Faculty of Manufacturing Engineering

ELECTRICAL DISCHARGE MACHINING OF TITANIUM ALLOY (TI-6AL-4V) USING VARIOUS TYPES OF ELECTRODES

Izyan Dayana Binti Jonid

Master of Manufacturing Engineering

(Manufacturing System Engineering)

2019

ELECTRICAL DISCHARGE MACHINING OF TITANIUM ALLOY (TI-6AL-4V) USING VARIOUS TYPES OF ELECTRODES

IZYAN DAYANA BINTI JONID

A thesis submitted
in fulfilment of the requirements for the degree of Master of Manufacturing Engineering (Manufacturing System Engineering)

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled "Electrical Discharge Machining of Titanium Alloy (TI-6AL-4V) using Various Types of Electrodes" 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 : IZYAN DAYANA BINTI JONID

Date :

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing System.

Signature :

Supervisor Name : PM. DR. LIEW PAY JUN

Date :

DEDICATION

This thesis is dedicated to

My beloved father and mother,

family and all my friends who encourage and support me.

ABSTRACT

Electrical Discharge Machining (EDM) is generally used in industry for machining high strength steel, tungsten carbide and hardened steel. EDM machining is also known as a spark erosion machining process. Titanium alloy is usually used in aerospace, automobile, spacecraft, gas turbine engine, medical and marine industry. The titanium alloy has a high strength and excellent corrosion resistance compared to aluminum, brass, and steel. However, the titanium alloy is a hard to cut material which difficult to be machined by using traditional machining process. Therefore, electrical discharge machining (EDM) was proposed in this study to machine titanium alloy. The main purpose of this research is to optimize the EDM machining of titanium alloy using various types of electrodes, such as copper, tungsten and copper-carbon nanofiber composite. In this experiment, the effect of different electrodes on the surface roughness (SR), tool wear rate (TWR) and material removal rate (MRR) were investigated. During the experiment, the value for machining parameters such as peak current and pulse on time were varied whilevoltage and pulse off time were remained constant. DOE was used to generated all the factors automatically. The data obtained in this experiment was analyzed using ANOVA. At the end of experiment, the optimum electrode that can improve the material removal rate (MRR) was copper carbon nanofiber (Cu-cnf) electrode, tool wear rate (TWR) and surface roughness (SR) was copper (Cu) electrode.

ABSTRAK

Pemesinan Nyahcas Elektrik (EDM) biasanya digunakan dalam industri untuk pemesinan keluli kekuatan tinggi, karbida tungsten dan keluli keras. Pemesinan EDM juga dikenali sebagai proses pemesinan hakisan percikan. Aloi titanium biasanya digunakan dalam aeroangkasa, kereta, kapal angkasa, enjin turbin gas, industri perubatan dan laut. Aloi titanium mempunyai kekuatan tinggi dan ketahanan kakisan yang sangat baik berbanding aluminium, tembaga, dan keluli. Walau bagaimanapun, aloi titanium adalah sukar untuk memotong bahan yang sukar diproses dengan menggunakan proses pemesinan tradisional. Oleh itu, pemesinan nyahcas elektrik (EDM) telah dicadangkan dalam kajian ini untuk pemesinan ke atas aloi titanium. Tujuan utama penyelidikan ini adalah untuk mengoptimumkan pemesinan EDM ke atas aloi titanium menggunakan pelbagai jenis elektrod, seperti tembaga, tungsten dan komposit nanofiber tembaga-karbon. Dalam eksperimen ini, kesan elektrod yang berbeza pada kekasaran permukaan (SR), kadar pakai alat (TWR) dan kadar penyingkiran bahan (MRR) telah disiasat. Semasa eksperimen, parameter pemesinan seperti puncak voltan dan masa naik denyut mempunyai pelbagai nilai manakala puncak voltan dan masa naik denyut tidak berubah. DOE digunakan untuk menjana semua factor yang digunakan secara automatik. Data yang diperolehi dalam eksperimen ini dianalisis menggunakan ANOVA. Pada akhir eksperimen, optimum elektrod yang dapat meningkatkan kadar penyingkiran bahan (MRR) adalah tembaga bertetulang gentian nano karbon (Cu-cnf), kadar pakai alat (TWR) dan kekasaran permukaan (SR) aloi titanium dapat ditentukan dengan menggunakan elektrod tembaga(Cu).

ACKNOWLEDGEMENT

First and most of all, I would like to give a special thanks to PM. Dr. Liew Pay Jun, for her expertise, assistance, guidance and patience throughout the process of the experiment and writing this thesis. Without your help this project and thesis would be not have been possible.

I also would like to express my deepest gratitude to all the technicians in Faculty of Manufacturing Engineering and Faculty of Engineering Technology for their assistance and guidance in the entire lab.

