CRYOGENIC CARBON DIOXIDE (CO_2) COOLING ON MACHINED SURFACE OF TITANIUM ALLOY

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering

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 requirement for Degree of Manufacturing Engineering (Engineering Process) (Hons). The member of the supervisory committee are as follow:

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(Dr. Mohd Amri Bin Sulaiman)

ABSTRAK

Proses melarik merupakan operasi pemesinan untuk membuang lebihan bahan untuk menghasilkan bentuk silinder atau permukaan yang berprofil. Dalam kajian ini, mata alat tanpa salutan digunakan dalam proses pelarikan terhadap bahan Ti-6Al-4V ELI (extra low interstitial). Banyak aplikasi dibentuk menggunakan bahan aloi titanium seperti aeroangkasa, peralatan perubatan dan automotif. Oleh sebab itu, aloi titanium mempunyai nisbah kekuatan terhadap berat yang tinggi, rintangan kakisan yang baik dan rintangan rapuh yang tinggi. Walau bagaimanapun, aloi titanium mempunyai keberairan tema yang rendah dan tindak balas kimia yang tinggi. Oleh itu, aloi titanium mudah bertindak balas kimia dengan bahan mata alat. Tujuan kajian ini adalah untuk mengenal pasti faktor yang paling mempengaruhi permukaan kasar dibantu oleh sistem *cryogenic.* Reka bentuk eksperimen kajian ini adalah melalui reka bentuk box-behnken (BBD) dari kaedah gerak balas permukaan (RSM). Reka bentuk Box-Behnken digunakan untuk mengatur parameter eksperimen iaitu laju pemotongan dengan julat dari 120 hingga 220 m/min, kadar suapan dari 0.1 hingga 0.2 mm/rev dan kedalaman pemotongan adalah dari 0.4 hingga 0.6 mm. Bacaan diambil dan direkod bagi setiap 20 mm perlarikan pada bahan aloi titanium sehinggan nilai haus (Vb) mencapai 0.2 mm. Analisis ANOVA menunjukkan kadar suapan dan kedalaman pemotongan adalah faktor yang lebih ketara dalam kekasaran permukaan dan bentuk model adalah linear. Berdasarkan kepada keputusan, nilai minimum kekasaran (0.7572 µm) telah dihasilkan oleh laju pemotongan (120 mm/min) , kadar suapan (0.10 mm/rev) dan kedalaman pemotongan (0.50 mm).

ABSTRACT

Turning is the process that removes the material to produce external cylindrical or conical surfaces. In this research, uncoated carbides were used in turning of titanium alloy, Ti-6Al-4V ELI (extra low interstitial). Titanium alloys have been created in many applications such as aerospace, medical devices and automotive. Because of that, titanium has a good combination of high quality to weight proportion, good erosion resistance and good fatigue resistance. Nevertheless, titanium alloy is classified as difficult to machine material. Titanium alloy has low thermal conductivity and high chemical reactivity. It is easy to react chemically with the cutting tools material. Thus, it is most challenging material in machining. Cryogenic carbon dioxide (CO_2) is one of the technique that introduced in cutting hard material especially titanium alloy. The objective of this study was to identify the significant of cutting parameter on surface roughness during turning of titanium alloy assisted by CO_2 cryogenic cooling. In this research, Box-Behnken (BBD) of Response Surface Methodology (RSM) was used to design the experimental matrix runs. The BBD was selected to arrange the cutting parameters of cutting speed with range of 120 to 220 m/min, feed rate with 0.1 to 0.2 mm/rev and depth of cut with range of 0.4 to 0.6 mm. Surface roughness was measured using portable surface roughness measurements. The values were recorded for each 20 mm on surface machine until flank wear (Vb) reached 0.2 mm. ANOVA analyses indicated that the feed rate and depth of cut are more significant factor in surface roughness and the linear model is formed. From the results, minimum surface roughness (0.7572 μm) obtained by cutting speed of 120 m/min, feed rate of 0.10 mm/rev and depth of cut of 0.50 mm.

DEDICATION

In the name of Allah, the Most Gracious and the Most Merciful

I dedicate this final year project to:

My beloved parents,

Mat Amin Ahmad & Marshitah Abu Bakar

My adored brother and sister,

Azlan & Azlida,

My cutest nephews,

Aqil Anaqi & Afif Afnan

You know who you are

for giving me moral support, money, cooperation, encouragement and also understandings

Thank You So Much & Love You All Forever

jet'aime.

