STUDY OF USING THREE DIMENSIONAL PRINTER FOR EDM ELECTRODE FABRICATION

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ABSTRACT

In this study, Cu-Al_2O_3 powder was prepared using ball mill and used separately for powder metallurgy (PM) and Three Dimensional Printer (3DP) application to fabricate electrode for electrical discharge machining (EDM). The materials in powder form were analyzed under scanning electron microscope (SEM) and particle size analyzer (PSA) to ensure that they fulfill the requirement for each fabrication method. For PM process, five compositions of Cu-%wt Al_2O_3 powder were prepared ranging from 0% to 20% Al_2O_3 contents at 5% increment. The powder were compacted and sintered in argon protected atmosphere to determine the suitable compaction pressure and sintering temperature to fabricate PM electrode. Microscopic analysis revealed that 48MPa and 921°C is the best compaction pressure and sintering temperature respectively for EDM electrode fabrication. EDM electrode samples were fabricated using both recommended parameters, and were tested to erode JIS SKD11 (mould steel) workpiece for 5 minutes, with solid Cu electrode as the benchmark. Electrodes' performances were assessed by calculating the tool wear rate (TWR), material removal rate (MRR) and by measuring the average surface roughness (Ra) of the eroded cavity. From the experiment conducted, the PM electrodes are not as good as solid Cu electrode in terms of MRR, but the addition of Al_2O_3 at around 10%wt could reduce the TWR and Ra. The composition of Cu-10%wt Al_2O_3 powder electrode that has the optimum machining results was then prepared for 3DP application. Green parts were fabricated using 3DP, sintered and infiltrated prior to being tested at EDM machine. Although sintering was a success, samples were still porous due to the failure in infiltration process. The performance of EDM electrodes fabricated using 3DP were evaluated the same way as the ones fabricated via PM process. Experiments using 3DP electrodes showed that the electrodes depleted and became the alloying element on the workpiece. Further studies are needed on the sintering and infiltration method in order to improve the quality of the electrode fabricated using 3DP.

ABSTRAK

Dalam kajian ini, serbuk Cu-Al_2O_3 disediakan berasingan menggunakan pengisar berbola untuk aplikasi metalurgi serbuk (PM) dan pencetak tiga dimensi (3DP) bagi tujuan menghasilkan elektrod untuk mesin discas elektrik (EDM). Bahan-bahan dianalisis menggunakan mikroskop pengimbas electron (SEM) dan penganalisis saiz butir (PSA) untuk memastikan ianya memenuhi keperluan kedua-dua teknik pembuatan. Untuk prosess PM, 5 komposisi serbuk Cu-%wt Al_2O_3 disediakan antara 0% hingga 20% kandungan Al_2O_3, pada selang kenaikan 5%. Serbuk Cu-0%wtAl_2O_3 dipadatkan dan dibakar untuk mencari tekanan dan suhu bakar yang sesuai untuk menghasilkan electrode EDM. Analisa di bawah mikroskop mendapati 48MPa dan 921°C merupakan tekanan dan suhu yang terbaik untuk menghasilkan elektrod EDM. Elektrod EDM kemudian dihasilkan menggunakan kedua-dua parameter yang dicadangkan, dan digunakan untuk memakan bahan kerja SKD11 selama 5 minit, dengan elektrod Cu padu sebagai tanda aras. Prestasi elektrod dinilai dengan mengira kadar kehausan alat (TWR), kadar pembuangan bahan (MRR) dan kekasaran purata permukaan yang telah dimakan (Ra). Hasil kajian mendapati elektrod PM tidak setanding dengan elektrod padu dari segi MRR, tetapi penambahan Al_2O_3 pada sekitar 10%wt mampu untuk mengurangkan TWR dan Ra. Komposisi elektrod dengan serbuk Cu-10%wt Al_2O_3 didapati menghasilkan keputusan pemesinan yang optimum, dan ianya disediakan untuk aplikasi 3DP. Sampel elektrod kemudian dihasilkan menggunakan 3DP, dibakar dan diinfiltrasi sebelum diuji pada mesin EDM. Walaupun proses pembakaran berjaya, tetapi elektrod masih lagi berongga kerana kegagalan pada proses infiltrasi. Prestasi elektrod dinilai dengan cara yang sama seperti electrod PM. Hasil ujikaji mendapati butir bahan pada elektrod 3DP gugur dan menjadi bahan aloi pada benda kerja. Kajian yang lebih mendalam perlu dibuat pada kaedah pembakaran dan infiltrasi bagi menambahbaik kualiti EDM elektrod yang dibuat menggunakan 3DP.

