SURFACE INTEGRITY EVALUATION ON TITANIUM ALLOY AFTER EDM MACHINING USING DIFFERENT GRAPHITE ELECTRODES

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical - Advanced Manufacturing Technology)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

MAY 2010

DEDICATION

First of all, all the praises and thanks be to Allah S.W.T for His Love,
This thesis is dedicated to my family,
To my beloved parent, Mat Jusoh Bin Latif & Siti Sarah Bt Daud.
My wife, Suriyati Bt Idris.
My daughters, Nur Alya Maisarah and Nur Ain Madiihah.
And last but not least to all my relatives and my close friends.
Thank you very much for your unstinting help and encouragement
May Allah bless all people that I love.
Sorry if I forgot to mention any name.

ACKNOWLEDGEMENT

I would like to thank Allah Almighty for blessing me and giving me strength to accomplish this thesis. In particular, I wish to express my sincere appreciation to my thesis supervisor, Assoc. Professor Dr. Izman Bin Sudin from Universiti Teknologi Malaysia for encouragement, guidance, critics and friendship.

I am indebted to my parents, Mat Jusoh Bin Latif and Siti Sarah Bt Daud, my wife, Suriyati Bt Idris, my daughters, Nur Alya Maisarah and Nur Ain Madiihah, my brother and sister, Siti Faridah, Mat Rahim, Aziz, Mohd Zulkifli, Siti Azizah, Nurul Azira and Mohd Anuar, without whose help, encouragement and patience I would never have gotten this thesis completed and who made it all worthwhile.

Many thank to Reazul Haq from UTHM and all of the technicians from UTM and UTHM especially Mr. Tarmizi and Mr. Anuar, Technicians in Advance Manufacturing Laboratory (UTHM), Mr. Ayub Technician in Material Science Laboratory (UTM) and other technical staff for their cooperation and assisting me in the various laboratory tasks. I am also grateful to my fellow postgraduate students should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space.

Finally, thank you to MARA and all the other people who have supported me during the course of this work. Thank You!

ABSTRACT

The quality of an EDM product is usually evaluated in terms of its surface integrity, having these specific characteristic like the surface roughness, existence of surface cracks and residual stresses. Many process variables affect the surface integrity such as Pulse Duration, Peak Current, Open Gap Voltage and electrode Polarity. Other than that, material properties of the tool electrode, workpiece and dielectric liquid in fact even the size of the electrode affects the surface integrity. The purposes of this study are to investigate the influences of the parameters involved in EDM especially on the machining characteristics, namely recast layer (white layer), heat affected zone, surface topography, micro cracks and voids on the titanium alloys using POCO 3 and POCO C3 as an electrode. The specimens were examined using Optical Microscope (Zeiss), Scanning Electron Microscope (SEM) XL-40 with EDAX analysis and X-Ray Diffraction (Siemens - D5000). The Full Factorial Design of Experiment (DOE) approach was used to analyze the effect of each parameter such as Pulse ON (ON), Pulse OFF (OFF), Peak Current (IP) and Servo Voltage (SV) on the EDM machining characteristics. In general, the Peak Current and Pulse ON have the most significant effect to the responses studied. EDMed with POCO 3 gives the better results compared to POCO C3 in term of recast layer thickness and in contrary with the HAZ thickness. The mathematical models for average recast layer thickness and average heat affected zone thickness were developed to predict the effects within the factors investigated.

