminum alloy is widely used in industry such as automation, aerospace and others industry. CNC milling was selected due to the versatile function. The goal of this research is to determine the influence of surface roughness and microhardness upon CNC milling due to the cutting speed, feed rate, and depth of cut. The response surface methodology (RSM) was used in this study to design and analysis the experiment. There are 20 trials were conducted by using 3-axis CNC milling machine and the high speed steel (HSS) end mill with 4 flutes was used in the experiment. The surface roughness was checked by using portable surface roughness tester, while, the microhardness were checked by micro DM2D Digital Micro Hardness tester. The result was analyzed by using the RSM in the Design Expert Software. The mathematical modeling was established after analysis. The significant parameters suggested are cutting speed and feed rate while depth of cut is not a significant factor. For the optimization section, the best predicted setting is cutting speed of 89.99 m/min, feed rate of 191mm/min and depth of cut of 0.57mm in order to archive good surface finish. The average deviation percentage value is 16.59%. In this experiment, the microhardness did not have significant changes except for certain trial sample.

ABSTRAK

Kajian ini adalah mengenai analisa integriti permukaan dan mengoptimiskan parameter mesin pada kelajuan mesin mengisar bagi aluminum aloi 6061-T6. Objektif kajian ini adalah untuk mengetahui kesan pembolehuabah mesin mengisar dari segi kelajuan potong, kadar suapan dan kedalaman pemotongan ke atas *'surface roughness'* and '*microhardness*'. Kaedah '*Response Surface Methodology'* (RSM) telah digunakan untuk menganalisis keputusan. Terdapat 20 kali percubaan yang dijalankan dengan menggunakan mesin mengisar 3-axis dan mata pemotong berjenis *High Speed Steel* (HSS). *'surface roughness'* telah dinilai dengan menggunakan '*portable surface roughness tester'*, Selain itu, '*microhardness*' telah dinilai dengan menggunakan '*micro DM2D Digital Micro Hardness tester'*. Keputusan telah dianalisis dengan menggunakan kaedah RSM pada perisian '*Design Expert*'. Model matematik telah diterbitkan dan eksperimen telah dijalankan sakali lagi untuk mengesahkan model matematik. Dalam seksen optimize, parameter yang diberi adalah kelajauan potong dengan 89.99 m/min, kadar suapan 191 mm/min dan kedalaman pemotongan 0.57mm untuk memcapai permukaan yang halus. Bagi nilai '*average deviation percentage'* adalah memcapai sebanyak 16.59%. Dalam kajian ini, '*microhardness*' tiada mempunyai keputusan yang ketara kecuali situasi lain. Keputusan yang tidak ketara adalah disebabkan oleh menggunakan pendingin masa menjalankan mesin.

DEDICATION

To my dearest family and friends, for their love, help, and supports.

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LIST OF ABBREVIATIONS

CNC	-	Computer Numerical Control
HSS	-	High Speed Steel
rpm	-	Revolution per minute
DOE	-	Design of Experiment
RSM	-	Response Surface Methodology
ANOVA	-	Analysis of variance

CHAPTER 1

INTRODUCTION

This chapter gives a brief overview of 3-axis CNC milling technology. Besides, this chapter includes the objective, scope, problem statement and importance of study.

1.1 Introduction

Kauppinen (2004) stated that CNC milling has been widely recognised as one of the key processes in fabricating aluminium parts in variety of manufacturing industry included aerospace and automotive sectors where to produce high precession and accuracy parts. Some major benefits of the CNC milling compared to conventional milling are reported as high material removal rate, reduction in lead time, low cutting force, and dissipation of heat from the cutting zone is transferred mainly into chips, resulting in high accuracy and better surface finish.

Furthermore, Kalpajian (2004) classified that surface roughness is using to determine the surface finish. Surface roughness influence several functional attributes of parts such as contact causing surface friction, wearing, light reflection, heat transmission or resisting fatigue. Besides, microhardness influence scratch and wear resistance. Therefore, selecting the appropriate machine parameter to achieve desired surface finish is very important.