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LIST OF ABBREVIATIONS

Ti-6Al-4V	-	Titanium Alloy
TiAlN	-	Titanium Aluminium Nitride
TiN	-	Titanium Nitride
TiC	-	Titanium Carbide
Ti(C) N	-	Titanium Carbide Nitride
Ti	-	Titanium
CO_2	-	Carbon Dioxide
LN_2	-	Liquid Nitrogen
N_2	-	Nitrogen
MQL	-	Minimum Quantity Lubrication
ISO	-	International Standard
Ti	-	Titanium
V	-	Vanadium
RSM	-	Response Surface Methodology
ANOVA	-	Analysis of Variance
BBD	-	Box–Behnken design
DOE	-	Design of Experiment
ELI	-	Extra Low Interstitial
CNC	-	Computer Numerical Control
CFD	-	Computational Fluid Dynamics

LIST OF SYMBOLS

RPM	-	Revolution per Minute
Ra	-	Roughness Average
%	-	Percent
mm	-	Millimeter
mm/rev	-	Millimeter per Revolution
m/min	-	Meter per Minute
in./min	-	Inches per Minute
sfpm	-	Surface Feet per Minute
Ns	-	Spindle Speed
°C	-	Degree Celsius
°F	-	Fahrenheit.
K	-	Kelvin
f	-	Feed rate
v	-	Cutting Speed
d	-	Depth of cut
µm	-	Micrometer
°	-	Degree
kPa	-	Kilopascal
Vb	-	Flank Wear

CHAPTER 1

INTRODUCTION

This chapter briefly described about the synopsis of study, problem statement, objective, scopes of study, significance of study, report organization and an overall summarization for this chapter.

1.1 Background

In the manufacturing industry nowadays, good surface finish of the product is crucial and important to provide a better result of product produce by industry. There are interested to get a high quality product by using many ways to achieve better productivity. High quality product can be measured by good surface finish, good accuracy and many more. The quality product can be obtained through machining. Machining is generally used form of process because it is suitable for forming different types of workpiece. In other words, machining is the most helpful and ideal of all producing processes in its ability to produce a range of part geometries and geometric features. In addition, the machinability of a material can be well-defined and measured as the suggestion of the ease or difficult with which it can be machined. Machinability of a material assessed by tool life, metal removal rate, cutting force and last but not least is surface finish (Namb, 2011).

There are many types of natural metal or other alloy elements are well-known to be alloys are often selected in machining industry as the purpose of metal workpiece. The workpiece that are increased many folds in recent time are titanium (Ti) and titanium alloys. Titanium alloy is the area unit of metal material that contains a combination of metal and other chemical element. One of the examples of titanium alloy is Ti-6Al-4V. It has their own characteristics which are high strength to weight ratio, high toughness, high corrosion resistance and others (Nithyanandam *et al.*, 2014). Seeing that, the application of titanium alloy widely used in various fields such as aerospace, marine, biomedical and chemical (Ramesh *et al.*, 2008). They are expensive compared to other material. However, titanium alloy are tough to machine as they have low thermal conductivity, low elasticity modulus and high chemical reactivity at elevated temperature (Leyens and Peters, 2003). The main issues when machining titanium alloy is the cutting temperature are high. Through that, machining titanium is challenging to the manufacturers. A cutting fluid is employed to cool down and lubricate the cutting process that might decrease the cutting temperature. Therefore, cryogenic cooling is the method that can control the cutting temperature during the machining of titanium alloy with an environment-friendly clean technology.

Cryogenics is the field associated with technology at deep cooling temperatures. The word "Cryogenics" derived from two Greek words which are „Kryos‟ and „Genes‟. Kryos is the cold or physical change whereas Genes suggests that born or generated. Once gases are change to liquid type, they become cryogenic liquids. Cryogenic liquids measured liquefied gases that have a standard boiling point below -238°F (-150°C). There are many examples of cryogenic liquid like liquid nitrogen, oxygen, helium, methane, carbon dioxide, ethane and argon. Cutting tool and/or part will be cooling by cryogenic cooling throughout the interval of machining process. The cryogenic will be delivered to the native cutting region of the cutting tool or to the part that is exposed to the very high temperature throughout the machining process. This process will change the characteristics of material and increase the machining performance (Pusavec *et al*., 2009)

