UNIVERSITI PUTRA MALAYSIA

THE EVALUATION OF MACHINABILITY AND SURFACE TEXTURE OF TOOL STEEL WITH COPPER ELECTRODE IN ELECTRO DISCHARGE MACHINING

MOHD AHADLIN BIN MOHD DAUD

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By

MOHD AHADLIN BIN MOHD DAUD

Thesis Submitted in Fulfilment of the Requirement for the Degree of Master Science in Faculty of Engineering
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To my Beloved, Mother, Wife, Halimah and Sons, Solehin, Safwan, Syafiq and Daughters, Nurfarahin and Siti Nuraisyah.

You are the reason for all this.

Abstract of thesis presented to Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree Master of Science

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October 2001

Chairman : Napsiah bt Ismail, Ph.D.

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The study reported in this thesis is a contribution towards the understanding on the relationship of Electro Discharge Machining (EDM) parameters in machining of tool steel. Some of the main parameters controlling material removal rate (MRR) in EDM, namely supply current, pulse on/off duration and electrode size with electrode wear rate (EWR) are studied and their effects on the machinability factors (MRR and EWR) are evaluated. The surface finish in term of surface texture, which determined by the roughness measurement on the machined surface (R_a) is also studied. Further, volumetric wear (VW) as the three-dimensional analysis among MRR, EWR and machining time or pulse on/off duration is analyzed. In the experiment using the die-sinking EDM, tool steel and copper were selected as the workpiece and electrode, respectively. Three sizes of copper electrode were used: diameter of 5 mm, 10 mm and 15 mm and two experimental setups were prepared. In setup-1, those electrodes were used to produce blind hole machining features at supply currents of 3A and 6A for machining time from 5 to 20 minutes, while pulse on/off duration was kept constant. In setup-2, machining time was kept constant, supply currents were also 3A and 6A but pulse on/off durations were varied from 6 to 12 μs. From the evaluation of MRR, EWR, surface roughness and VW, the results show that the electrode with diameter of 15 mm gives the best performance at all supply currents, machining time and pulse on/off durations. The values of MRR and EWR increase as the increasing of machining time, supply current and pulse on/off duration. Surface roughness has no relationship with machining time. In contrast, it has a close relationship with pulse on/off duration where the higher the pulse on/off duration the higher is the magnitude of surface roughness.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN TERHADAP KEBOLEHMESINAN DAN TEKSTUR PERMUKAAN BAGI KELULI ALAT DENGAN ELEKTROD KUPRUM DI DALAM "ELECTRO DISCHARGE MACHINING"

Oleh

MOHD AHADLIN BIN MOHD DAUD

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Kajian yang telah dijalankan adalah satu sumbangan bagi memahami perkaitan beberapa parameter "Electro Discharge Machine" EDM di dalam pemesinan keluli alat. Terdapat beberapa parameter utama yang mengawal Kadar Penyingkiran Bahan "MRR" pada EDM, termasuklah bekalan arus, jangkamasa "on/off" denyutan dan saiz elektrod, dengan Kadar Haus Elektrod "EWR" juga dikaji dan kesan terhadap faktor kebolehmesinan (MRR dan EWR) di nilai. Kemasan permukaan dengan erti kata tekstur permukaan ditentukan dengan mengukur kekasaran permukaan (R_a) dimesin dikaji. Seterusnya, Isipadu Haus "VW" di analisis. Di dalam ujikaji yang menggunakan "die-sinking" EDM, keluli alat dipilih sebagai bahan kerja dan kuprum sebagai elektrod. Tiga saiz elektrod telah digunakan iaitu yang bergarispusat 5 mm, 10 mm dan 15 mm dan pada ujikaji pertama, elektrod kuprum digunakan untuk menghasilkan ciri-ciri "blind hole" pada arus 3 A dan 6 A dengan masa pemesinan selama 5 hingga 20 minit dengan jangkamasa "on/off" denyutan adalah tetap. Pada ujikaji kedua, masa pemesinan adalah tetap pada arus 3A dan 6A tetapi jangkamasa "on/off" denyutan berubah dari 6 hingga 12 µs. Hasil penilaian, mendapati MRR, EWR, kekasaran permukaan yang diukur dengan parameter R_a dan VW bagi elektrod yang bergarispusat 15 mm memberikan prestasi yang terbaik untuk semua arus, masa pemesinan dan jangkamasa "on/off" denyutan. Nilai bagi MRR dan EWR meningkat dengan bertambahnya arus, masa pemesinan dan jangkamasa "on/off" denyutan. Kekasaran permukaan tidak mempunyai perkaitan rapat dengan masa pemesinan. Sebaliknya kekasaran permukaan mempunyai perkaitan rapat dengan jangkamasa "on/off" denyutan di mana lebih panjang masa denyutan, lebih tinggi magnitud kekasaran permukaan.

