UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

PERFORMANCE OF CARBIDE INSERT IN TURNING OF TITANIUM ALLOY UNDER CARBON DIOXIDE CRYOGENIC COOLING

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Master of Science in Manufacturing Engineering

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PERFORMANCE OF CARBIDE INSERT IN TURNING OF TITANIUM ALLOY UNDER CARBON DIOXIDE CRYOGENIC COOLING

SITI ASIYAH BINTI MAT

A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
in Manufacturing Engineering

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DECLARATION

I declare that this thesis entitled "Performance of Carbide Insert in Turning of Titanium Alloy under Carbon Dioxide Cryogenic Cooling" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Siti Asiyah binti Mat

Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature : ………………………………………………..

Supervisor Name : Associate Professor Dr. Mohd Amri bin Sulaiman

Date : ………………………………………………

DEDICATION

To my beloved father, mother, my family, my supervisor and my supportive friends that accompanying me along the difficult pathway in my university life.

ABSTRACT

In manufacturing industries, such as aerospace, automotive, chemical and medical, the application of titanium alloys has received more attention, especially in dental implant and orthopedic implant. Although this titanium alloy has a unique characteristics, such as difficulties to machining due to high hardness, lower thermal conductivity and higher chemical reactivity, this material is always in high demand. During machining of titanium alloy, the major issues frequently discussed are rapid cutting tool wear and generation of high cutting temperature. The proper cooling method needs to be used in order to reduce high cutting temperature that causes rapid tool wear thus increases the tool life of the cutting tool during machining titanium alloy. Many studies have been reported by researchers of cryogenic cooling in machining titanium. In this research, an attempt has been made to investigate the effect of cryogenic cooling using carbon dioxide (CO_2) liquid, when it is applied to the workpiece and cutting tool during turning of titanium alloy Ti–6Al–4V ELI. The operation process was carried out using a 3-axis CNC Haas ST-20 lathe machine. Response Surface Methodology (RSM) has been used to design the experiment in determining the effect of the cutting parameters: cutting speed, feed rate and depth of cut towards tool life of the uncoated carbide insert. From RSM, Box-Behnken design has been 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 is 0.4 to 0.6 mm. The flank wear was measured using tool maker microscope. The cutting time values were recorded for each 20 mm on the workpiece until flank wear (Vb) reaches the tool life criterion followed by JIS B4011-1971 standard. From the experiment, the longest tool life recorded is 17.58 minutes obtained at cutting speed 120 m/min, feed rate 0.15 mm/rev and depth of cut 0.40 mm. The shortest tool life is 0.45 minutes obtained at the cutting speed 220 m/min, feed rate 0.15 mm/rev and depth of cut 0.6 mm. The ANOVA analysis showed that for tool life, cutting speed is the most significant factor followed by feed rate and depth of cut to determine and optimise the tool life values. From the detailed observation using SEM, it can be concluded the tool failure mode presents at the cutting tool are flank wear and crater wear. In addition, the observed dominant wear mechanism at the cutting tool is abrasion and adhesion.

