# PERFORMANCE EVALUATION
# OF ELECTRICAL DISCHARGE MACHINING
# ON STAINLESS STEEL 316L USING COPPER IMPREGNATED GRAPHITE

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***To my beloved parents***

*Haji Safiei bin Che Din*

*Hajjah Azizah binti Mat Noh*

***My wonderful wife and son***

*Siti Masayu binti Abdul Jalil*

*Muhammad Habibullah bin Wahaizad*

*and all my supportive relatives.*

*May us always in Allah S.W.T bless and protection.*

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# ABSTRACT

The electrical discharge machining (EDM) is considered as non-conventional machining due to its different method of machining compared to conventional machining. This study presents the results of experimental studies carried out to conduct a comprehensive investigation on the influence of EDM input parameters on the characteristics of EDM process. The machining parameters include peak current, servo voltage, pulse ON time and pulse OFF time. The study was conducted using 2 levels of full factorial method in Design of Experiments (DOE). The design expert version 9 software was employed to perform all the data analysis for full factorial and Central Composite Design (CCD) experiments. Basically, this study evaluates the EDM performance on Stainless Steel 316L using Sodick EDM linear motor series AM3L which employed copper impregnated graphite of diameter 7.0 mm as the tool electrode. The machining responses are material removal rate (MRR), electrode wear rate (EWR), surface roughness (SR) and dimensional accuracy. An optimum setting was determined based on DOE and analysis of variance analysis (ANOVA). Result's showed that peak current was the most significant factors to all machining responses. The servo voltage does not have significant effect to the machining responses in the Response Surface Methodology (RSM). Higher current produced higher MRR, EWR, SR and dimensional accuracy. Maximum MRR was obtained at peak current ranging from 27amp to 38amp, pulse on time range from 120µs to 145µs and 60µs of pulse off time. Maximum EWR was obtained at peak current ranging from 27amp to 37amp, pulse on time range from 140µs to 160µs and 60µs of pulse off time. Lower dimensional accuracy and SR obtained at 5amp of pulse on time. Higher pulse off time produced lower MRR and EWR.

# ABSTRAK

Pemesinan nyahcas elektrik dianggap sebagai bukan pemesinan konvensional kerana kaedahnya adalah berbeza dengan pemesinan konvensional. Kajian ini membentangkan hasil kajian eksperimen yang dijalankan dengan siasatan menyeluruh mengenai pengaruh parameter Pemesinan Nyahcas Elektrik (EDM) terhadap bahan yang dimesin. Parameter pemesinan adalah arus elektrik, voltan servo, *pulse ON* dan *pulse OFF*. Kajian ini dijalankan dengan menggunakan dua aras pemfaktoran penuh dalam rekabentuk eksperimen. Perisian *Design Expert* versi ke-sembilan telah digunakan untuk menjalankan semua analisis data eksperimen *Central Composite Design (CCD)* dan *Full Factorial.* Pada asasnya, kajian ini menilai prestasi pemesinan menggunakan *Sodick EDM linear motor series AM3L* dengan mata alat elektrod *Copper impregnated graphite* berdiameter 7.0 mm terhadap *Stainless Steel 316L*. Pemboleh ubah tindak balas adalah *material removal rate (MRR), electrode wear rate (EWR), surface roughness (SR)* dan *dimensional accuracy*. Penetapan optimum ditentukan berdasarkan Rekabentuk Eksperimen dan Analisis Varians (ANOVA). Keputusan menunjukkan bahawa arus elektrik adalah faktor yang signifikan terhadap respon pembolehubah. *Servo Voltage* tidak signifikan terhadap respon pemesinan dalam RSM. Arus elektrik tinggi menghasilkan MRR, EWR, SR dan ketepatan dimensi yang tinggi. MRR yang tinggi dan optimum diperolehi pada julat arus elektrik 27amp hingga 38amp, julat *pulse on time* pada 120µs to 145µs and pada 60µs *pulse off time*. Maksimum EWR diperolehi pada julat arus elektrik 27amp hingga 37amp, julat *pulse on time* dari140µs hingga 160µs dan pada 60µs *pulse off time*. Ketepatan dimensi yang rendah dan SR diperoleh pada *pulse on time* 5 amp. *Pulse off time* yang tinggi menghasilkan MRR dan EWR yang rendah.

