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JUDUL: Influence of EDM machining on surface integrity of SKD 11 tool steel.

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I hereby, declared this thesis entitled “Influence of EDM machining on surface integrity of SKD 11 tool steel” is the results of my own research except as cited in references.

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ABSTRACT

This paper presents a study on influence of Electrical Discharge Machining to surface integrity of SKD 11 tool steel. The factors that concerned in this paper were pulse on time and peak current. The surface integrities that have been checked were, white layer thickness and surface hardness. EDM is essentially a thermal process with a complex metal –removal mechanism, involving the formation of plasma channel between the tool and workpiece electrode. The sparks produced during the EDM process locally melt the metal surface, which then undergoes an ultrarapid quenching. After solidification, a layer is formed at the workpiece surface, the so-called white layer. By using DOE full factorial design, 16 trials have been carried out. Each of the 10mmX10mm cross sectional area block of tool steel was EDMed by copper electrode with pulse on time and peak current varies. The EDMed surfaces of blocks were observed for its white layer thickness and surface. The results were analyzed to determine the most significant impact factor and relationship of the parameters selected with the WLT and surface hardness. With respect to white layer thickness, both factors were found to be insignificant, but peak current was the most impact factor compared to pulse on time. Both factors are proportional to the white layer thickness, while peak current and pulse on time increase, the white layer was also increase. On the other hand, with respect to surface hardness, both of the effects were insignificant. The relationship of the factor and surface hardness is direct proportional.

ABSTRAK

Kertas ini membentangkan satu kajian tentang pengaruh Electrical Discharge Machining ke atas integriti permukaan SKD 11 tool steel. Faktor-faktor yang akan dikaji dalam kertas ini ialah pulse on time dan arus puncak. Integriti permukaan yang akan diperiksa ialah ketebalan lapisan putih dan kekerasan lapisan permukaan. EDM ialah satu proses terma di mana kompleks mekanisme pemindahan logam berlaku, dan pembentukan saluran plasma antara benda kerja dengan elektrod. Bunga api akan dihasilkan sepanjang EDM dijalankan untuk mencairkan permukaan logam, yang kemudiannya melalui satu ultrarapid quenching. Selepas pemejalan, satu lapisan putih akan terbentuk di permukaan. Dengan menggunakan kaedah DOE full factorial design, 16 eksperimen telah ilaksanakan. Setiap 10mmX10mm luas keratan rentas blok tool steel telah dimesinkan oleh elektrod kuprum dengan pulse on time dan arus puncak yang berbeza. Permukaan blok yang dimesin akan dikaji dari segi *white layer thickness* (WLT) dan *surface hardness*. Hasil eksperimen ini dianalisis untuk menentukan hubungan parameter terpilih dengan *white layer thickness* dan *surface crack density*. Daripada keputusan ketebalan lapisan putih, kedua-dua factor tidak memberi impak yang tinggi kepada ketebalan lapisan putih. Walau baigai mana pun, arus puncak memberi impak yang lebih tinggi berbanding dengan pulse on time. Apabila kedua-dua factor tersebut meningkat, ketebalan lapisan putih juga meningkat. Daripada keputusan yang dapati, puncak arus dan pulse on time juga tidak memberi impak yang tinggi kepada kekerasan lapisan permukaan. Apabila kedua- dua factor tersebut meningkat, keputusan kekerasan lapisan permukaan tidak menunjuk hubungan meraka dengan jelas, iaitu meningkat atau menurun.

DEDICATION

For my beloved father and family

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TABLE OF CONTENTS

1. CHAPTER 1

2. CHAPTER 2

3. **CHAPTER 3 METHODOLOGY**

4. **RESULT AND DISCUSSION**

5. CHAPTER 3 METHODOLOGY

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EDM	- Electric Discharge Machining
SCD	- Surface Crack Density
WLT	- White Layer Thickness
RC	- Relaxation Circuit
t_i	- Pulse On Time
t_0	- Pulse Off Time
I	- Intensity
IC	- Integrated Circuit
3D	- Three-dimensional
RPM	- Rotation per Minute
DOE	- Design of Experiment
SEM	- Scanning Electron Microscope
V_w	- Material Removal Rate
SH	- Surface Hardness
E_f	- Effect of Factor

CHAPTER 1

INTRODUCTION

This chapter will discuss the basic concept of the electrode discharge machining (EDM) die sinking. Background and statement of problem will also state in this chapter. It will followed by objective, scope and importance of study.