Kauppinen (2004) stated that the machinability of aluminium alloys is relatively high. Milling aluminium materials with conventional cutting parameters is easy. Cutting forces are low and tool wear relatively small. Tool wear rates of the cutting tools do not normally play a significant role in the machining of aluminium alloys. The 6061-

T6 aluminium alloys have been choosing in this study because it was widely and successfully used in aeronautical, dies and mould industry.

1.2 Background of Problem

The elevated cutting speed of the CNC milling will yield unexpected mechanical force and thermal cycle on the material. Furthermore, the improper or inadequate selection of the machining parameters will cause the surface defects such as cracks, creep, and plastic deformation to cause an overall deterioration of the component's mechanical properties. An undesired surface finish will decrease the fatigue life or durability and cause an unwanted failure happen. Besides, scratches or scribe marks may appear on the surface of structures in service due to unpredicted damage, repairing actions or application of large decals. Zhao et al (2009) reported that the preliminary stage is tiny but may increase the potential risk of fatigue failure for the structures of airplanes or other aerospace vehicles under the variable service loads. Furthermore, traditional 'trial and error' method are time consuming and inaccurate. Therefore, in this study, an analysis and optimization of the surface finish was carried out.

1.3 Statement of Problem

- Improper or inadequate selection of the machining parameters will cause the surface defect such as crack, and plastic deformation to cause an overall deterioration of the component's mechanical properties.

- Traditional 'trial and error' method are time consuming and inaccurate.

1.4 Objective

The objectives of this paper are:

- To analyze the effect of CNC milling parameters such as cutting speed, depth of cut, and feed rate to the surface roughness and microhardness of 6061-T6 Aluminium Alloy.
- To determine the best setting for the machining to achieve the best result of surface roughness by using Response Surface methodology (RSM).

1.5 Scope

This study investigates the effect of cutting speed, feed rate, and depth of cut on the surface finish of the material upon the high speed end milling. The material was used in this study is 6061-T6 aluminium alloy. On the other hand, the cutting tool that used in this study is high speed steel (HSS). Furthermore, the response surface methodology (RSM) was applied to generate the experiment matrix. Finally, mathematical model was developed to represent the study and validation was conducted to determine the consistency of the mathematical model. Others responses such as, cutter geometry, and tool wear were not discussed in this study.

1.6 Importance of Study

CNC milling has becomes a cost-effective manufacturing process to produce parts with high precision and good surface quality. By applying the RSM method, the correlation of machining variables and responses (surface roughness and microhardness) could be obtained easily. This will help the industry to save time and cost compared to the previous "trial and error" method. Besides, by identifying the optimum parameters setting could help the industry to reduce the product failure which caused by surface finish problems.

1.7 Expected Result

The main factors that influence the surface finish of material are cutting speed, feed rate, and depth of cut. Different value of parameters will result different surface finish. By applying RSM method, the most influential parameter and relation between the parameter and response can be analysed. The mathematical modelling will be established and the optimal surface finish will be obtained at the end of the study.

CHAPTER 2

LITERATURE REVIEW

This chapter describes the theory of milling process and the parameters by referring from the journal. Besides, cutting tool, workpiece, response variable and summary of journal were explained in this chapter.

2.1 Machining Center

Kalpajian (2004) reported that a machining centers is an advanced, computer controlled machine tools that is capable of performing a variety of machining operations on different surfaces and different orientations of a workpiece without having to remove it from its workholding device or fixture. The workpiece is generally stationary, and the cutting tools rotate as they do in milling, drilling, honing, tapping, and similar operations. Whereas in transfer lines or in typical shops and factories the workpiece is brought to the machine, note that in machining centers, it is the machining operation that is brought to the workpiece. CNC machine allow more operation to be done on a part in one setup instead of moving from machine to machine for various operations. These machines greatly increase productivity because the time formerly used to move a part from machine to machine is eliminated.

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2.2 Milling Machining Operation

2.2.1 End Milling

Kalpajian (2004) classified that the cutter called end mill has either straight shank or a tapered shank and is mounted into the spindle of the milling machine. End mill can produce variety type of surfaces at any depth such as curved, stepped and pocketed. The cutter removes material on both its end and its cylindrical cutting edges as shown at Figure 2.1. One of the more common applications is high speed milling using an end mill, which observes the same general provisions regarding the stiffness of machines, workholding devices, etc. Consequently, end milling process was selected to carry out in this study.