The common coolants use in cryogenic machining is carbon dioxide and liquid nitrogen. Carbon dioxide (CO_2) is one of the cryogenic liquid that naturally present in air and slightly soluble in water. It can exist as a liquid only at high pressure. The characteristics of CO_2 are colorless, non-flammable and odorless in the gaseous and liquid states (Latif *et al.,* 2009).Boiling point of CO_2 is −109.3 °F (-78.4 °C). Other than that, CO_2 has slightly less expensive per pound. Liquid nitrogen (LN_2) is one of the cryogenic liquid that used in research lab. As „cryogenic‟ related to very low temperature, it is a very cold material. In addition, LN_2 liquefied under high pressure condition and can increase to a very high volume of gas. The characteristics of LN_2 are inert, non-flammable, non-corrosive, odorless, colorless and extremely cold. Besides, nitrogen is inert and will not provide combustion. When nitrogen converts to a liquid form, it called cryogenic liquid. LN_2 has a boiling point of -320.50 F (-195.80 °C) (Stefansson, 2014).

Cutting process such as turning is used to machine this titanium alloy. According to Groover (2010), turning is machining process that remove the material from the workpiece through the single-edge cutting tool to get the cylindrical shape or tough surface profile. There are three cutting parameters for the turning process which are cutting speed, feed rate and depth of cut. Based on Stefansson (2014), the common of research work on cryogenic machining has been created on turning operation. It can be explained because in the turning, it smooths access of the cryogenic media to enter the cutting zone with an external nozzle in a single-point turning. Uncoated carbide tools are broadly used in the machining industries for many machining operations of assorted materials especially in turning. Coated carbide is not suitable to use in this process because of the coating material such as titanium aluminium nitride (TiAlN), titanium nitride (TiN), titanium carbide TiC) and titanium carbide-nitride Ti(C) N can generate chemical reaction with the workpiece cutting temperature (titanium alloy). Titanium is extremely chemical reactive, its tendency to weld to the cutting tool throughout machining. Therefore, uncoated carbide tools are better performance in turning process.

Response surface methodology (RSM) is a group of statistical techniques and mathematical. This method can help in modeling and analyze for a certain problem (Moghaddam and Khajeh, 2011). RSM is used to create experimental design in order to achieve optimization of manufacturing process by arranging the cutting parameter while analysis of variance (ANOVA) is used to analyze significant cutting factors and develop empirical model for surface roughness. In other words, RSM is a technique that use before, during and after regression analysis is performed for the data. In this study the optimization method provided by the Box–Behnken design (BBD) which is a response of RSM. BBD was used to identify the best performance, interaction effect and significant of factor. The design do not have simple generator and have complex confounding of interaction. Other than that, BBD are reasonable and significantly helpful once it is expensive to perform the necessary experimental run.

1.2 Problem Statement

Titanium alloys are hard material and tough to machine material. Many cutting tools materials are reacting with the titanium alloy because it has low thermal conductivity and high chemical reactivity. Low thermal conductivity of the titanium alloy will increase the temperature at the leading edge of the tool. Because of high cutting temperature and solid connection amongst tool and workpiece make the cutting tool wear off quickly during machining (Che-Haron and Jawaid, 2005). Tool wears off rapidly giving poor surface machine. Therefore, by applying the cryogenic cooling, it can decrease cutting tool temperature as well as the surface machine will be improved. Other than that, cryogenic cooling has better waste management compared to conventional cooling.

The cutting fluid is a variety of fluids designed specifically for metalwork methods like machining process of turning. Variety purpose of cutting fluid during machining process which are cool the workpiece, reduce friction also wash away the chip. From previous study, majority were claimed that conventional cutting fluid unsuccessful to control the cutting temperature within the cutting zone (Dhananchezian and Pradeep Kumar, 2011). Thus, conventional cutting fluid is ineffective to remove heat effectively and the function cannot be well enough as the cutting fluid can be. The use cryogenic cooling is a powerful cooling since it can control the cutting temperature and handling process of cryogenic cooling cost easier. The low cost of cryogenic cooling compared to conventional based on the reduction in number of machine tools required.

