# EFFECTS OF MACHINING CHARACTERISTICS ON ELECTRIC DISCHARGE MACHINE USING DIFFERENT ELECTRODE MATERIALS

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A report submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing

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# **STUDENT'S DECLARATION**

"I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award and in candidature of other degree."

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"To my beloved mother, father, family and someone special who gave me encouragement and support towards this study"

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### ABSTRACT

Electric discharge machining (EDM) is a non-traditional machining processes that involved a transient spark discharges through the fluid due to the potential difference between the electrode and the work piece. The aim of this project is to determine the proper electrode material for machining tool steels work pieces using electrical discharge machining (EDM). Basically, improper choose of electrode material in EDM machine may result a few problems like the machine may cause of poor machining performance and it will decrease the accuracy of the products. This paper presents a fundamental study of characteristic of electrode discharge machine (EDM) that is electrode wear ratio (EWR) and material removal rate (MRR) by using different electrode materials in order to increase the understanding of EDM processes. To archive this project objective, an experiment will be doing properly. By following the method, some literature review is going to do first before preparing the experimental set-up. Then experiment will be runs and the data of the experiment are taken. This is to make sure the analysis can be done in order to find the best electrode material. There are three electrodes material should be compared that are copper, brass and aluminum. Regarding the literature review, the higher material removal rate in the EDM machine, the better is the machining performance while the lower electrodes wear ratio in the EDM machine is the better and accurate performance characteristic. Thus as the expected result for this experiment, the copper electrode material will be the best electrode among others electrode for EDM machining process.

#### ABSTRAK

Mesin elektrik discas atau lebih dikenali sebagai EDM ialah salah satu alternatif baru dalam proses pemesinan dan pemotongan bahan. Teknologi EDM melibatkan perbezaan potensi cas elektrod dalam konduktor bendalir yang seterusnya menyahcas dan menghasilkan daya tenaga elektrik untuk memotong bahan kerja. Dewasa ini, EDM telah diperluaskan penggunaannya dalam industri untuk menghasilkan sesuatu produk disebabkan ketepatan simetri hasil produk, pantas, efisyen dan banyak lagi kelebihannya. Menyedari hakikat ini, satu kajian mengenai EDM telah dirangka untuk menyelongkar dan memastikan elektrod yang sesuai digunakan dalam EDM untuk memotong bahan terutamanya besi. Realitinya, pemilihan elektrod yang tidak sesuai akan mengakibatkan kesan tidak diingini seperti jangka masa proses yang perlahan, mutu pengeluaran yang tidak bagus serta mengurangkan ketepatan dan kualiti produk. Tesis ini berobjektifkan untuk meyelidik kesahihan kesan dan pengaruh karekter utama pemesinan iaitu kadar pemotongan bahan (MRR) dan nisbah hakisan elektrod (EWR) dalam misi menentukan elektrod terbaik untuk pemotongan unsur besi. Rentetan itu, experimentasi harus dilakukan demi menjadikan tujuan asal projek ini terlaksana. Eksperimen ini dilakukan setelah selesai membaca serta mentelaah bahan-bahan artikel dan juga pencarian maklumat di jalur lebar. Apabila selesai, data yang dikumpul bakal dianalisa untuk menentukan nilai MRR dan EWR. Namun, eksperimen melibatkan pemotongan besi ini hanya dihadkan untuk mengkaji 3 jenis elektrod sahaja jaitu kuprum, perak dan aluminium. Merujuk hasil kajian yang lepas, lebih tinggi nilai MRR bakal mencanangkan produktiviti yang lebih baik. Sebaliknya, semakin merosot nilai EWR pula menjadikan mutu kerja yang semakin efisyen. Melalui informasi ini juga, ramalan mengenai elektrod terbaik untuk pemesinan besi dengan EDM kemungkinan besar adalah kuprum.

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# **CHAPTER 1**

# **INTRODUCTION**

## **1.1 INTRODUCTION**

Electrical Discharge Machine (EDM) is now become the most important accepted technologies in manufacturing industries since many complex 3D shapes can be machined using a simple shaped tool electrode. Electrical discharge machine (EDM) is an important 'non-traditional manufacturing method', developed in the late 1940s and has been accepted worldwide as a standard processing manufacture of forming tools to produce plastics moldings, die castings, forging dies and etc. New developments in the field of material science have led to new engineering metallic materials, composite materials, and high tech ceramics, having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. At the present time, Electrical discharge machine (EDM) is a widespread technique used in industry for highprecision machining of all types of conductive materials such as: metallic alloys, graphite, or even some ceramic materials, of whatsoever hardness. Electrical discharge machine (EDM) technology is increasingly being used in tool, die and mould making industries, for machining of heat treated tool steels and advanced materials (super alloys, ceramics, and metal matrix composites) requiring high precision, complex shapes and high surface finish. Traditional machining technique is often based on the material removal using tool material harder then the work material and is unable to machine them economically. An electrical discharge machining (EDM) is based on the eroding effect of an electric spark on both the electrodes used. Electrical discharge machining (EDM) actually is a process of utilizing the removal phenomenon of electrical-discharge in dielectric. Therefore, the electrode plays an important role, which affects the material removal rate and the tool wear rate [4].