ABSTRAK

Kualiti sesuatu produk yang dihasilkan oleh proses EDM biasanya dinilai berdasarkan kepada integriti permukaannya yang dicirikan kepada kekasaran permukaan, keretakan permukaan dan tegangan sisa yang terbentuk. Terdapat beberapa pembolehubah yang mempengaruhi integriti permukaan, sebagai contoh, tempoh denyut (ON), masa rehat (OFF), voltan dan kekutuban elektrod. Selain itu, sifat elektrod, bahan kerja dan cecair *'dielectric'* dan saiz elektrod juga mempengaruhi integriti permukaan. Tujuan utama kajian ini adalah untuk mengkaji faktor-faktor yang terlibat dalam pemesinan EDM bagi respons seperti lapisan tuangan semula (RL), zon kesan daripada haba (HAZ), topografi permukaan, keretakan kecil dan ruang kosong pada titanium aloi yang telah dimesin dengan menggunakan POCO 3 dan POCO C3 sebagai elektrod. Spesimen tersebut diperiksa dengan menggunakan Mikroskop Optik (Zeiss), *Scanning Electron Microscopy* (XL40) dengan analisis EDAX dan *x-ray diffraction* (Siemens - D5000). *Full Factorial Experiment* (DOE) adalah pendekatan yang digunakan untuk menganalisis kesan daripada setiap parameter seperti tempoh denyut (ON), masa rehat (OFF), arus puncak (IP) dan voltan servo (SV) terhadap pemesinan. Secara umumnya, arus puncak (IP) dan tempoh denyut (ON) merupakan pembolehubah yang sangat mempengaruhi respons yang dikaji. POCO 3 memberikan hasil yang lebih baik berbanding dengan POCO C3 bagi lapisan tuangan semula (RL) dan sebaliknya berlaku kepada HAZ. Model matematik dibangunkan bagi menilai anggaran kesan kepada lapisan tuangan semula dan HAZ bagi julat faktor yang telah dikaji.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Al	-	Aluminium
ANOVA	-	Analysis Of Variance
C	-	Carbon
EDAX	-	Energy Dispersive X-Ray Spectroscopy
EDM	-	Electro Discharge Machining
ARLT	-	Average Recast Layer Thickness
AWLT	-	Average White Layer Thickness
EWR	-	Electrode Wear Rate
HAZ	-	Heat Affected Zone
MRR	-	Material Removal Rate
SEM	-	Scanning Electron Microscopy
SR	-	Surface Roughness
ON	-	Pulse On Time (Pulse Duration)
OFF	-	Pulse Off Time (Pulse Interval)
IP	-	Peak Current
SV	-	Servo Voltage
Ti	-	Titanium
XRD	-	X-Ray Diffraction
θ	-	Angle
Ø	-	Diameter
μ	-	Micro
Ω	-	Ohm

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Machining is one of the most important processes in manufacturing. There are two types of machining processes; traditional machining and non-traditional machining.

The traditional also known as conventional machining requires the presence of a tool that is harder than the workpiece to be machine and this tool should penetrate the workpiece into a certain depth. Moreover, a relative motion between the tool and workpiece is responsible for forming or generating the required shape. Without of these elements such as the absence of tool – workpiece contact or relative motion makes the process a nontraditional one.

The expectations from present day manufacturing industries are very high in term of high economic manufacturing with high performance precision and complex parts made of very hard high strength materials. Every customer demands products to suit their own taste or choice; there is a need for high-quality low-cost parts made in small batches and large variety (Jain, 2002). Furthermore, there is a trend in the market for miniaturization of parts with high degree of reliability.

The traditional machining methods, even with added CNC features, are unable to meet such stringent demands of various industries such as aerospace, electronics, automobiles, *etc*. As a result, a new class of machining processes has evolved over a period to meet such demands, named non-traditional, unconventional, modern or advanced machining processes (Jain, 2002, Benedict, 1987, McGeough, 1988). These advanced machining processes (AMP) become still more important when one considers precision and ultra-precision machining. In some AMPs, materials were able to remove even in the form of atoms or molecules individually or in groups. These advance machining processes was base on the direct application of energy for material removal by mechanical erosion, thermal erosion or electro-chemical / chemical dissolution.

Developments in materials science have led to the evolution of difficult to machine, high-strength temperature-resistant materials with many amazing qualities. Nano-materials and smart materials are the demands of the day. To make different products in various shapes and sizes, traditional manufacturing techniques are often founds not fit for that purposes. One needs to use non-traditional or advanced manufacturing techniques in general and advanced machining processes in particular (Jain, 2002).

The search for new, lightweight material with greater strength and toughness has led to the development of new generation of materials, although their properties may create major challenges during machining operations. Having greater hardness and reinforcement strength, these materials are difficult to machine by the traditional methods. Although these materials can be machine conventionally, sub-surface damages such as metallurgical alterations, work hardening, micro cracks and others can occur under certain circumstances that cause a damaging effect on the performance of the machined component.

Titanium alloys are generally use for a component that requires the greatest reliability and then the surface integrity must be maintained. Therefore, when machining any component it is essential to satisfy surface integrity requirements (Harun and Jawaid, 2005).