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I certify that an Examination Committee met on 19th October 2001 to conduct the final examination of Mohd Ahadlin bin Mohd Daud, on his Master of Science thesis entitled "The Evaluation of Machinability and Surface Texture of Tool Steel with Copper Electrode in Electro Discharge Machining" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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Date : 10 JAN 2002

DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions

(MOHD AHADLIN BIN MOHD DAUD)

Date: 21/11/2001

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LIST OF ABBREVIATIONS

A	sphere area	[mm^2]
AC	Alternating Current	[V]
C	Capacitor	[F]
C	velocity of debris ejection [m/sec]	
CNC	Computer Numerical Control	
D	Diodes	
DC	Direct Current	[V]
EDG	Electro Discharge Grinding	
EDM	Electro Discharge Machining	
EWR	Electrode Wear Rate	[g/min]
EWW	Electrode Wear Weight	[g/min]
HRB	Brinnel Hardness Number	[HB]
HRC	Rockwell Hardness Number	[HRC]
HSM	High Speed Machining	
L	Inductor	
MRR	Material Removal Rate	[mm^3/min]
NTM	Non-traditional manufacturing	
R	Resistor	[Ω]
R	sphere radius	[mm]
R_a	Surface roughness parameter (rms)	[μm]
R_{max}	Surface roughness parameter (peak to valley)	[μm]
T	machining time	[min]
t_e	pulse diration	[μs]
VW	Volumetric Wear	
WEDM	Wire Electro Discharge Machining	
Zc	Charge impeder	
Zd	Discharge impeder	

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CHAPTER 1

INTRODUCTION

1.1 Background

Excessive tool wear, short tool life and poor surface finish are the characteristics of machining tool steel due to its hardness and toughness (Che Haron et al., 2000a, 2000b). To illustrate, machining of tool steel in the mold-making and die industries is usually performed before the heat treatment process. At the condition of tool steel as manufactured with hardness of 27 HRC, it is rough machined to such die and molds components' shape and dimension. The rough machining process is followed by the heat treatment to increase the hardness and toughness of tool steel up to 40-60 HRC and finally the light finish machining is performed to achieve the final components' shape and dimension. Those processes to produce the components are time consuming and hence high production cost.

Recently, high speed machining (HSM) technique is implemented to overcome the problem in the above. Hardened tool steel is directly machined into its final shape and dimension. Some problems are successfully solved by this technique. Production time is reduced as the result of high material removal rate (MRR) and the quality of surface finish is improved (Shirai, 2001). However, not all of machining tasks can be done by HSM such as producing the deep internal cavities, miniaturized electronics, fine features on thick or even very thin plate form workpiece. In specific example, the deep drilling by HSM to produce small hole or bore hole in die and mold parts cannot be done without burr formation. Moreover, when the depth of holes are much greater than its' diameter (e.g. depth is 20 mm and diameter is 0.8 mm), tool in HSM is deflected and thus, run-out of cutting tool distorts surface finish and dimension of the holes. An EDM, in particular the die-sinking EDM and from now on the die-sinking EDM is abbreviated by EDM, is particularly well suited for components, which are made from difficult to machine materials that contain small and/or odd-shaped features. The direct of mechanical contact between tool and workpiece in traditional manufacturing process is the most probable reason of the limitations in the above.

Machining of tool steel as the main material in the mold-making and die industries is one example of material among them. In the other field of applications, the previous study of Jeswani (1979) reported that EDM replaced the use of mechanical drilling in producing injector nozzle of diesel engine with diameter of 0.15 mm. Moreover, in the recent study, Thoe et al. (1999) utilized EDM in making the cooling hole of nozzle vane in aeroengine turbine with diameter less than 1 mm. Unlike the other traditional manufacturing processes, machining with EDM is burr-free machining.

So far, the drawbacks in EDM process are the low MRR and it can be used only to machine the conductive materials. For removing the equal volume of workpiece material, the required machining time using EDM is much longer than the traditional manufacturing processes. The EDM cutting tool or electrode does not as aggressive as the cutting tools of traditional manufacturing processes in producing chips or as called debris in EDM. If cutting speed, feed rate, depth of cut and tool life are the parameters that controlled the MRR in traditional manufacturing processes, in EDM the dependency of MRR are more on the supply current, voltage, pulse on/off duration (duty factor), pulse shape, electrode size with its wear rate and the type of dielectric fluid including the method to flush it. Among those parameters, some of the previous studies by Bhattacharyya et al. (1981), Tariq Jilani and Pandey (1984), Hon and Li (1987), Amin and Sardar (1997), Yeo and New (1999), Ginting et al. (2000) and Lin et al. (2000) show that supply current, pulse on-off duration and electrode size with its wear rate are the main parameters that directly determine the MRR in EDM process. For the purpose of seeking the possibility to increase the MRR in EDM, the study that aimed to gain the understanding on the relationship of those parameters that controlling the MRR is important to carry out.

