UNIVERSITI TEKNIKAL MALAYSIA MELAKA

A STUDY ON THE QUALITY OF MICRO HOLE MACHINING OF TUNGSTEN CARBIDE BY EDM PROCESS

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

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) with Honours. The member of the supervisory committee is as follow:

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ABSTRACT

This paper describes the study of the quality of micro-hole electrical discharge machining (EDM) of tungsten carbide by using copper electrode. The EDM process is a thermal machining process, which the conductive workpiece is melted through repetitive sparks generate through ignition and cut off of voltage and current. The micro-EDM is gaining popular in recent years due to its advantages in machining micro-hole of hard and brittle material such as ceramic due to its non contact machining process. Through this study, the parameters such as peak current, pulse duration, electrode polarity and flushing were investigated. The setup of the experiment was based on the design of experiment (DOE) method. Response surface methodology (RSM) was used to generate the experiment matrix in this study in order to minimize the runs of experiment. The totals of 26 runs were done by manipulating the parameters (peak current, pulse duration and flushing). Then, the quality of the micro-hole machined by using micro-EDM was investigated based on the surface roughness (SR) of the micro hole and the thickness of heat affected zone (HAZ). Based upon the experimental results, that surface roughness of machined surface and HAZ thickness were influenced by pulsed current, pulse duration and flushing. Lower peak current, pulse duration with flushing produces finer surface finish. The optimum parameter in order to obtain finest surface is 4.5A peak current, 5μs pulse duration with flushing, which result to 1.264μm surface roughness. Besides that, higher peak current, pulse duration without flushing produced higher HAZ thickness.

ABSTRAK

Kertas ini membentangkan satu kajian tentang qualiti lubang bersaiz mikro dengan menggunakan teknologi *electrical discharge machining* (EDM) ke atas *Tungsten Carbide* dengan menggunakan elektrod kuprum. Process EDM ialah salah satu *thermal machining process*. Pengalir elektrik akan dileburkan semasa proses pemotongan dengan bunga api yang dihasilkan daripada penjanaan voltan dan arus sebaik sahaja voltan melebihi kekuatan dielektrik cecair di antara elektrod dengan bahan. Kini, EDM bermikro size telah menjadi lebih popular disebabkan kebolehanya untuk memotong bahan yang keras dan rapuh tanpa penyentuhan antara elektrod dengan bahan. Dalam kajian ini, pembolehubah seperti *peak current*, *pulse duration* dan *flushing* telah dikaji. Eksperimen ini telah dijalankan dengan menggunakan teknik *design of experiment* (DOE). *Response surface methodology* (RSM) diaplikasikan untuk mendapatkan matrik eksperimen. 26 kali eksperimen telah dijalankan dengan memanipulasikan pembolehubah (*peak current, pulse duration, electrode* dan *flushing*). Selepas itu, lubang bermikro size itu dikaji dalam aspek kekasaran permukaan (SR) dan ketebalan *heat affected zone* (HAZ). Berdasarkan kajian eksperimen yang telah dibuat, kekasaran permukaan dan ketebalan HAZ telah dipengaruhi oleh *peak current, pulse duration, electrode* dan *flushing*. Permukaan yang lebih licin boleh didapati dengan menggunakan *peak current* dan *pulse duration* yang rendah dengan *flushing*. 4.5A *peak current*, 5µs *pulse duration* dengan *flushing* telah menghasilkan permukaan yang paling licin, iaitu 1.264µm. Selain itu, ketebalan HAZ yang lebin tebal boleh didapati dengan menggunakan *peak current* dan *pulse duration* yang tinggi tanpa *flushing*.

DEDICATION

For my Father & Mother

Chua Leong Bee & Cheah Yoke Chun

in gratitude

and to

A youngest brother

Chua Ka Chun

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LIST OF ABBREVIATIONS

2FI	-	Two Factor Interaction Model
ANOVA	-	Analysis of Variance
ASTM	-	American Society for Testing and Materials
C. V.	-	Coefficient of Variance
Cu	-	Copper
DC	-	Direct Current
df	-	Number of Degrees of Freedom
DOE	-	Design of Experiment
DVEE	-	Diameter Variation between Entrance and Exit
EDM	-	Electrical Discharge Machining
EWR	-	Electrode Wear Rate
F	-	F Test (ANOVA)
HAZ	-	Heat Affected Zone
HCL	-	Hydrochloric Acid
HNO_3	-	Nitric Acid
HOAc	-	Acetic Acid
HV	-	Hardness Vickers
L	-	Lack of Fit Score
M	-	Sequential Model Sum of Squares Score
MRR	-	Material Removal Rate
NC	-	Numerical Control
PRESS	-	Predicted Residual Sum of Squares
Prob	-	Probability
RSM	-	Response Surface Methodology
RWR	-	Relative Wear Rate
SEM	-	Scanning Electron Microscopy
SR	-	Surface Roughness
WC	-	Tungsten Carbide

CHAPTER 1

INTRODUCTION

This chapter section contains the introduction of the electrical discharge machining (EDM), problem statement, objectives, scope, importance of study and expected result on this project.