I would like to extend my sincere gratitude to all the lecturers in Faculty of Manufacturing Engineering to make my time valuable and for the numerous ways they helped me to finish this master program.

Last of all, I would like to express my wholehearted thanks to my family, all my colleagues, and everyone else who helped contribute to this project and thanks for being with me all along my master journey. Thanks for their generous support along the way of doing my thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

TWR	-	Tool wear rate
SR	-	Surface roughness
MRR	-	Material removal rate
ANOVA	-	Analysis of variance
CU-CNF	-	Copper carbon nanofiber
EDM	-	Electrical discharge machining
DOE	-	Design of experiment
RSM	-	Response surface methodology
CCD	-	Central composites design
BBD	-	Box behnken design
CU	-	Copper
W	-	Tungsten

LIST OF SYMBOLS

A	-	Ampere
V	-	Voltage
I	-	Current
Ton	-	Pulse on time
Toff	-	Pulse off time
tm	-	time machining
Wa	-	Workpiece weight after machining
Wb	-	Workpiece weight before machining
Ea	-	Electrode weight after machining
Eb	-	Electrode weight before machining

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Electrical Discharge Machining (EDM) is generally used in industry for machining high strength steel, tungsten carbide and hardened steel. EDM machining is also known as a spark erosion machining process. In this process, the material is removed by controlled erosion through a series of electric sparks between the tools or known as an electrode and the workpiece. Normally, the tool is set as a cathode and workpiece as an anode. During the process, voltage is supply to the servo motor and it is used to control the gap between an electrode and workpiece. When the voltage applied, the heat is discharge between the gaps due to the collision of the electron. Then the spark is generated and due to the high heat, the material will be melted and vaporized. The melted material is splash away by a dielectric fluid (Choudhary and Jadoun, 2014).

There are two main types of EDM, which are die sinking machine and wire cut machine. EDM die sinking machine is a thermal process which the spark erosion is generated by a voltage supply on the servo motor (Garg, 2010). During the process, both of an electrode and workpiece must be submerged in dielectric fluid. While in Wire Cut EDM the material is eroded from the workpiece with a series of discrete spark occurring between the workpiece and the wire separated by the dielectric fluid flow. It is continuing to be fed into the machining zone. The thin wire is known as an electrode and it was feed on the workpiece. Brass, copper, and tungsten are normally used as an electrode. In WDM, water

is usually used as a dielectric medium. The workpiece also must be submerged into the dielectric during the machining processed (Garg, 2010).

The dielectric fluid is one of the important elements need to be considered during the machining process. There are several types of dielectric fluid use in die sinker machine which are kerosene, EDM oil, paraffin, white spirit and deionized water (Jeevamalar, 2015). The dielectric fluid is act as an insulator medium that used to remove the erode particles and it also will influence the machining performance. The material of both workpiece and electrode must have electrical conductivity to get the finest machining performance. The electrode is commonly categorized into metallic, non-metallic and combination. Besides, the election of the electrode must consider their conductivity, resistance, and capacity.

Inagaki *et al.* (2014) stated that titanium alloy is a good material that usually used in aerospace, automobile, spacecraft, gas turbine engine, medical and marine industry. The titanium alloy has a high strength compared to aluminum, magnesium, and steel nickel alloy. It also has an excellent corrosion resistance compared to aluminum, brass, and steel. However, the titanium alloy is hard to cut material which difficult to be machined by using traditional machining process.

Therefore, in this study, EDM die sinking is proposed to machine titanium alloy, owing to its advantages such as low installation cost and ability to machine complex three-dimensional shapes easily regardless of material hardness (Reynaerts *et al.* 1998). The major consideration of this experiment is to optimize the EDM die sinking machining with concerning the output response that consists of surface roughness tool wear rate and material removal rate of titanium alloy. In this study, the significance setting on the EDM die sinking are on their pulse duration, voltage and peak current.

1.2 Problem Statement

Nowadays implementation of composite material in aerospace was increased but the demand for monolithic alloy such as titanium could not be reduced. In industry, titanium alloys have been used extensively in many areas such as automotive, aerospace, petroleum and biomedical because of the good strength to weight ratio and high corrosion resistance of their guests (Pramanik and Littlefair, 2015). However, to machine titanium alloy it needs a high cost. Titanium alloy has low thermal conductivity and will cause high temperature during machining process and high tool wear.

Machining the titanium alloy is very difficult due to its properties. During the processing of titanium alloy using conventional methods, higher tool wear and lower surface quality are frequently observed phenomenon, due to their higher strain hardening effect, pseudoelastic behavior and high toughness (Manjaiah *et al*. 2013).