1.1 Introduction

Electric discharge machining (EDM) provide an effective manufacturing technique that enable the production of parts made of hard material with complicated geometry that are difficult to produce by conventional machining processes. Its ability to control the process parameter to achieve the required dimensional accuracy and surface finish has placed this machining operation in a prominent position in industrial applications [1].

EDM removes electrical conductive material by mean of rapid, repetitive spark discharge from a pulsating direct-current power supply with dielectric flow between the workpiece and the tool. The shaped tool (electrode) is fed into the workpiece under servo control. A spark discharge then breaks down the dielectric fluid. The servo control maintains a constant gap between the tool and the workpiece whilst advancing the electrode. The dielectric oil cools and flushes out the vaporized and condensed material whilst re-establishing insulation in the gap [2].

There is a structure change of the EDMed surfaces. For tool steels, it has been shown that the top most surface layer is an uneven, non-etchable layer, namely the ‘white layer’. This is a re-cast layer formed by the molten metal solidifying at an extremely high rate after the discharge process. Immediately beneath the ‘white layer’ there is an intermediate layer, a heat-affected zone, where the heat is not high enough to cause melting but is sufficient high to induce micro-structural transformation in the material [3]. The re-cast layer is found to be heavily alloyed with the pyrolysis products of the cracked dielectric. With suitable reagents, it has been shown that, depending on the steel and on the machining condition, a variety of micro-structures can result [4]

1.2 Background of Problem

During machining of metals by electrical discharged machining (EDM) process a large amount of heat is generated. For which the affected layer is beneficial in terms of enhanced abrasion and erosion resistance, the defects within it such as void, cracks, induced stress, etc cause an overall deterioration of the component’s mechanical properties[5]. Since the quenching is happen during the EDM process, thus the surface hardness undergoes hardening process. This unexpected and uncontrollable hardening process will yield unknown surface hardness, and unfavorable mechanical properties.

In order to remove the recast layer, manufacturers will perform a finish operation such as the lapping process. By polishing the surface with abrasive grains (e.g. silicon carbide, alumina, or diamond) in the presence of lubricant, the white recast layer can be removing and a lustrous, mirror-like finish can be achieved. It is important to determine the average thickness of the white layer in order to define the proper polishing/lapping conditions. This is because the polishing process is removing material from the EDM surface, and if too much of material is removed there might be loss in tolerance. Hence it is necessary to determine the thickness of the white layer formed under a given set of process conditions. Then the depth to which the material needs to be spark eroded can be calculated. Eventually, by removing the white layer, the required dimension and tolerance of the workpiece would be achieved, and the surface would be engineered according to the required finish and free from defects [7].

Although esteemed institutions and researchers all over the world have already initiated some researches and investigated the effect of EDM parameters on surface integrity, but most of response are qualitative. This paper will discuss the surface integrity in term of quantitative (white layer thickness and surface crack density), it will be beneficial to the recent industrial; if the average of the white layer thickness regard to its parameter is known.

1.3 Statement of Problem

Base on this study, several question need to be answer at the end of the experiment and analysis.

- What is the influence of peak current and pulse on time to the white layer thickness and surface hardness?
- Which of the factor give most influence to the white late thickness and surface hardness?

1.4 Objective

The objectives of this paper are to:

- Investigate the most influence factor among peak current and pulse on time.
- Investigate the sequence of white layer thickness (WLT) and surface hardness that influenced by peak current and pulse on time.

1.5 Scope

The study of this paper has covered the effect of the EDMed White Layer Thickness (WLT) and surface hardness. The response such like surface roughness and residual stress was not discussed in this paper. Since the parameter of the experiment is set to peak current and pulse on time, so the other parameters such as voltage and pulse off time, type of electrode and material, were not put in to consideration in the experiment. The electrode that used in the experiment is copper and the material that undergoes the EDM process is SKD 11 tool steel. This paper did not consider the difference of the surface integrity by using other type of electrode and material.