1.1 Introduction

EDM, also known as Electrical Discharge Machining is a non-traditional machining process, which is greatly applied in the manufacturing sector. This advance machining process has taken the important role in the human technology development in machining the superior hardness material, which unable to be done by conventional machining process such as milling, turning and drilling. Fallbohmer *et al.* (1996) surveyed applications of the EDM process and pointed out that almost 90% of mold and die makers employed that EDM process to finish the products in USA, Germany and Japan.

This technology had been invented by two Russian scientists, who are Dr. B.R. Lazarenko and Dr. N.I. Lazarenko in 1943. After 37 years of development of this technology, a Japan scientist named Makino in Japan had successfully integrated the EDM process with the numerical controlled (NC) system in 1980. By using the NC system, the machining process can be done more reliability and higher productivity.

Kalpakjian and Schmid (2006) have stated that electrical discharge machining (EDM) is based on the erosion of metal by spark discharges. A basic die-sinker EDM system consists of a shaped electrode and the workpiece connected to a DC power supply and placed in a dielectric fluid. During the machining process, the movement of the workpiece and electrode is controlled by a servo motor, which is connected to the numerical controller (NC) system. As the gap between the electrode and the workpiece is sufficiently small, the current will create an ionized channel in the gap. Then, the spark is broken down and this made the ionized channel collapse very quickly. This has transfer a sufficient energy to melt the workpiece and the molten metal on the surface of the material evaporates explosively, forming a small crater. Finally, the eroded metal is flushed away by the dielectric fluid and the processes are repeated until the shaped is formed.

In the past, the electrical discharge machining can only be done to machine large part. In 20^{th} century beyond, there is a new trend of the EDM development towards micro machining in order to machine the parts with micro size texture and hole. The reason leads to this trend is gaining popularity is due to the recent advancement in micro-electro mechanical system according to Lim *et al.* (2003).

As development of human technology, the reduction of product size is highly advantageous in order to suite the product with multi functional purpose, more compact and easy to carry. Hence, the EDM process plays an important role to machine these micro parts due to its advantages in higher precision and capability in machining high hardness, strength and brittle part. This leads to the great advantage in machining the new hard material such as tungsten carbide, titanium alloy, nickel alloy and powdered metallurgy steel.

Among these hard materials, tungsten carbide is the most popular material due to its wide range of applications from machining tools, aerospace, military, medical, sport to domestic product for consumer as listen in Table 1.1.

Table 1.1: Applications of tungsten carbide in various sectors

Sector	Application
Machine Tool	Tungsten carbide tool and insert
Aerospace	Nozzle body, Fuel inlet fitting
Military	Armor-piercing ammunition and shell
Medical	Surgery Equipment
Consumer product	Ink jet nozzles in printer cartridge

1.2 Background of problems

In military sector, the expert tends to design the missile to be smaller size so that the penetration power can be focused and higher to destroy the object such as armored tank and concrete wall. This armor-piercing ammunition is normally made by tungsten carbide and other alloy due to its extreme hardness and advantage in penetration. On the structure of the missile, there are lots of parts in micro size so that it is highly sensitive. This has lead to important role in micro machining to machine these hard materials into precise and accurate parts.

Besides that, in aerospace sector, the nozzle body and fuel inlet fitting is also designed with micro size hole. Hence, the machining process is very important in fabricate these components so that it have the excellent surface quality besides having good accuracy and precision. This is due to the rougher surface will generate higher wall friction between the fuel and the nozzle and this will decrease the efficiency.

By referring to the problems stated above, there is very essential to study the parameters, which can affect the quality of the micro hole machined by using die-sinker EDM. Hence, this project is very important to determine the best parameters in machining product with good surface quality of the micro hole with diameter of 500µm on tungsten carbide by using die sinker EDM.

1.3 Objectives

The objectives of this project are to:

1. Study the effect of using different machining parameters (peak current, pulse duration and flushing) to the responses of surface roughness and thickness of heat affected zone by EDM process.
2. Determine the optimum parameters to obtain finest surface roughness in micro-hole EDM by using Response Surface Methodology (RSM).

1.4 Scope

This project includes manipulating of the machining parameter of EDM such as peak current, pulse duration and with/without jet flushing. The type of electrode is copper and the material is tungsten carbide, WC. This project studied the effect of the responses of surface roughness (SR) and the thickness of the heat affected zone (HAZ), machined by different parameters. The responses will then be measured and inspected by using surface roughness tester and optical microscopy. The optimization in this study was only being done to surface roughness. Along this project, the design of experiment (DOE) was applied together with response surface methodology (RSM).