# **1.2 PROJECT BACKGROUND**

Electrical discharge machine (EDM) is commonly used in tool, die and mould making industries for machining heat-treated tool steel materials. The heattreated tool steels material falls in the difficult-to-cut material group when using conventional machining process. The high rate of tool wear is one of the main problems in electrical discharge machine (EDM). The wear ratio defined as the volume of metal lost from the tool divided by the volume of metal removed from the work material, varies with the tool and work materials used. If the rate of tool wear is high means that the material is easy to wear and not good for machining performance [3].

The significant of this study is to promote the consideration of electrode selection in electrical discharge machine (EDM) machine for advance machining in the manufacturing industries. This is because every electrode materials have their own characteristic that lead to different result due to its properties. Electrical discharge machine (EDM) has been analyzed since several years in order to improve the material removal rate and the wear ratio, which are the most critical aspects of the process. In the machining of electrical discharge machine (EDM), there are a few characteristics which influence the machining process. Most important are the material removal rate (MRR) and electrode wear ratio (EWR). These characteristics should be taken into account when good machining performance is needed [10].

The case studies of this project are to determine the best material removal rate (MRR) and electrode wear ratio (EWR) from different selection materials. This would lead to the better process and product finishing. In other words, if we can determine the best material removal rate (MRR) and electrode wear ratio (EWR), the best performance of machining for electrical discharge machine (EDM) can be archived. However, the machining characteristics of electrical discharge machine (EDM) remain unclear, especially in regard to the total energy of discharge pulses and tool electrode wear, since the energy is not only used to machine the work piece, but also degrades the tool electrode [10]. Hence, some investigation needs to do to find the best electrode for best performance in machining using electrical discharge machining (EDM). Generally, the summary of the literature review have found that

the higher material removal rate (MRR) and the lower electrode wear ratio (EWR) are the better for machining process performances.

## **1.3 PROBLEM STATEMENT**

In electrical discharge machine (EDM), improper choose of the electrode material may cause of poor machining rate or performance. This is due to material removal rate (MRR) characteristic. Less material removal rate (MRR) needs more time for machining process and become waste and not goods for production. The second problem is it will decrease the accuracy of the product because influence of the electrode wear ratio (EWR) characteristic. The accuracy of the product occurs maybe because the electrode wear ratio (EWR) is high or material removal rate (MRR) is not suitable. Furthermore, electrode wear imposes high costs on manufacturers to substitute the eroded complicated electrodes by new ones for die making. In order to increase the machining efficiency, erosion of the work piece must be maximized and that of the electrode minimized in EDM process. Therefore, studying the electrode wear and related significant factors would be effective to enhance the machining productivity and process reliability.

# **1.4 OBJECTIVE**

The objective of this project is to determine the proper electrode material for machining tool steels work pieces using electrical discharge machining (EDM). When the best electrode can be determine, it would lead to better process performance in electric discharge machining (EDM). To archive this, the characteristic of machining must be determine because the higher material removal rate (MRR) and less electrode wear ratio (EWR) will lead to better performance.

# **1.5 PROJECT SCOPES**

The research scope is limited to: Machining parameters refers to electrical parameters on electrical discharge machine (EDM) i.e. polarity, pulse-on-duration,

discharge current, discharge voltage. The scope should be limited in this experiment due to low cost and time. Beside, there are three tool electrode used that are Aluminum, brass and cooper. The reason for using these only three materials is regarding to cost limitation and availability. This is also including calculation of the machining characteristics i.e. material removal rate (MRR) and electrode wear ratio (EWR). The calculation is needed to analyze the result and data collections.

Beside, this paper project hopefully can gain a lot of understanding and get more knowledge about the electric discharge machine (EDM). This is important to get familiar with this method nowadays. Among the non-traditional methods of material removal processes, electrical discharge machining (EDM) has drawn a great a deal of researchers' attention because of its broad industrial applications. This process is well suited for machining of casting and forging dies, powder metallurgy and injection molds, and aerospace parts.