1.6 Importance of Study

This paper is important in the sense of the need of the industrial to know the effect of the parameters to the white layer thickness. This will help them to remove the white layer within the tolerance. The study is also important at investigation of surface hardness which is the potentially concerns by industrial. The surface hardness may lead to unwanted mechanical property change of EDMed product. Therefore minimize the failure of the product by controlling the parameters could help the moulding industry to produce better quality parts and increase the challenges in the global markets.

1.7 Expected Result

The WLT and surface hardness can be investigated by varies the peak current and pulse on time. Different peak current and pulse on time will produce different WLT and surface hardness. Besides, by applying DOE method on this experiment, the most influence parameter and relation between the parameter and the response can be analyzed.

CHAPTER 2

LITERATURE REVIEW

This chapter discussed the theory about the study in detailed. The previous researches and study also summarized in a table.

2.1 Electro Discharge Machining (EDM) Die Sinking

Electrical discharge machining (EDM) is one of the most extensively used non-conventional material removal processes. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage in the manufacture of mould, die, automotive, aerospace and surgical components. In addition, EDM does not make direct contact between the electrode and the workpiece eliminating mechanical stresses, chatter and vibration problems during machining. Today, an electrode as small as 0.1 mm can be used to 'drill' holes into curved surfaces at steep angles without drill 'wander' [8].

2.1.1 History Background

The first EDM application was carried out by Mr. and Mrs. Lazarenko in the Technical Institute of Moscow during the Second World War [9]. The first of the two important improvements, also carried out by these Soviet scientists, who make it feasible to elevate this electrical technique to the category of manufacturing process, was the RC relaxation circuit (Fig. 2.1), which provided the first consistent dependable control of pulse times. The second innovation consisted of adding a simple servo control circuit in order to find and hold a given gap automatically. In spite of these first trials and innovations, EDM technology got nearly unknown until the 1950s. At this time, this technique began to be interesting for the industrial marketing mainly in the USA. Some of the causes that eased a much more widespread use of the EDM process were the vacuum tubes, its combination with the basic RC relaxation circuit and finally, the development of the transistor. These solid state devices were able to provide high currents and a really much faster switch on and off than the previous vacuum tubes. Nowadays, EDM is widely used both in the European market and in the American market.

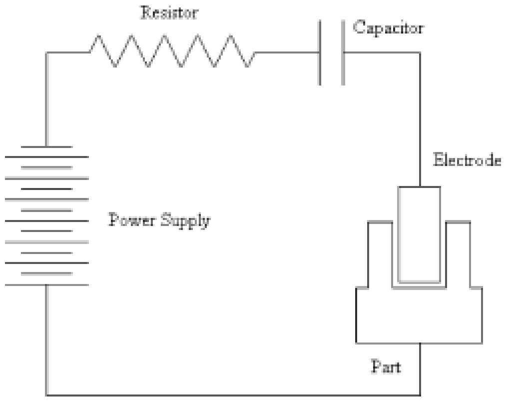


Figure 2.1: The basic RC relaxation circuit

2.1.2 EDM Process

Electrical-discharge machining (EDM) removes electrically conductive material by means of rapid, repetitive spark discharges from a pulsating direct-current power supply with dielectric flow between the workpiece and the tool. The shaped tool (electrode) is fed into the workpiece under servo control. A spark discharge then breaks down the dielectric fluid. The servo control maintains a constant gap between the tool and the workpiece whilst advancing the electrode. The dielectric oil cools and flushes out the vaporised and condensed material whilst re-establishing insulation in the gap [10]. Several theories were proposed by early investigators to account for the erosion mechanism of the EDM process [11]. It has been accepted generally that the metal removal phenomenon is predominantly thermal in nature [2]. The best explanation of EDM phenomena has been established by extensive experimental studies [12, 13].