Therefore, in this research, EDM die sinking is proposed to machine titanium alloy. The purpose of this research is to optimize the EDM machining of titanium alloy using various types of electrodes since it is hard to encounter a good machining performance. In this experiment, the surface roughness, tool wear rate and material removal rate (MRR) will be investigated.

1.3 Objectives

The main objectives of this study are as follow:

i. To investigate the effect of EDM parameters (current and pulse on time) and types of electrodes on the machining performances towards MRR, TWR and SR of titanium alloy.
ii. To determine the optimum parameters that can maximize the machining performance of titanium alloy.
iii. To determine the optimum electrode that can maximize the EDM machining efficiency of titanium alloy.

1.4 Scope of the study

In this experiment, the EDM die sinker machine was used to machine titanium alloy. Three different types of the electrode were used, which are copper, tungsten and copper-carbon nanofibers composite electrode (Cu-CNF), and titanium alloy selected as the workpiece. In this study, pulse on time, pulse off time, peak current, and voltage were used as control parameters. The material removal rate, tool wear rate and surface roughness will be investigated.

1.5 Significance of the study

The significance of this study is to understand the machining behavior regarding the die sinker machine which is imperatively needed for the benefit of industry and research community. This research is aims to suggest the optimum electrode towards surface roughness, tool wear rate (TWR) and material removal rate (MRR). These are several contributions involve in this research:-

i. The suggestion of optimum electrode for machining titanium alloy will contribute to the best performance to the tool wear.

ii. Reduce the machining cost and time processing to machined titanium alloy.

iii. The industry got the solution to machined titanium alloy with efficient results.

1.6 Research Activity

Gantt chart for the research is shown in appendix A

CHAPTER 2

LITERATURE REVIEW

2.1 Electrical Discharge Machining (EDM)

Electrical Discharge Machining (EDM) has its capability to produce precise and unique shapes. EDM machine is also known as spark erosion which it can machine the difficult and complex shapes. In industries, EDM has been used for manufacturing processes (Jahan, 2015). Basically, the EDM machine can be categorized into two types which are Wire cut EDM and Die Sinker EDM. There are many components in EDM process such as a workpiece, tool electrode, dielectric fluid, servo system, power supply, and the DC pulse generator.

Choudhary and Jadoun (2014) stated that Electrical Discharge Machining (EDM) also known as non-traditional machining because there is no physical cutting forces or contact between the tool and the workpiece. In EDM machining process, thermal energy is used for high precision metal removal process through the spark in between workpiece and electrode to erode the workpiece.

In EDM machining process, the workpiece must be submerged in dielectric fluid and the material of workpiece must be electrically conductive. EDM machine has varied application in the production of die cavity with large components, deep small diameter hole and various intricate holes and another precision part (Choudhary and Jadoun, 2014). In EDM there are two parameters need to be considered which are known as process parameter and performance parameter. The distance between electrode and workpiece is an important parameter that needs to be considered in this machine during discharge. The

electrical discharge in this machining is generated due to the high heat occur during the process and the electrical discharge has spark erosion.

Dhirendra *et al.* (2014) stated the spark erosion is a metal removal process using electric current and it is generated in the machining in between 8000 to 12000-degree celsius. The spark erosion has no mechanical abrasion and the process of spark erosion begin with transform electrical energy into heat and initiates a melting process within the electrodes. While servo motor is one of the components in EDM machine and it is to control and maintain the spark gap between the tool and workpiece. Spark erosion in machining process is a good concept because it is possible to achieve the desired design easily.

In this machining process, the complicated sections or weak materials also can be worked on without any distortion because of there has no direct contact between tool and workpiece. Most of metals and alloys material can be machined with EDM and it must have a minimum electrical conductivity of 0.1S/cm (Choudhary and Jadoun, 2014).

2.1.1 Working Principles of EDM

Electrical Discharge Machine (EDM) is used for metal removal. The process of EDM is well known as electrical spark erosion which is the material was removed by the spark that generated by voltage and current from servo motor in the machine. The main component in EDM machine is servo motor, tool electrode, workpiece, and dielectric (Dhirendra *et al.* 2014). Figure 2.1 shows the working principle of EDM. The spark erosion in EDM will burn a small hole on a piece of metal through which it contacts and it is similar as an electric spark. The metal is removed by an erosion and evaporation during the spark erosion. It is because the heat produced that generated by a spark. The conductive material was used in EDM machining process for both of the workpiece and electrode to

ensure the results of machining process is fine. Figure 2.2 shows the complete cycle of EDM process.