1.5 Importance of Study

This project is very important to the operating of the die sinker EDM process in order to run the machining process in most effective way to get the best surface finish by manipulating the machining parameter. Besides that, this is very important especially to the aerospace and automotive industry since many of their parts require excellent surface finishing and these industries using lots of extremely hard material, which is hard to machine with conventional machining process.

1.6 Expected Result

At the end of this study, it was expected that the effect of the machining parameter (peak current, pulse duration and with/without flushing) to the response (surface roughness and thickness of HAZ). Besides that, an optimum machining parameter for surface roughness will be determined through the response surface methodology.

CHAPTER 2

LITERATURE REVIEW

This chapter summarizes the theory and review of this project. Besides that, it also includes the studies made by the researchers recently.

2.1 Electrical Discharge Machining (EDM)

Electrical Discharge Machining (EDM) is an advanced manufacturing process, which is used commonly in machining the high hardness, very brittle and electrical conductive material. Suleiman and Ahsan (2007) have stated the example of hard material such as silicon, titanium, stainless steel, hardened steel, nickel, tungsten alloys etc. that are difficult to machine with traditional methods. This machining process has a unique machining process, which different from others. Norliana *et al.* (2006) have stated that EDM does not make direct contact between the electrode and the workpiece. Therefore, the machining is carried out by inducing thermoelectric energy created between workpiece and electrode submerged in a dielectric fluid according to Pham *et al.* (2004). Tlusty (2000) has noted that a typical Electrical Discharge machine consist of a servo controlled motor system, electrode, dielectric fluid, direct current pulse generator and the fixture to hold workpiece.

2.1.1 Micro EDM

Micro EDM is the machining process to machine micro parts and drill small hole without contact among workpiece and electrode. Micro EDM is basically scaled down version of the EDM process according to Allen *et al.* (1999). Lim *et al.* (2003) verified that the micro EDM is the most efficient technology for fabricating micro components. It means that the electrode used is in micro size from as low as 50µm. Pham *et al.* (2004) also stated that the micro EDM is the best means for achieving high aspect ratio micro features. It means that the length of the tool is usually 3-5 times of its diameter according to Lim *et al.* (2003). Therefore, it is hard to run the machining by traditional machining process due to high probability of tool vibration of high aspect ratio micro tool. The high tool vibration of traditional machining will result of out of tolerance, rougher surface and sometimes damage the workpiece. Hence, EDM is the best choice for this type of process due to no contact between the tool and workpiece along the machining process.

2.1.2 Electrical Discharge Machining Process

Luis *et al.* (2005) mentioned that the EDM process is based on removing material from a part by means of series of repeated electrical discharge between tool called the electrode and the workpiece in the presence of dielectric fluid. Bojorquez *et al.* (2002) stated the electrode is moved toward the workpiece until the gap is small enough so that the impressed voltage is great enough to ionize the dielectric. Luis *et al.* (2005) had shown that the machining is accomplished through spark, which can generate a temperature between 10,000^{o}C – 12,000^{o}C. This temperature is large enough to melt most types of material. According to Marafona and Chousal (2005), the material is removed with the erosive effect of the electrical discharges tool to workpiece. Finally, the eroded debris is flushed away by dielectric fluid and the machining processes are repeated until the shape is formed.

2.1.3 Parameters of Electrical Discharge Machining

The parameters of the EDM must be controlled in very effective in order to get the optimum tolerance and surface finish of the machined workpiece. According to Todd *et al.* (1994), the parameters that affect the EDM process include accuracy and alignment of electrode, pulse frequency, types of dielectric fluid, spark gap between electrode and workpiece. Besides that, Tlusty (2000) also stated that magnitude of peak current and power source characteristics will also affect the machined part response. Liu *et al.* (2008) has proved that the machining polarity of electrode, pulse duration also affect the machining result. Yao and Masuzawa (2004) had also showed that the types of material used for electrode is also important parameter during machining.

The parameters such as peak current, dielectric used and frequency have great effect on the machined surface roughness according to Schey (2000). He had noted that surface finish rougher by higher current density (which gives high discharge energies), more viscous dielectric and lower pulse frequency. The rougher finish will result to more overcut and deeper Heat Affected Zone (HAZ). Besides that, the debris should also be flushed out to prevent short circuit.

The EDM parameters according to Kumar *et al.* (2009):

(a) Discharge voltage

Before current can flow, the open gap voltage increases until it has created an ionization path through the dielectric. Once the current flow, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between electrode and workpiece. Higher voltage settings increase the gap, which improve the flushing conditions and helps to stabilize the cut.