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SYMBOL

ρ	-	Density

ABBREVIATIONS

3DP	-	Three Dimensional Printer
CAD	-	Computer aided design
EDM	-	Electrical discharge mahining
EDX	-	Energy dispersive X-ray spectroscopy
SEM	-	Scanning electron microscope
MRR	-	Material removal rate
PM	-	Powder metallurgy
TWR	-	Tool wear rate
Ra	-	Average surface roughness of the eroded cavity
RP	-	Rapid prototyping

CHAPTER I

INTRODUCTION

1.1 Background of Study

Electrical discharge machining (EDM) is one of the most extensively non-conventional material removal processes in industry for its capability to machine parts regardless of their hardness, as long as it is electrically conductive. EDM is carried out by means of electric sparks that jump between electrode and workpiece subjected to a voltage and submerged in a dielectric fluid. Since there are no direct contact between the electrodes and the workpiece, EDM eliminates the mechanical stresses, chatter and vibration arising during the machining. EDM is widely used in the manufacturing of mould, die, automotive, aerospace and surgical components (Kechagias et al., 2008).

EDM uses electrodes as the cutting tool, which has the mirror image of designed shapes. The traditional materials for EDM electrodes are copper, brass, tungsten and steel of various forms for metal and graphite generally for non-metal material. However, these electrodes have high wear rate. Electrode wear is an important concern since it affects dimensional and form accuracy, and is related to the melting point of the electrode material. Composite EDM electrodes combining good electrical properties and high melting point materials such as copper tungsten (Cu-W), silver tungsten, tungsten carbide and copper graphite are thus used nowadays in order to improve material removal rate (MRR) and tool wear rate (TWR) ratio (Kern, 2008).

EDM electrodes are produced conventionally by stamping, coining, grinding, extrusion or drawing, and turning or milling. Manufacturing of electrodes is the major cost and time spent in EDM, which can take more than 50% of the total machining costs (Zhao et al., 2003). With advancement of technology, electrodes can also be produced these days using powder metallurgy (PM) technique. As the name implied, PM uses powder as the raw materials. In PM, powders are blended prior to cold pressing and sintering. This method is used widely in the production of composite material on account of its simplicity (Kaczmar, Pietrzak & Wlosinski, 2000).

Another considerably new method to fabricate EDM electrode is through rapid prototyping (RP). Over the last few years, the potential of producing EDM electrode using RP has generated not less interest among researchers. This is partly because of rapid prototyping’s ability to produce physical object directly from its CAD data source. The main objective is to reduce the production cost by shortening the production time and minimizing the need of multiple electrodes for production of complex geometry part. Several investigations have been done over the last few years on RP manufactured electrodes. Among RP technologies that are involved in the studies are Selective Laser Sintering (SLS), Stereolitography (SLA), Thermojet, and Three Dimensional Printer (3DP). The results showed that RP manufactured electrodes are only suitable for semi-roughing and finishing purpose (Anil & Çoĝun 2008; Hsu et al., 2008; Ferreira, Mateus & Alves, 2007; Rambo et al., 2005; Zhao et al., 2003; Ho & Newman, 2003). Nevertheless, better understanding of the various failure modes may provide openings for some improvements.

Excellent electrical conductivity and high wear resistance is seen as the requirements for EDM electrode, thus copper-alumina (Cu-Al_2O_3) composite is another material that has the potential to be used as electrode material. This composite has gained a lot of interest in the academic area. Fine alumina particles reinforced copper composite have almost identical electrical and thermal conductivity with copper and high strength due to dispersion of fine Al_2O_3 particles (Shi & Yan, 1998). These characteristics meet the requirement for EDM electrode.

Therefore, this study explores the potential of using Cu-Al_2O_3 composite to produce EDM electrode by two different techniques, PM and RP, spesifically 3DP. As PM is already common in producing Cu-Al_2O_3 composite, this project also explore the potential of fabricating Cu-Al_2O_3 composite green part using 3DP.