Titanium, stainless steel, hardened steel and other superalloys are the example of hard material. It has particular metallurgical characteristics. The characteristics such as more resistant to corrosion, low sensitive and harder make it them became difficult to machine. Low machinability of the material makes it more challenging during the machining. Along cutting this material, cryogenic liquid nitrogen (LN_2) was introduced in cutting hard material. LN_2 commonly uses because of the properties like clean, non-toxic and non-corrosive gas. Dilip *et al.,* (2012) stated that different analyses were done before by the researcher by utilizing cryogenic LN_2 as the prime cryogenic coolant and prevailing to a more noteworthy degree in getting the decreased cutting temperature, cutting power, surface roughness and tool wear. Nevertheless, cryogenic carbon dioxide (CO_2) gases are not well be used in cutting process especially Titanium Alloy. Cryogenic CO_2 are capable to reduce heat of the cutting area and could function as well as LN_2. Thus, by applying cryogenic CO_2 would be improved in terms of surface roughness due to low cutting temperature and low cutting forces.

1.3 Objective

The objectives of this study are:

a) To identify the significant cutting parameter on surface roughness during turning of titanium alloy assisted by CO_2 cryogenic cooling.

b) To develop mathematical model for the surface roughness during turning titanium alloy.

c) To determine set of optimization process cutting parameter towards surface roughness, Ra using RSM.

1.4 Scope

This study focused on the effect of applying liquid carbon dioxide (CO_2) to develop better surface finish of the workpiece. The material used in this research is titanium alloy Ti-6Al-4V ELI. During the processing of titanium alloy, the turning operation is using straight turning process. This project was conducted at the laboratory in Universtiti Teknikal Malaysia Melaka (UTeM) by using CNC Lathe Haas ST-20. Besides, the properties of cryogenic cooling which can improve the surface roughness of the material are characterized. The value of surface roughness is measured using a portable surface roughness measurement. The machining parameters such as cutting speed, feed rate and depth of cut are evaluated. The cutting parameters of cutting speed with range of 120 to 220 m/min, feed rate with 0.1 to 0.2 mm/rev and depth of cut with range of 0.4 to 0.6 mm.

The optimization of control parameter for Ti-6 Al-4V ELI is used RSM and Analysis of Variance (ANOVA).

1.5 Significant of study

During processing of titanium alloy Ti- 6 Al-4V ELI, liquid carbon dioxide (CO_2) is applied. In this research, liquid CO_2 is using because its ability to replace the conventional cooling liquid to improve the quality on the surface machine of titanium alloys Ti-6Al-4V ELI. The study will develop the mathematical model for the surface roughness of surface machine using design of experiment (DOE) analysis. The optimization toward surface roughness also determined using response surface methodology (RSM).

1.6 Organization of Study

In overall, these researches are majorly consists of five section. The five sections are introduction, literature review, methodology, result and discussion and in addition conclusion and recommendation. For first part is introduction. It provides a synopsis of study of this research, problem statement about this study, objective and lastly scope. It is involve the hugeness or important of this exploration to industry.

Second section is emphasized on writing audit on past related research on the topic. This section involves important procedure to apply liquid carbon dioxide as cryogenic cooling in machining during the process of turning of titanium alloy. Concerning of this project, cryogenic cooling is use to give better productivity compare with the conventional.

Last but not least, chapter three which is methodology had covered the method involved in order to explain on the preparation of the experiment, testing method and studies of each sample. All the result and finding are explained and analyzed in chapter four. Chapter four is result and discussion. Finally, chapter five is conclusion. It is contains the overall conclusion discoveries result and new thought suggested. The thought and recommended keeping in mind the end goal to enhance the examination later on.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the basic theory of conventional cutting fluid and cryogenic cooling system are discussed with some related published works will follow to prove the theory. This review covers work-piece materials, titanium alloys (Ti-6AL-4V-ELI), cutting tool material and uncoated carbide also the design of experiment (DOE) methods.

2.1 Conventional Cutting Fluid

In machining stages, cutting fluid is a form of coolant and lubricant designs specifically for metalwork process. Conventional cutting fluids consist of three types which are neat cutting fluid, water soluble fluid and gases. Based on Ten (2017), straight cutting fluids are defined as traditional mineral oils or mineral oils through addictive. Examples of straight cutting lubricant are mineral lubricant, fatty oils and others. Next, machining operation is suitable to use the water soluble fluids because in operation has high cutting speed and low pressure of the tool. The water-miscible consist of three parts which are emulsifiable oils, semichemical (semisynthetic) and chemical (synthetic fluid). Thirdly, there are cutting fluids in gases such as argon, helium and others.