ELECTRICAL DISCHARGE MACHINING OF TITANIUM ALLOY USING COPPER TUNGSTEN ELECTRODE WITH SiC POWDER SUSPENSION DIELECTRIC FLUID

R I V A L

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To my beloved family that were gone in Tsunami disaster 26 december 2004

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ABSTRACT

Titanium alloys which are categorized as lightweight materials, posses greater strength and toughness are usually known to create major challenges during conventional and non-conventional machining. Electrical discharge machining (EDM) which is very prominent amongst the non-conventional machining methods is expected to be used quite extensively in machining titanium alloys due to the favorable features and advantages that it can offer. This project was undertaken to study the machining performance of EDM and powder mixed dielectric-electrical discharge machining (PMD-EDM) on titanium alloy, Ti-6246 using copper tungsten (CuW) electrode. Silicon carbide (SiC) powder at various concentration was mixed in the dielectric to evaluate its effectiveness during the PMD-EDM process. The effect of varying the machining parameters on the machining responses such as material removal rate (MRR), electrode wear ratio (EWR), surface integrity and overcut was investigated. The experimental plan for both processes were conducted according to the design of experimental (DOE) and the results were statistically evaluated using analysis of variance (ANOVA). Response surface methodology (RSM) was employed in evaluating the machining performance of the PMD-EDM process and mathematical models for MRR, EWR and machined surface roughness (SR) were established. Result showed that current was the most significant parameter that influenced the machining responses on both EDM and PMD-EDM of Ti-6246. It was also found that PMD-EDM process produced less damaging effect on the surface integrity of the machined surface as compared to EDM process.

ABSTRAK

Aloi titanium yang dikategorikan sebagai bahan ringan yang mempunyai kekuatan dan ketahanan yang tinggi dikenali kerana menimbulkan cabaran yang besar semasa pemesinan konvensional ataupun pemesinan bukan konvensional. Proses pemesinan nyahcas elektrik (EDM) yang agak dominan di antara proses pemesinan bukan konvensional dijangkakan akan bertambah meluas penggunaannya disebabkan sifat-sifat dan kelebihan yang dihasilkan keatas bendakerja. Projek ini dilaksanakan untuk mengkaji prestasi proses EDM dan proses pencampuran serbuk dalam dielektrik-pemesinan nyahcas elektrik (PMD-EDM) semasa memesin aloi titanium, Ti-6246 menggunakan elektrod tungsten kuprum (CuW). Serbuk karbida silikon (SiC) pada kepekatan yang berbagai dicampurkan ke dalam dielektrik untuk menilai keberkesanannya semasa proses PMD-EDM. Kesan perubahan parameter pemesinan ke atas tindak balas pemesinan seperti kadar pembuangan material (MRR), nisbah kehausan elektrod (EWR), integriti permukaan dan 'overcut' telah dikaji. Ujian pemesinan untuk kedua-dua proses telah dinilai secara statistik menggunakan analisa variasi (ANOVA). Kaedah tindak balas permukaan (RSM) telah digunakan untuk menilai prestasi proses PMD-EDM dan model matematik untuk MRR, EWR, kekasaran permukaan (SR) telah dihasilkan. Keputusan menunjukkan arus lektrik merupakan parameter yang paling signifikan yang mempengaruhi tindak balas pemesinan untuk kedua-dua proses EDM dan PMD-EDM ke atas Ti-6246. Juga didapati proses PMD-EDM telah menghasilkan kesan yang tidak merosakkan ke atas integriti permukaan bendakerja berbanding dengan proses EDM.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	-	Analysis of variance
CCD	-	Central composite design
CMM	-	Coordinate measuring machine
EDAX	-	Energy dispersive X-ray spectroscopy
EDM	-	Electro discharge machining
EWR	-	Electrode wear rate
EWW	-	Weight of electrode used
FCD	-	Face centre cube design
HAZ	-	Heat affective zone
H_{cla}	-	Centre line average value of the surface produced
HRC	-	Hardness Rockwell unit for steel (cone indenter)
HRB	-	Hardness Rockwell unit for soft steels (ball indenter)
MRR	-	Material/metal removal rate
PMD-EDM	-	Powder mixed dielectric electro discharge machining
RSM	-	Response surface methodology
SEM	-	Scanning electron microscopy
SR	-	Surface Roughness
t_m	-	Machining times
USM	-	Ultra Sonic Machining
W_a	-	Weight of workpiece after machining
W_b	-	Weight of workpiece before machining
WRW	-	Weight of workpiece used
$x_1, x_2, x_3, \ldots, x_k$	-	Input variables
α	-	Alpha phase
β	-	Beta phase

y	-	Response
ε	-	Error
η	-	Expected response

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CHAPTER 1

INTRODUCTION

1.1 Overview

The use of light, thin and compact mechanical elements has recently become a global trend. 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 machined conventionally, sub surface damages such as metallurgical alterations, work hardening, delamination and microcracks and others can occur under certain circumstances which cause a detrimental effect on the performance of the machined component. Since the cost of using conventional machining is generally prohibitive, non-conventional machining such as electric discharge machining (EDM) and laser machining probably amongst the ideal technique in dealing with these materials, which includes titanium alloys.