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# LIST OF ABBREVIATIONS AND SYMBOLS

| | | |
|---|---|---|
| ANOVA | - | Analysis of Variance |
| CCD | - | Central Composite Design |
| CMM | - | Coordinate Measuring Machine |
| CP | - | Center Point |
| $DH_E$ | - | Diameter Hole Electrode |
| $DH_W$ | - | Diameter Hole Work piece |
| DOE | - | Design of Experiment |
| EDM | - | Electro Discharge Machining |
| EW | - | Electrode Wear |
| $EW_a$ | - | Electrode Weight before Machining |
| $EW_b$ | - | Electrode Weight after Machining |
| EWR | - | Electrode Wear Rate |
| FCCD | - | Face Centered Central Composite Design |
| FCD | - | Face Central Cube Design |
| kHz | - | Spark Frequency |
| MRR | - | Material/Metal Removal Rate |
| RSM | - | Response Surface Methodology |
| Ra | - | Surface Roughness |
| SF | - | Surface Finish |
| SR | - | Surface Roughness |
| Tm | - | Machining Times |
| $t_{on}$ | - | Pulse On Time |
| $t_{off}$ | - | Pulse Off Time |
| TWR | - | Tool Wear Rate |
| Vs | - | Servo Voltage |
| Wa | - | Weight of Workpiece after Machining |

| | | |
|---|---|---|
| Wb | - | Weight of Workpiece before Machining |
| Zeiss | - | Coordinate Measuring Machine |
| 3D | - | 3 Dimensional |
| + | - | High Value |
| - | - | Low Value |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

There are many machining processes that are available in tool making industry. These processes can be divided into conventional and non-conventional machining. For example, milling and turning machining process are considered as conventional machining. The electrical discharge machining is considered as non-conventional due to its different method of machining. The Electrical Discharge Machining (EDM) is one of the most useful processes for the production of complicated shapes and tiny apertures of high quality with greater accuracy. EDM is also one of the most widely employed non-traditional machining because it has been accepted as a standard process to manufacture mould and dies for aerospace, automotive, nuclear and marine components (Gopala *et al.*, 2012).

EDM is a non-conventional, thermo electric process in which the material from work pieces is eroded by series of discharge sparks between the work and tool electrode immersed in a liquid dielectric medium (Yang *et al.,* 2009). EDM technology is developed and is widely use in applications such as die and mild machining, micromachining, and prototyping. Very hard and brittle materials can be machined easily and also to the desired form. It removes electrically conductive materials by means of rapid, repetitive spark discharges from pulsating direct-current power supply with dielectric flow between work piece and the electrode. There are many parameters that may affect machining results. Researchers or engineers should have a deep knowledge about EDM process parameters prior to get high efficiency during machining process.

Among all EDM processes, die sinker EDM is widely used (Fonda *et al.,* 2008). Die sinking EDM is a machining process where positive feature shapes on the work piece are mapped from the negative features in the electrode. It is relatively low machining process which requires electrode specially made for machining of a given product. The advantage of EDM machine is its ability to produce small, even micro features. The EDM process is used mostly for making dies and moulds (Valentilic *et al.*, 2009).

In order to get a good quality parts with minimum cost there are several parameters of the EDM that have to be controlled. There are the polarity, pulse on duration, pulse off duration, jump speed, flushing jet rate, discharge voltage and discharge current are several parameters that need to be controlled. Advances in information and communication technology have force industrial activities to use computers in each phase of manufacturing process. This has put computerization at the forefront of competitive factors in manufacturing business. During EDM, the tool and the work piece are submerged in dielectric fluid and operated by a small gap.

The discharge energy produces very high temperature on the surface of the work piece on the point of spark. This causes local melting and vaporization of molten metal, which is washed away by circulating dielectric fluid.

## 1.2 Background of Research

EDM is a process for eroding and removing material from electrically conductive materials by use of consecutive electric sparks. This technique has been developed in the late 1940s where the process is based on removing material from a pert by means of a series of repeated electrical discharges between electrode and the work piece in the presence of a dielectric fluid (Norliana Mohd Abbas *et al*., 2006).