The conventional machining processes are sometimes unable to provide good machining characteristics on titanium alloys. The non-conventional machining such as electric discharge machining (EDM) and laser machining were consider one of the best ideal techniques in dealing with these materials.

EDM electrodes are manufacture in variety of forms depending on the EDM electrode materials used and the application. Copper is a common base material and used as electrode because it is highly conductive and strong. A copper zirconium diboride electrode is similar to a copper tungsten electrode, but has much higher erosion resistance and is more expensive to produce. Other EDM electrode materials include graphite, silver, and molybdenum. A metal graphite electrode is the most common type of EDM electrode because it is easily too machined, has high wear resistance and operating temperature capabilities, and is cost effective. A molybdenum electrode is typically use for special applications, such as small electrodes or EDM wire designed for high strength and arc erosion resistance. A silver tungsten electrode may be use in deep slot applications that function under poor flushing conditions. Tungsten has a high melting point, which makes it a useful EDM electrode material in combination with more conductive metals. Tungsten carbide and other metal carbides were use for EDM electrode materials because they have high hardness qualities and are wear-resistant.

1.2 Background of Problem

Titanium alloys have been found to have a very wide application area such as aerospace especially in jet engine and airframe components, automotive, medicine and dentistry due to their excellent corrosion resistance, lightweight and mechanical properties (Ezugwu, 1997). These metals would have been difficult to machine by conventional methods, but EDM has made it relatively simple to machine intricate shapes that would be impossible to produce with conventional cutting tools (Lee, 2003). The machinability of titanium and its alloys is consider rather poor due to several inherent properties of materials. Poor thermal conductivity, chemically reactivity and low elastic modulus are the common problems. EDM does not make direct contact between the electrode and the workpiece where it can eliminate mechanical stresses chatter and vibration problems during machining. Materials of any hardness can be cut as long as the material can conduct electricity (Hascalic, A., and Caydas, U., 2007). Hence, titanium, although difficult to cut material can be machined effectively by EDM (Wang, C.C., and Yan, B.H., 2000).

The overall research of machining process is to study the interaction of the cutting parameter and the workpiece in order to optimize the cutting conditions and maximize the product quality. Many researchers have actively tried to carry out the innovative research work with the main objectives such as tool life, material removal rate, cutting force etc. However, less attention given to improve the surface quality especially in the heat affected zone layer. In this case, the selection of EDM parameters is important in determining the accuracy and surface finish obtained for a particular application.

For the past years, there are researches and developments have being carried out to develop a new type of graphite with improve features. One of them is mixing copper into graphite or known as copper-graphite. This new type of electrode may contribute to a better result in machining titanium as other electrodes are less effective to do so. It is claim that the performance of these new graphite supposed to be much better compared to the earlier type of graphite. The aim of this study is fulfilling a detailed investigation of electrical discharge machining characteristic of titanium alloys Ti6Al4V in relation to process parameters and different graphite electrode materials.

1.3 Research Statement

Electrical Discharge Machine of materials using a new type of graphite electrode will improve the machining characteristics.

1.4 Problem Statement

Does POCO EDM-C3 (graphite infiltrated with copper) perform better in terms of Surface Integrity of titanium alloys (Ti-6Al-4V) compared to POCO EDM 3?

1.5 Objectives of Study

The objectives of this study were:

a) To investigate the effect of the different graphite electrodes on the surface integrity such as Recast Layer, Heat Affected Zone, Surface Topography, Micro-cracks and Void of machined titanium alloy.
b) To determine the significance of EDM parameters that affect machined surface integrity.

1.6 Scopes of Study

The scopes of study were limited to the following:

i. The types of graphite electrodes under study were limited to POCO EDM 3 and POCO EDM-C3 only.
ii. The work material used in this study was limited to Ti-6Al-4V.
iii. The surface integrity under investigation includes Recast Layer, Heat Affected Zone, Surface Topography, Micro-cracks and Void.
iv. The equipments used to analyse surface integrity were limited to Optical Microscope, Scanning Electron Microscope (SEM) with EDAX and X-Ray Diffraction (XRD) analysis.
v. The machining parameters to vary were servo voltage, peak current, pulse ON time and pulse OFF time.
vi. Design of Experiment (DOE) tool was used for analysis of recast layer (RL) and heat affected zone (HAZ).