PERFORMANCE EVALUATION OF ELECTRICAL DISCHARGE MACHINE ON TITANIUM ALLOY USING COPPER IMPREGNATED GRAPHITE ELECTRODE

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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,

Maimunah Hj Abdullah,

My supportive wife,

Amizah Abdul

My wonderful brothers and sisters,

Hamnah Mohd Isa, Mohd Helmi Mohd Isa, Huda Mohd Isa

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And last but not least to all my relatives and my close friends

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May Allah bless all people that I love and it's my honor to share this happiness with my love ones.

Sorry if I forgot to mention any name.

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ABSTRACT

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 offers. This thesis presents the EDMing of titanium alloy (Ti-6246) using copper impregnanted graphite electrode with diameter of 8 mm. The main purpose of this study was to investigate the influenced of various parameters involved in EDM on the machining characteristics, namely, material removal rate (MRR), electrode wear ratio (EWR), surface roughness (Ra) and overcut.

In this investigation, the machining trials were performed using a Sodick linear motor EDM sinker series AM3L The experimental plan for the processes were conducted according to the design of experimental (DOE) and the results were statistically evaluated using analysis of variance (ANOVA). Results showed that current was the most significant parameter that influenced the machining responses on EDM of Ti-6246.

Confirmation tests were also conducted for the selected conditions for each machining characteristics in order to verify and compare the results from the theoretical prediction using Design Expert software and experimental confirmation tests. Overall, the results from the confirmation tests showed that the percentage of performance was acceptable due to all results obtained were within the allowable values which was less than 15% of marginal error.

ABSTRAK

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. Kajian yang dijalankan ini adalah mengenai pemesinan EDM *sinker* terhadap bahan aloi titanium (Ti-6246) dengan menggunakan *copper impregnanted graphites* yang berdiameter 8 mm sebagai elektrod. Tujuan utama kajian ini adalah untuk mengkaji kesan beberapa parameter yang terlibat dalam EDM proses terhadap kriteria pemesinan seperti kadar pembuangan bahan (MRR), nisbah kehausan elektrod (EWR), kekasaran permukaan (Ra) dan '*overcut*'.

Dalam kajian ini, pemesinan yang dijalankan ke atas titanium dilakukan menggunakan *Sodick linear motor EDM series AM3L*. Ujian pemesinan untuk kedua-dua proses telah dinilai secara statistik menggunakan analisa variasi (ANOVA). Keputusan menunjukkan arus lektrik merupakan parameter yang paling signifikan yang mempengaruhi tindak balas pemesinan EDM ke atas Ti-6246.

Ujikaji pengesahan juga telah dijalankan bagi tujuan pengesahan dan perbandingan keputusan di antara nilai ramalan teori menggunakan perisian *Design Expert* dengan nilai yang diperolehi dari ujikaji. Secara keseluruhan, keputusan pengesahan ujikaji menunjukkan bahawa kesemua peratusan ralat perbezaan yang diperolehi berada di dalam lingkungan nilai yang dibenarkan iaitu peratus ralat kurang daripada 15%.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	-	Analysis of variance
CCD	-	Central composite design
CMM	-	Coordinate measuring machine
EDM	-	Electro discharge machining
EWR	-	Electrode wear rate
EWW	-	Weight of electrode used
MRR	-	Material/metal removal rate
RSM	-	Response surface methodology
SR	-	Surface Roughness
Tm	-	Machining times
Wa	-	Weight of workpiece after machining
Wb	-	Weight of workpiece before machining
WRW	-	Weight of workpiece used
x1,x2, x3,…,xk	-	Input variables
α	-	Alpha phase
β	-	Beta phase

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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 such as titanium and nickel alloys, 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, delimitation 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.

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, E.O and Wang, Z.M. 1997). 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] (ASM International, 1988) can be machined much easier than aircraft alloys.

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 (Rival, 2005).

1.2 Background of Research

EDM is a non-traditional concept of machining which has been widely used to produce dies and molds. It is also used for finishing parts for aerospace and automotive industry and surgical components. This technique has been developed in the late 1940s (Norliana Mohd Abbas *et al*., 2006).where the process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of a dielectric fluid (Norliana Mohd Abbas *et al*., 2006).

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 its

capability especially in the machining of super tough, hard and electrically conductive materials such as the new space age alloys (Rival, 2005). The process variables include not only the electrical but also non-electrical parameters, which have received quite a substantial amount of research interest.

Optimum selection of process parameters is very much essential, as this is a costly process to increase production rate considerably by reducing the machining time. Several researchers carried out various investigations for improving the process performance. As EDM is a very complex and stochastic process, it is very difficult to determine optimal parameters for best machining performance, i.e., productivity and accuracy (T. A. El-Taweel, 2009). Material removal rate, tool wear, surface finish and also overcut are most important output parameters, which influence the cutting performance. But these performance parameters are conflicting in nature. The higher the MRR, the better, whereas the lower the tool wear, the better. In a single objective optimization, there exists only one solution. But in the case of multiple objectives, there may not exist one solution, which is the best with respect to all objectives. In EDM process, it is difficult to find a single optimal combination of process parameters for the performances parameters, as the process parameters influence them differently. Hence, there is a need for a multi-objective optimization method to arrive at the solutions to this problem.

The published literature indicates that few studies have been reported for the optimization of process parameters in EDM. Therefore, this study is aims at investigating the best performance of various input process parameters in EDM die-sinking process of Ti-6246. Further, no technology tables or charts are available for EDM of titanium alloy (Ti-6246) using copper graphite electrode. Therefore, it is imperative to develop a suitable technology guideline for appropriate machining of Ti-6246. Electrodes with copper graphite, peak current, servo voltage, pulse on time and pulse off time are considered as input EDM machining parameters. The process performance such as material removal rate (MRR), surface roughness (SR), overcut and electrode wear rate (EWR) were evaluated.

1.3 Statement of the research problem

How does a new developed electrode performed when EDM alpha beta titanium alloy Ti-6246 with respect to material removal, electrode wear, dimensional hole accuracy and surface finish.

1.4 Research Question

a. What are the machining parameters that influence the EDMing of Ti-6246 using copper impregnanted graphite electrode.
b. What are the significant parameters that influence to the responce during EDM of Ti-6246.
c. What correlations exist among the parameters and machining responses and also how to quantify.
d. What mathematical model is suitable to represent the performance evaluation of EDMing Ti-6246.

1.5 Objectives

The objectives of the study are:

a) To evaluate the performance of copper Impregnated graphite electrode when Electro-Discharge Machining Ti-6246 with respect to various machining responses.

b) To determine the significant parameters that influences the machining responses during Electro-Discharge Machining of Ti-6246.
c) To establish mathematical model for the MRR, EWR and surface finish during EDM of Ti-6246 using DOE approach.

1.6 Scope of study

a) Machining responses to be investigated are material removal rate (MRR), electrode wear rate (EWR), surface roughness (SR) and overcut.
b) Electro-Discharge Machining (Die sinking) AM3L SODICK will be employed.
c) Alpha-beta alloy, Ti 6Al 2Sn 4Zr 6Mo (Ti-6246) will be selected as workpiece material.
d) Copper impregnated graphite will be used as the EDM electrode.
e) Kerosene will be used as the dielectric fluid.