1.2 Statement of Problem

In mould production, whenever complex geometrical shape is concerned, the usage of multiple EDM electrodes is unavoidable. The developments in PM and RP technology, which have the advantage of producing net shape or near net shape product could if not eliminate entirely, reduce the number of electrodes used in producing complex resulting product. While in RP, methods such as stereolithograp (SLA) and selective laser sintering (SLS) have been explored to directly fabricated EDM electrodes, only a few scholars have examined the usage of 3DP methods in this area. Thus not much data are currently available regarding EDM electrode fabricated using 3DP either on the electrodes' properties or the EDM machining performances especially material removal rate (MRR), tool wear rate (TWR) and average surface finish of the eroded cavity (Ra) that are commonly used for assessing electrodes' performance.

1.3 Objectives of Study

This study focuses on the fabrication of powder based Cu-Al_2O_3 EDM electrode using PM and 3DP. The whole project embarks on the following objectives:

i. To study the feasibility of EDM electrode fabricated using PM and RP in terms of performances, namely TWR, MRR and Ra.
ii. To study the feasibility of Cu-Al_2O_3 as the material for PM and 3DP applications.

1.4 Scope of Study

Several outlines were drawn in order to ensure that this project is within its scope of study. The outlines are as follows:

i. Two different fabrication methods were used for fabrication of EDM electrode, which are powder metallurgy (PM) and Three Dimensional Printing (3DP).
ii. Cu-Al_2O_3 powder was prepared separately for PM and 3DP application.
iii. SKD11 mould steel workpieces were used on the performances testing.
iv. Electrodes' performances were assessed by calculating the MRR, TWR and measuring the average surface roughness (Ra) of the eroded cavity.

1.5 Organization of Thesis

This thesis is written in 6 chapters. Following this chapter, chapter 2 explains the theory and concept involved in this study, especially for EDM electrode, PM and 3DP. Chapter 3 presents the methods used in this study. Chapter 4 and 5 presents the results for electrode fabricated using PM and RP respectively. Chapter 6 presents the conclusions as well as some recommendations for future works.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the basic theories and working principle of EDM, with more details on EDM electrode. Previous studies on methods for producing of EDM electrode are also reviewed in this chapter and its production techniques. The principles of PM and RP, particularly 3DP are also discussed. Finally, review on Cu-Al_2O_3 composites are presented in this chapter.

2.2 Electrical discharge machining (EDM)

Electrical discharge machining (EDM) has gained wider industrial acceptance compared to other non-traditional machining process. The history of EDM dates back to 1940s when B.R. and N.I. Lazarenko invented the machining process based on the principle of production of arc by two current-conducting wires that are allowed to touch each other. EDM removes materials by thermal erosion. EDM is used in numerous applications for producing die cavities, connecting rods, and various intricate shapes to high degree of accuracy. Figure 2.1 shows the schematic diagram of the components of an EDM system.

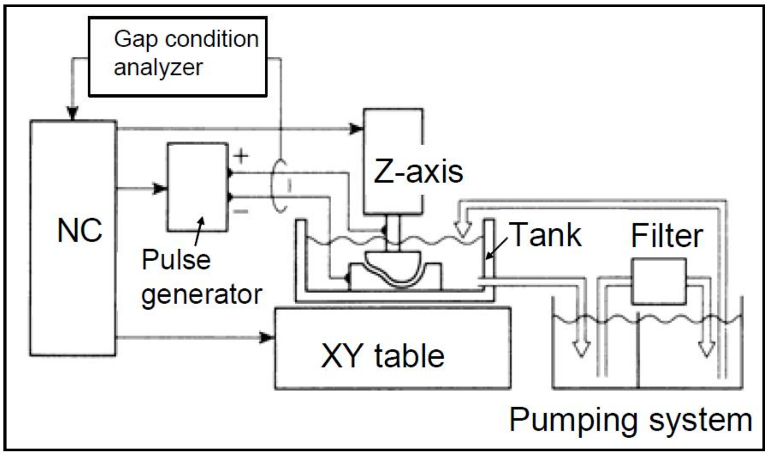

Figure 2.1 Schematic diagram of the sinking electrical discharge machine. (Kunieda et al., 2005).

As shown in Figure 2.1, pulses at certain voltage and current, off-time and on-time is provided by the power supply through the pulse generator. The numerical controler (NC) monitors the gap conditions (voltage and current), axes and pulse generator syncronously. Dielectric fluid is flushed into the interelectrode gap after being filtered from machining debris and decomposition products (El-Hofy, 2007; Kunieada et al., 2005).