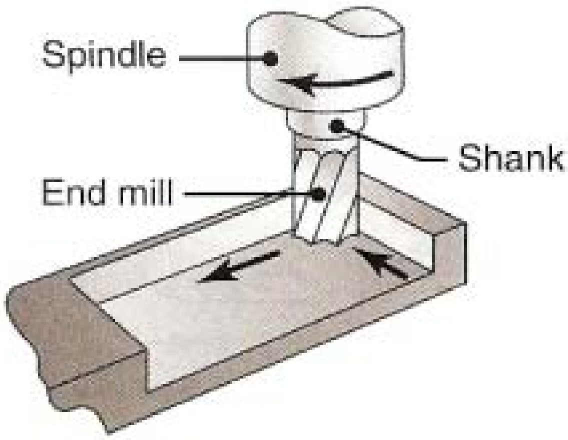

Figure 2.1: End milling.

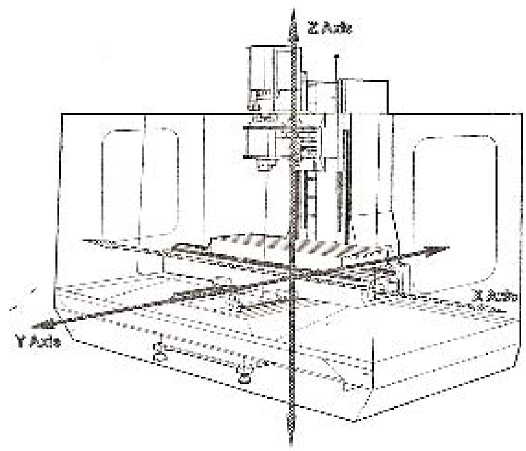

Figure 2.2: Movement of the VCM machine.

2.3 Milling Parameter

There are several type of parameters exist in milling machine or milling process, such as cutting force, feed rate, depth of cut, cutting speed, spindle speed, cutting temperature and etc. Those parameters will affect the response variable depend on the input.

From the literature review, Rao and Shin (2001) revealed that the parameters such as feed rate, cutting speed and depth of cut will affect the surface finish. Besides, the increasing depth of cut is shown to slightly deteriorate surface roughness. Furthermore, Sun and Gou (2009) classified that the cutting speed, feed rate, and depth of cut affected surface roughness and residual stress. Moreover, Suresh Kumar Reddy et al (2008) shown that the most influential factors affecting the surface finish consider as cutting speed, feed, and depth of cut. Furthermore, Benardos and Vosnaikos (2003) reported that the cutting speed, feed rate and depth of cut are parameters that mostly influence the Ra value of surface quality in machining, particularly in the milling machining process. And lastly, Zhang et al (2006) mentioned that the cutting speed was a significant factor affecting surface roughness.

In the literature, the effect of the different parameters on the surface integrity was researched. In this study, cutting speed, feed rate, and depth of cut as machining conditions will be selected.

2.3.1 Cutting Speed

Seames (2002) stated that the cutting speed is the edge or circumferential speed of a tool. In a machining center or milling machine application, the cutting refers to the edge speed of the rotating cutter. Proper cutting speed varies from material to material. Basically, the softer the materials, the higher the cutting speed will be choosing.

$$Cutting\ speed = Diameter \times \pi \times rpm \quad \text{---------------} \quad (1)$$

2.3.2 Feed Rate

Seames (2002) reported that feed rate is the velocity at which the cutting tool is feed into the workpiece. Feed rate are critical to the effectiveness of a job. Too heavy a feed rate will resulting a premature dulling and burning of tools. While, feed rate with too light will result in tool chipping. This chipping will rapidly lead to cool burning and breakage. Moreover, Kalpajian (2004) classified that it is often express in unit inch per minutes (ipm) or millimetres per minutes (mm/min) with consideration of how many teeth or flutes.

Basic formula for feed rate:

$$F = R \times T \times rpm \quad \text{------------------------} \quad (2)$$

Where:

F=the milling feed rate expressed in mm per minute

R=the chip load per tooth

T=the number of teeth on the cutter

rpm=the spindle speed in revolution per minute