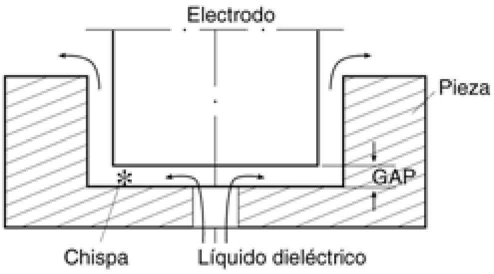
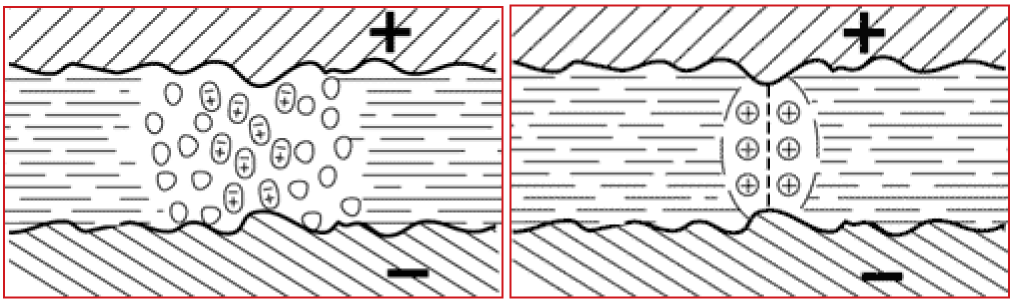


Figure 2.1: EDM machining, (JLS Machine Tool, Inc. 2005).

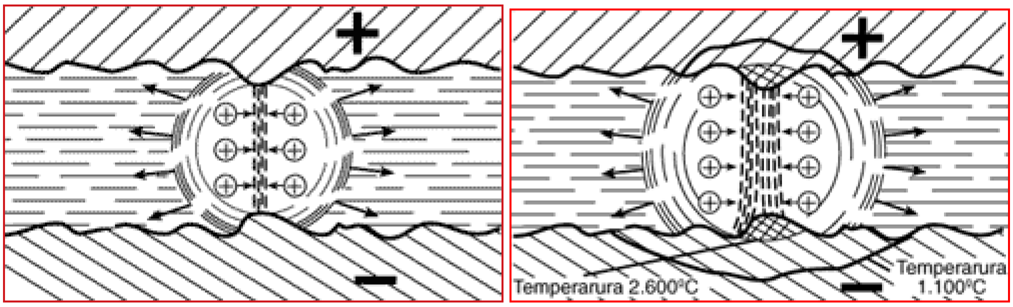
EDM machining is performed, therefore, by means of electric sparks which jump between two electrodes subjected to a given voltage which are submerged in an insulating liquid (dielectric fluid). Since the two electrodes are in a dielectric or insulating medium, the voltage applied to them must be sufficient to create an electric field which is greater than the dielectric rigidity of the fluid.



(a) **(b)**

Figure 2.2: **(a)** Free positive ions and electrons are accelerated **(b)** A channel of plasma is thus formed

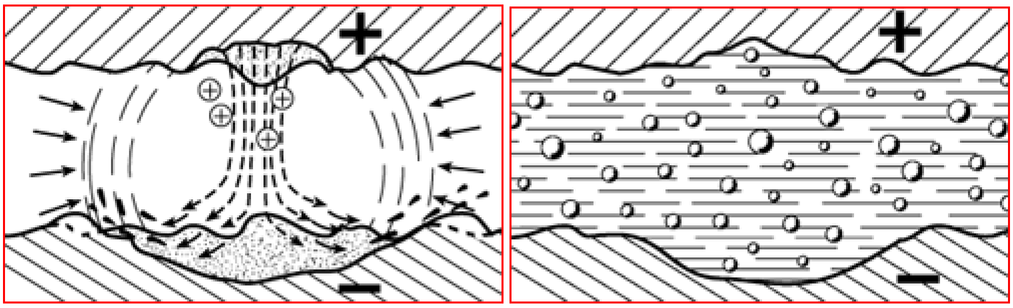
As a result of the action of this electrical field, free positive ions and electrons are accelerated, creating a discharge channel which becomes a conductor, and it is precisely at this point where the spark jumps. This causes collisions between the ions (+) and the electrons (-). A channel of plasma is thus formed.



(a) **(b)**

Figure 2.3 **(a)** Collision happened **(b)** heat generated

These collisions create high temperatures in both poles and a ball of gas is formed around the plasma channel, which begins to grow. At the same time, the high temperatures in the two poles melt and vaporise part of the material of the part, while the electrode itself suffers only very slight wear.