2.2.1 Material removal mechanism in EDM

Figure 2.2 shows the schematic process of material removal mechanism in EDM. In EDM, materials are removed based upon the electrodischarge erosion effect of electric sparks between the electrode and the workpiece that are separated by small gap of 10 to 500µm. The electrode and workpiece are both submerged in electrically nonconducting dielectric fluid. When the potential difference between the electrode and the workpiece is sufficiently high, the dielectric in the gap is partially ionized, so that the transient sparks discharge ignites through the fluid, at the closest points between the electrode and workpiece. Each spark of thermal power concentration, typically 10^8W/mm^2, is capable of vaporizing very small amount of material from the electrode and the workpiece. Some of the total energy is absorbed by the electrode and thus result in some tool wear.

The instantaneous vaporization of the dielectric produces a high pressure bubble that expands radially. The discharge ceases with the interruption of the current, and the metal is ejected, leaving tiny craters in the workpiece and metal globules suspended in the dielectric. Sludge of black carbon particles formed by hydrocarbon of the dielectric produced in the gap and expelled by the explosive energy of the discharge, remains in suspension until removed by filtering. Immediately after the discharge, the dielectric surrounding the channel dionizes and becomes effective again as an insulator (Youssef & El-Hofy, 2008).

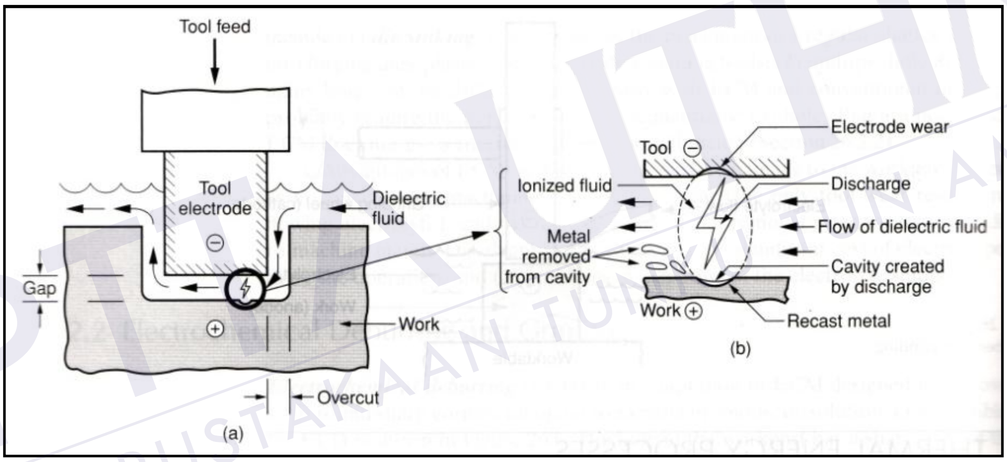

Figure 2.2 EDM machining process (a) machining setup and (b) close-up view of gap, showing discharge and metal removal (Groover, 2007).

2.3 EDM electrode properties

Machining is done using electrode as the cutting tool in EDM. Electrode materials thus play a very important role in determining the quality of machined cavity, alongside with the machining parameters. The ideal electrode materials is the one that have high electrical conductivity, high melting point, easy to fabricate and strong enough to sustain deformation due to the EDM process. Among electrode material properties that should be taken into consideration are:

i. Electrical conductivity:
Since EDM uses flowing electric current to erode cavity, electrical conductivity is at utmost importance to promote efficient cutting. It is preferable to have high conductivity, or conversely low resistivity compared to low conductivity.

ii. Melting point:
Since EDM is a thermal process, higher melting point will increase the MRR to TWR ratio.

iii. Structural integrity:
Each sparks generated during EDM process is violent to the electrode material at microscopic scale. Structural integrity (the ability of the electrode material to sustain these sparks) will determine the electrode's performance regarding tool wear, surface finish and ability to withstand poor flushing condition.

iv. Mechanical properties:
Mechanical properties such as tensile strength, hardness, transverse rupture strength and grain size if applicable will affect the fabrication of electrode as well as its performance in EDM process.

v. Manufacturability:
Sometimes, the usefulness of an electrode material is also determined by the material behavior during the fabrication process. Some of the factors may include machinability, stability and burr formation and removal.

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