1.2 Thesis Scope and Problem Statement

There are three main scopes of this thesis, namely (a) the machinability factors (MRR and electrode wear rate) and the EDM parameters that controlling them (supply current, pulse on/off duration, electrode size), (b) surface texture that is determined by the measurement of roughness on the EDM machined surface, and (c) tool steel material and copper electrode.

As in the traditional manufacturing process, the MRR in EDM process is also respected to the volume of material removed divided by the machining time. In EDM, the MRR varies from as little as 16.4 mm^3/hr or less for precision machining with smooth surface texture to 245 mm^3/hr or more for rough machining with coarser surface texture (Drozda and Wick, 1983). The MRR is nearly a direct function of supply current where higher amperage removes more material but produces rougher surface texture (Bhattacharyya et al., 1981; Drozda and Wick, 1983).

In removing the workpiece material during EDM process, the electrode that used as a tool in EDM is worn due to the occurrence of electric spark that works on the gap between the electrode's cutting surface and the machined surface. The electrode wear is expressed as a ratio of the electrode volume that worn away during machining to the volume of workpiece material removed (Poco, 1993). Types of electrode wear in EDM process can be classified as the corner wear, side wear and end wear. The combination of those wears over the entire cutting surfaces of electrode are crucial to evaluate in order to achieve the high MRR, the smooth surface texture and the dimensional accuracy of product. In relation with electrode wear rate, high supply current and short pulse on/off duration tends to produce high rate of electrode wear and particularly for small size electrode diameter, the higher supply current and the shorter pulse on/off duration, the higher is the electrode wear rate (Hon and Li, 1987; Ginting et al. 2000).

Tool steel material and copper electrode are the other aspects framing the scope of this study. Both materials are selected as the specimens in this study since they are widely used in the mold-making and die industries; and the difficulty to increase the MRR and surface finish of tool steel when machining with copper electrode in EDM. Some previous researchers were also working with these materials in order to study the characteristics of EDM process (Shanker and Ghosh, 1975; Jeswani, 1979; Bhattacharyya et al., 1981; Tariq Jilani and Pandey, 1984; Hon and Li, 1987; Suzuki et al., 1997; Amin and Sardar, 1997; Yeo and New, 1999; Ginting et al., 2000; Li et al., 2000). In general, they conclude that the combinations of the EDM parameters are urgent to define since not all of high setup supply current, pulse on/off duration and electrode size will end with the high MRR. Moreover, although electrode wear rate is possible to minimize; however, it does not produce high MRR and smooth surface finish (Bhattacharyya et al., 1981; Hon and Li, 1987; Ginting et al., 2000).

1.3 Objectives

The study reported in this thesis is a contribution towards the understanding on the relationship of EDM parameters in machining of tool steel. Some of the main parameters controlling MRR in EDM, namely supply current, pulse on/off duration and electrode size with its wear rate, are studied and its' effect on the machinability factors (MRR and wear rate) are evaluated. Further, the surface finish in term of surface texture, which determined by the roughness measurement on the machined surface is also of interest.

In detail, the objectives mentioned in the above can be divided into two groups of study:

1. Machinability and surface texture as a function of machining time. The importance of this study is to evaluate the effect of machining time on machinability factors and surface texture of machined surface. For this purpose, the EDM process is carried out with the various machining times, supply currents and electrode sizes, while the pulse on/off duration

that controlling the duty factor, voltage and pulse shape is kept constant. The dielectric fluid and the way to flush it into the machining zone also are not varied for all experiments.

2. Machinability and surface texture as a function of pulse on/off duration. In this study the effect of pulse on/off duration is the main concern. The EDM experiments are carried out with various pulse on/off durations, supply currents and electrode sizes, while machining time, voltage, pulse shape and dielectric fluid including the way to flush it are kept the same as that the study in group one.

1.4 Thesis Organization

This thesis consists of five chapters. The introduction in chapter one is aimed to bring in the background of this study including the objectives and thesis scope and problem statement. The importance of this study is elucidated in this chapter. There are two approaches are taken in order to realize the objectives of this study. Firstly, the literature study that given in chapter two is aimed to scrutiny the achievement of the previous researchers. From this approach, it is indicated that the study in EDM process can be classified into three, i.e. (a) studies conducted to understand the physical aspects of spark mechanism and control, (b) the attempts to obtain the relationship between the machining parameters and the machinability aspects, and (c) the investigation on debris formation. Secondly, the experiments are designed and data are collected through the trials that described previously in the objectives of this study in chapter one. The experimental methods including the equipment used, materials, machining parameters, experimental procedure and data collection as well as its analyses are details in chapter three.

Chapter four is the core of this thesis. In this chapter, results of study are compiled and discussed. Graphs are plotted based on the data obtained through the machining trials and reasons of the results are described. The results are also compared to the results of the previous researches and the important findings that related to the objectives in this study are pointed out.

In the last chapter, the conclusions of study are listed. Some interesting points from the latter chapter are highlighted. Conclusions are made based on the details of the objectives given in chapter one. To complete this chapter, some recommendations for the future study in EDM machining also are listed.