Most titanium alloys and component design characteristics make them expensive to be machined and historically, titanium has been perceived as a material that is difficult to machine (Ezugwu and Wang, 1997; and Hong *et a*l., 2001). Due to titanium's growing acceptance in many industries, along with the experience gained by progressive fabricators, a broad base of titanium machining knowledge is now exist. It was reported that commercially pure grades of titanium [ASTM B, Grades 1,2,3,4] can be machined much easier than aircraft alloys [i.e. ASTM B, Grade 5 : Ti 6Al 4V] (ASM International, 1988).

Although titanium alloys is tough it can experienced sub-surface damaged during machining operations. Damage appears in the form of microcracks, built up edge, plastic deformation, heat affected zones and tensile residual stresses **(**Sharif, 1999; and Hong *et al*., 2001**)**. In service, these can lead to degraded fatigue strength and stress concentration.

Non-traditional machining of metal removal such as EDM expected to be used extensively years to come, because it's favorable results. It is particularly useful for rapid removal of metal of free form surface or complex shaped parts, thin sections, and from large areas down to shallow depths. This process has less damaging effect on the mechanical properties of the metal.

1.2 Background of Research

EDM is a non-traditional process that is used to remove metal through the action of an electrical discharge of short duration and high current intensity between the tool (electrode) and the workpiece. There are no physical cutting forces between the tool and the workpiece. This process is finding an increasing demand owing to its ability to produce geometrical complex shapes as well as its ability to machine hard materials that are extremely difficult to machine when using conventional process. EDM has proved valuable especially in the machining of super tough, hard and electrically conductive materials such as the new space age alloys (Lee and Li, 2001). Although EDM machining technology is widely used in mechanical components manufacturing, its low efficiency and poor surface quality have been the key problems restricting its development.

Numerous research studies **(**Wong et al., 1998, Tzeng and Lee, 2001, and Zhao *et al*., 2002**)** showed that powder mixed dielectric electrical discharge machining (PMD-EDM) process can distinctly improve the surface roughness, material removal rate and decrease tool (electrode) wear. PMD-EDM employs powder particles which are mixed in the dielectric fluid and it has a different machining mechanism when compared to conventional EDM machining. Many studies have applied this process in several kind of materials, but little work has been carry out to study PMD-EDM on titanium alloys. In the previous study, the process was carried using a copper electrode which was designed as a rotational diskette for machining Ti 6Al 4V(Chow *et al*., 2000). In the same year, a combination of EDM-USM (ultrasonic machining) for cutting Ti 6Al 4V was done by Lin *et al*. (2000). One of the above methods were used hole making operations (EDM-USM).

From the above description it was found that comprehensive study on the effect of machining conditions on Ti-6246 using EDM was not reported so far. New machining data on EDM of Ti-6246 served a great significance and could be further exploited especially for hole making operation. Further research on PMD-EDM machining mechanism and its machining effect on this kind of material will ensure better machining efficiency. This project is undertaken to study the effect of machining conditions when PMD-EDM of Ti-6246 during the hole making operation.

1.3 Research Statement

Electrical discharge machining of materials with added powder in dielectric fluid will lead to improvement in machining characteristics.

1.4 Problem Statement

a. Does the performance of SiC powder in dielectric fluid deliver better results in terms of surface integrity of titanium alloys (Ti-6246), mateial removal rate and electrode wear rate.
b. Does PMD-EDM of Ti-6246 contribute to new machining characteristics.

1.5 Objective

a. To study the machinability of Ti 6246 using copper tungsten electrode during the PMD-EDM process
b. To study the effect of machining parameter on the surface integrity
c. To establish mathematical models for some of the dependent variables by using RSM in a specific range of parameter
d. To optimize the machining parameters in order to increase the PMD-EDM performance

1.6 Scope

a. The material used in this study is Ti 6Al 2Sn 4Zr 6Mo (Ti-6246)
b. Charmilles Roboform 100 EDM die sinking machine was used for experiment
c. Copper tungsten (CuW) was used as the electrode
d. Silicon carbide (SiC) powder of 130 nm grain size was used as the assisted powder

e. The machining responses that were investigated are material removal rate (MRR), surface roughness (SR), electrode wear rate (EWR), dimensional accuracy (hole diameter) and subsurface defect which include heat affective zone (HAZ)
f. Experimental studies on EDM of Ti-6246 were carried out to determines the significant parameters effecting five responses for PMD-EDM process

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