(a) **(b)**

Figure 2.4 **(a)** Implode (explode inwards) **(b)** EDM splinter

In this situation (large ball of gas and molten material at both poles) the electric current is turned off. The plasma channel collapses and the spark disappears. The dielectric fluid then breaks the ball of gas making it implodes (explode inwards). This creates forces which force the molten material by forming two craters on the surfaces. The molten material solidifies and is carried away in the form of balls by the dielectric fluid to form what we might call the "EDM splinter"[14].

Some of the most important parameters implicated in the EDM manufacturing process are the following ones:

i. On-time (pulse time or t_i: is the duration of time (µs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.
ii. Off-time (pause time or t_0): is the duration of time (µs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.

iii. Arc gap (or gap): is the distance between the electrode and the part during the process of EDM. It may be called as spark gap.

iv. Duty cycle: is a percentage of the on-time relative to the total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time plus off-time). The result is multiplied by 100 for the percentage of efficiency or the so called duty cycle.

v. Intensity (*I*): points out the different levels of power that can be supplied by the generator of the EDM machine. (*I*) represents the mean value of the discharge current intensity [15].

2.1.3 EDM Application

In some applications, EDM has replaced traditional machining processes such as the milling of heat-treated tool steels. Milled material has to be within an acceptable hardness range of less than 30–35 HRC with ordinary cutting tools [16]. However, EDM allows tool steels to be treated to full hardness before machining, avoiding the problems of dimensional variability, which are characteristic of post-treatment [17]. Since EDM does not induce mechanical stresses during machining, it provides an additional advantage in the manufacture of intricate products. Weng and Her [18] carried out several successful experiments involving an electrode of 50 μm diameter and a multi-electrode for the batch production of micro-parts. The proposed method significantly reduces the production time and costs of fabricating both the electrodes and parts.

The recent trend in reducing the size of products has given micro-EDM a significant amount of research attention. Micro-EDM is capable of machining not only micro-holes and micro-shafts as small as 5 μm in diameter but also complex three-dimensional (3D) micro cavities [19]. This is unlike mechanical drilling, which can produce holes just up to 70 μm, or the micro-fabrication process such as laser machining, which can only create holes of 40 μm [20]. Masuzawa et al. [21-23] also made several successful attempts producing micro parts such as micro-pins, micro-nozzles and micro-cavities using micro-EDM. In addition, a feasibility study of applying micro-EDM as an alternative method for producing photo-masks used in the integrated circuit (IC) industry has been conducted [24]. Other applications include the general interest in developing trajectory EDM to solve the machining problems of water-cooling channels used in moulds or manifolds. Ishida and Takeuchi [25] recently proposed a trajectory EDM technique facilitating the electrode to move along a smooth trajectory, while performing EDM eliminating the conventional drilling or boring operation required. Other attempts [26, 27] have also been made on trajectory EDM but special apparatus or complex control mechanism is needed to develop the trajectory motion of electrode.

2.2 Electrode

Drozda (1998) reminds that the tool electrode is responsible to transport the electrical current to the workpiece. Therefore, any material to be used as a tool electrode is required to conduct electricity. In fact, there is a wide range of materials used to manufacture electrodes, for instance, brass, tungsten carbides, electrolytic copper, copper-tungsten alloys, silver-tungsten alloy, tellurium-copper alloys, copper-graphite alloys, graphite etc. In practical terms the choice of the electrode material will depend mainly on the tool size, the workpiece requirements, type of EDM machine and the methods of making the electrodes. Other important factors shall be considered when selecting the electrode material:

i. Workpiece material removal rate V_w [mm^3/min]: a correct choice of EDM parameters to the pair tool /workpiece electrode materials will increase the value of V_w.

ii. Electrode resistance to wear: there are four types of wear: volumetric, corner, end and side wear. Of the four, volumetric and corner wear are very important in finish EDM operations of fine details. Minimization of those wear requires choosing adequate EDM parameters and proper electrode material.

iii. Workpiece surface roughness: good workpiece quality is obtained by the proper choice of electrode material, good flushing conditions and adequate EDM parameter settings.

iv. Tool electrode material machinability: copper and graphite are the most commonly used. However, it is important to select an electrode material