Each electrical discharge generates heat energy in a narrow area that locally melts, evaporates and even ionizes work piece material. EDM does not make direct contact between the electrode and the work piece where it can eliminates mechanical stress and vibration problems during machining (Jaihindus *et al*., 2013). During EDM, the tool and the work piece are submerged in dielectric fluid and operated by a small gap. The discharge energy produces very high temperature on the surface of the work piece on the point of spark. This causes local melting and vaporization of molten metal, which is washed away by circulating dielectric fluid.

During EDM process, the surface of the work piece gets affected heavily because of variation in processing variables which depend on material to material and because of this, some adverse effects in terms of properties are observed. These properties can vary to different levels with the variation in the main processing parameters. If the process parameter for machining is optimized, the EDM can be easily used as a routine valuable tool.

Optimum selection of process parameters is very crucial as it is a costly process to increase the production rate considerably by reducing machining time. Hence, by optimizing the process parameters like peak current, pulse on time, pulse off time, voltage, type of electrode, shape of electrode and etc., a desired result in EDM machining is able to obtain. As the process parameters increases the numbers of experiments also increases and consequently increases in the cost of experiments. Overall, material removal rate, tool wear, surface finish and overcut or dimensional accuracy are the most important output parameters which usually influence the machining performance. In a single objective optimization, there is only one solution. However, for multiple objectives, there may not be any solution exist, 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 performance parameters, as the process parameters influence them differently. Thus, there is a need for a multi-objective method to derive solutions to this problem (Mohd Halimuddin, 2010).

Stainless Steel 316L is the standard molybdenum-bearing grade, the second most important out of 304 austenitic stainless steels. The molybdenum gives 316 better overall corrosion resistant properties than Grade 304, particularly higher resistance to pitting and crevice corrosion in chloride environments. Grade 316L, the low carbon version of 316 is immuned from sensitization (grain boundary carbide precipitation). Thus, it is extensively used in heavy gauge welded components (over about 6mm). The austenitic structure gives these grades excellent toughness, even down to cryogenic temperatures. Compared to chromium-nickel austenitic stainless steels, 316L stainless steel offers higher creep, stress to rupture and tensile strength at elevated temperatures.

The published literature indicates that few studies have been reported for the optimization of process parameters in EDM. Therefore this study is aimed to investigate the best performance of various input process parameters in EDM die-sinking process of stainless steel 316L. Furthermore, no tables or charts are available for EDM of stainless steel 316L using copper graphite electrode. Therefore it is needed to develop a suitable technology guideline for appropriate machining of stainless steel 316L. Electrodes with copper graphite, peak current, servo voltage, pulse off time and pulse on time are considered as input EDM machining parameters. The process performance such as material removal rate (MRR), surface roughness (SR), electrode wear rate (EWR) and dimensional accuracy were evaluated.

## 1.3 Statement of the Research Problem

How does the performance of copper impregnated graphite EDM-C3 give better results in terms of, material removal rate, surface roughness, electrode wear rate and dimensional hole accuracy of stainless steel 316L.

## 1.4 Research Objectives

The objectives of the study are:

a. To determine the most significant factors of EDM that influences the response parameters for machining Stainless Steel 316L.
b. To define the optimization of EDM process parameters for Stainless Steel 316L using copper impregnated graphite electrode.
c. To develop mathematical model for material removal rate (MRR), surface roughness (Ra), tool wear rate (TWR) and dimensional accuracy during EDM machining of Stainless Steel 316L using DOE approach.

## 1.6 Scope of Study

The scopes of the research consist of:

a. Machining responses to be investigated are material removal (MRR), electrode wear (EWR), dimensional hole accuracy and surface roughness (Ra).

b. Electro Discharge Machining (Die sinking) AM3L SODICK is employed.

c. Stainless Steel 316L is used as work piece material.

d. Copper impregnated graphite EDM-C3 is used as EDM electrode.

e. Kerosene is used as the dielectric fluid.

f. EDM parameters used in the experiment are Pulse On Time (ton), Pulse Off Time (toff), Peak Current (Ip) and Servo Voltage (Vs).

g. Design of experiment using Response Surface Model (RSM) is applied to determine the most significant factors affecting the main results.

h. Mathematical models are developed based on Analysis of Variance (ANOVA) and confirmation run also is conducted.

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