PRESTASI MATA ALAT KARBIDA DALAM PELARIKAN ALOI TITANIUM DI BAWAH PENYEJUKAN KRIOGENIK KARBON DIOKSIDA

ABSTRAK

Di dalam industri pembuatan seperti aeroangkasa, automotif, bahan kimia dan perubatan, aloi titanium selalu mendapat perhatian yang lebih terutamanya dalam implan pergigian dan implan ortopedik. Walaupun aloi titanium ini mempunyai ciri-ciri yang unik seperti sukar dimesin disebabkan kekerasan yang tinggi, keberaliran terma yang rendah dan mudah bertindak balas secara kimia terhadap bahan mata alat, bahan ini sentiasa dalam permintaan yang tinggi. Semasa pemesinan aloi titanium, isu utama yang sentiasa dibincangkan ialah haus mata alat yang cepat dan suhu pemotongan yang tinggi. Kaedah yang betul perlu digunakan dalam mengurangkan haus yang cepat dan meningkatkan hayat mata alat semasa pemesinan aloi titanium. Banyak kajian telah dilaporkan oleh penyelidik tentang penyejukan kriogenik dalam pemesinan titanium. Dalam penyelidikan ini, kajian telah dilakukan untuk menyiasat kesan penyejukan kriogenik menggunakan cecair karbon dioksida (CO_2) apabila digunakan terhadap bahan kerja dan mata alat semasa pelarikan aloi titanium Ti-6Al-4V ELI. Proses operasi dijalankan menggunakan mesin larik 3-paksi CNC Haas ST-20. Kaedah sambutan permukaan (RSM) telah digunakan dalam mereka bentuk ujikaji untuk mengkaji kesan parameter pemotongan seperti kelajuan pemotongan, kadar suapan dan kedalaman pemotongan terhadap hayat mata alat karbida yang tidak bersalut. Daripada RSM, reka bentuk Box-Behnken telah dipilih untuk mengatur parameter pemotongan untuk laju pemotongan dengan kadar 120 hingga 220 m/min, kadar suapan dengan 0.1 hingga 0.2 mm/pusingan dan kedalaman pemotongan adalah 0.4 hingga 0.6 mm. Haus rusuk diukur menggunakan mikroskop. Nilai haus direkod pada setiap 20 mm pemesinan sehingga haus rusuk (Vb) mencapai kriteria hayat mata alat berdasarkan piawai JIS B4011-1971. Daripada ujikaji, hayat mata alat yang paling lama direkodkan ialah 17.58 minit diperoleh pada laju pemotongan 120 m/min, kadar suapan 0.15 mm/pusingan dan kedalaman pemotongan 0.40 mm. Hayat mata alat yang paling singkat ialah 0.45 minit diperoleh pada laju pemotongan 220 mm/min, kadar suapan 0.15 mm/pusingan dan kedalaman pemotongan 0.6 mm. Analisis ANOVA menunjukkan bahawa untuk hayat mata alat, parameter pemotongan yang paling penting ialah kelajuan pemotongan diikuti dengan kadar suapan dan kedalaman pemotongan dalam menentukan dan mengoptimumkan nilai hayat alat. Berdasarkan pemerhatian yang terperinci dengan menggunakan SEM, dapat disimpulkan mod kegagalan alat yang hadir pada mata alat ialah haus rusuk dan haus kawah. Di samping itu, mekanisme haus dominan yang diperhatikan pada mata alat adalah lelasan dan lekatan.

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LIST OF ABBREVIATIONS

Al	-	Aluminum
ANOVA	-	Analysis of variance
C	-	Carbon
CBN	-	Cubic boron nitride
CNC	-	Computer numerical control
Co	-	Cobalt
CO_2	-	Carbon dioxide
CVD	-	Chemical vapour deposition
d	-	Depth of cut
Df	-	Degree of freedom
DOE	-	Design of experiment
ELI	-	Extra low interstitial
f	-	Feed rate
Fe	-	Iron
H	-	Hydrogen
HSM	-	High speed machining
ISO	-	International standard organization
JIS	-	Japanese industrial standard
LN_2	-	Liquid nitrogen
MQL	-	Minimum quantity lubrication

N	-	Nitrogen
O	-	Oxygen
PCBN	-	Polycrystalline cubic boron nitride
PCD	-	Polycrystalline diamond
PVD	-	Physical vapour deposition
RSM	-	Response surface methodology
S	-	Sulfur
SEM	-	Scanning electron microscopy
Si	-	Silicon
Ti	-	Titanium
v	-	Cutting speed
V	-	Vanadium
VB	-	Flank wear
WC	-	Tungsten carbide
Y	-	Yttrium

LIST OF SYMBOLS

m/min	-	Meter per minute
%	-	Percent
°C	-	Degree celsius
mm	-	Millimeter
µm	-	Micrometer
K	-	Kelvin
kg/m^3	-	Kilogram per cubic meter
mm/rev	-	Millimeter per revolution
N	-	Newton
kW	-	Kilowatt
rpm	-	Revolution per minute
Nm	-	Newton meter
L/min	-	Liter per minute
HRC	-	Rockwell C hardness
HV	-	Vickers hardness
MPa	-	Megapascal

W/ m/K	-	Watts per meter per kelvin
J/ g.K	-	Joule per gram per kelvin
GPa	-	Gigapascal
Psi	-	Pound per square inch

LIST OF PUBLICATIONS

Journal

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CHAPTER 1

INTRODUCTION

This chapter describes the background of the study and briefly explains the problem statement, objectives, scope and significance of the research.

1.1 Research background

Nowadays, the demand for super-alloys of titanium alloy has been increased day by day because of the large utilization in the industries sector. These materials are extensively used in aerospace, medical instrument, and automotive because of their high specific strength (strength-to-weight ratio), which is retained at elevated temperatures, as well as their fracture resistance and exceptional corrosion resistance (Ramesh et al., 2012; Sartori et al., 2017). Besides, these materials give a superior challenge to some machining operation like turning, drilling and milling, as well as a high temperature producing during machining. These materials are well known to be difficult to machine material (Ezugwu, 2005; Elshwain et al., 2013). According to Che-Haron and Jawaid (2005), the machinability of titanium and other titanium alloy is generally known as poor owing because of the existence of some inherent properties of materials. In fact, this material was low thermal conductivity and high chemical reactivity with cutting tool materials. The properties of titanium alloy with low thermal conductivity causes the temperature to increase at the cutting edge of tool. Due to that, the tool will wear out very fast and hence poor surface finish is generated.