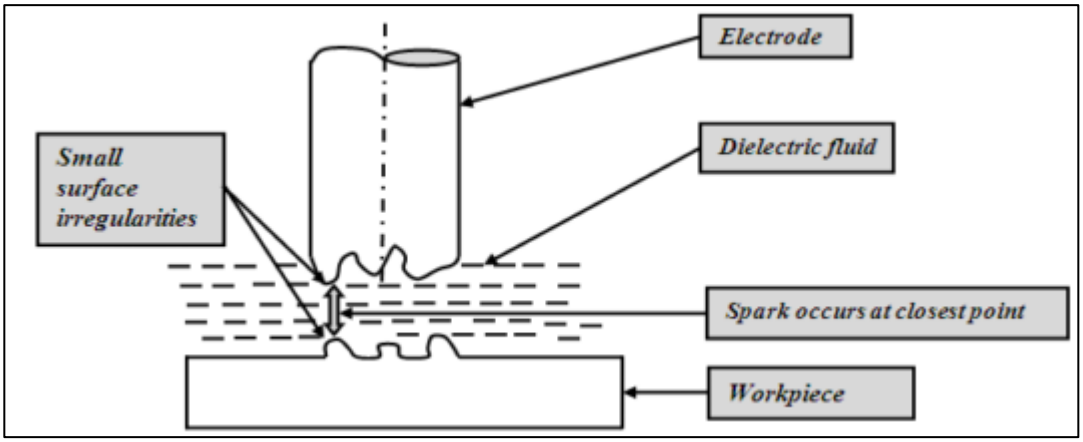

Figure 2.1: Working Principle of EDM (Ojha *et al.* 2010)

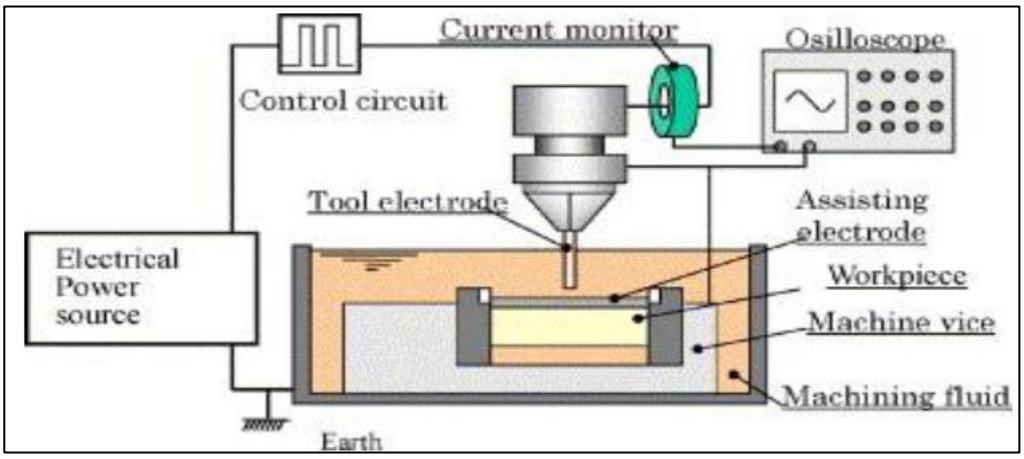

Figure 2.2: Complete EDM Process Representation (Dhirendra *et al.* 2014)

Garg *et al.* (2010) stated that thermoelectric energy concept is used in the working principle of EDM. The thermoelectric energy or known as the spark is formed in between of an electrode and a workpiece. During the process, a workpiece must be immersed in a dielectric for conduction of an electric current. There is no direct contact between the

workpiece and an electrode and it is known as a spark gap. The pulse duration is considered in the gap and filled with an insulating medium. The selected of dielectric in this machining is important to ensure the machine obtain a precision machining and must be selected the dielectric that can minimize the gap between workpiece and electrode.

2.2 Types of EDM

There are several types of Electrical Discharge Machine (EDM) but the main type of EDM are Die Sinker EDM and Wire Cut EDM (WEDM). EDM can be used for hard material and high-temperature alloy. However, the material used in this machining must be a conductive material.

2.2.1 Die Sinker EDM

The Die Sinker EDM is known as cavity EDM or volume EDM that consists of an electrode and workpiece submerged in an insulating fluid or dielectric fluid such as, extra typically, oil, deionized water or other dielectric fluid. During the process, the electrode and workpiece are mounted and connected to the supply voltage then the current will flow. The machining will be automatically on and off based on the parameter setting. The main component in die sinker machine is servo motor, an electrode, the workpiece and dielectric fluid. The most common types of applications for EDM is die making. Dies are tools used to cut or shape materials into a solid product. EDM is used to create these dies, despite the size or commonness of the shape needed. The other application is mould making in which the moulds are containers that transform liquid or substance into the shape of the container. A moulds dimension and depth is achieved with the use of EDM. Another application is small hole drilling which can drill small holes easier. The ability of EDM to create small shapes accurately makes it ideal for drilling the exact size of holes needed. In order to