## 1.6 SUMMARY

Chapter 1 has been discussed briefly about project background, problem statement, objective and scope of the project. This chapter is as a fundamental for the project and act as a guidelines for project research completion. Generally, this thesis consists of five chapters. Chapter 1 that has you read is the introduction about this study. Chapter 2 is the review of literature which discusses methods and findings previously done by other people which are related to the study. Chapter 3 is the Methodology which explains the approaches and methods used in performing the thesis. Chapter 4 is the chapter which reports the outcomes or results and discussion from the project and chapter 5 consists of the recommendation and conclusion.

# **CHAPTER 2**

## LITERATURE REVIEW

# 2.1 INTRODUCTION

Literature review is one of the scope studies. It works as guide to run this analysis. It will give part in order to get the information about electrical discharge machine (EDM) and will give idea to operate the test. From the early stage of the project, various literature studies have been done. Research journals, books, printed or online conference article were the main source in the project guides. This part will include almost operation including the test, history, machining properties and results. History of the electrical discharge machine (EDM) will be story little bit in this section. Literature review section work as reference, to give information and guide base on journal and other source in the media.

## 2.2 HISTORY OF ELECTRICAL DISCHARGE MACHINE (EDM)

The history of EDM Machining techniques goes as far back as the 1770s when it was discovered by an English Scientist. However, Electrical Discharge Machining was not fully taken advantage of until 1943 when Russian scientists learned how the erosive effects of the technique could be controlled and used for machining purposes. When it was originally observed by Joseph Priestly in 1770, EDM Machining was very imprecise and riddled with failures. Commercially developed in the mid 1970s, wire EDM began to be a viable technique that helped shape the metalworking industry we see today. In the mid 1980s, the EDM techniques were transferred to a machine tool. This migration made EDM more widely available and appealing over traditional machining processes [6].

# **2.3 ELECTRICAL DISCHARGE MACHINE (EDM)**

Electrical discharge machine (EDM) is a modern machine that can drilling, milling, grinding, and other traditional machining operation. EDM now become the most important accepted technologies in manufacturing industries since many complex 3D shapes can be machined using a simple shaped tool electrode. In manufacturing industry, Electro Discharge Machining (EDM) is commonly used for producing mould and die component. This machine is use because the ability of the machining process that is very accurate in creating complex or simple shape within parts and assemblies. The cost of machining is quite high payable to its initial investment and maintenance for the machine but very desirable machining process when high accuracy is required. Since electrical discharge machining (EDM) was developed, much theoretical and experimental work has been done to identify the basic processes involved. It is now one of the main methods used in die production and has good accuracy and precision with no direct physical contact between the electrodes so that no mechanical stress is exerted on the work piece. The important output parameters of the process are the material removal rate (MRR) and tool electrode wear ratio (EWR) [10].

#### 2.4 ELECTRIC DISCHARGE MACHINE (EDM) PROCESS

The electrical discharge machine (EDM) removes work piece by an electrical spark erosion process. Common methods of evaluating machining performance in EDM operation are based on the following performance characteristic: MRR, SR, and EWR. Basically, this characteristics' are correlated with the machining parameters such as work piece polarity, pulse on time, duty factor, open discharge voltage, discharges current and dielectric fluid. Proper selection of the machining parameters can obtain higher material removal rate, better surface roughness, and lower electrode wear ratio [10]. Machining takes place by the discharge pulse from the cathode to the anode. Usually, the polarity is set, so that the work piece acts as the anode and the tool electrode acts as the cathode, in order to obtain a higher material removal rate. The discharge pulse gap is relatively small, thus the accuracy of components or parts manufactured by EDM is very high. EDM is a thermo-

electrical material removal process, in which the tool electrode shape is reproduced mirror wise into a work material, with the shape of the electrode defining the area in which the spark erosion will occur [14]. EDM is accomplished with a system comprising two major components: a machine tool and power supply. The machine tool holds a shaped electrode, which advances into the work material and produces a high frequency series of electrical spark discharges. The sparks are generated by a pulse generator, between the tool electrode and the work material, submerged in a liquid dielectric, leading to metal removal from the work material by thermal erosion or vaporization [14]. The EDM phenomenon, as it is understood, can be divided into three stages namely application of adequate electrical energy, dielectric breakdown, sparking, and expulsions (erosion) of work material [14]. The spark erosion of the work material makes use of electrical energy, converting them into thermal energy through a series of repetitive electrical discharges between the tool electrode and the work material electrode [14]. The thermal energy generates a channel of plasma between the two electrodes, at a temperature ranging from 8000 to 12,000 °C, and as high as 20,000 °C [8]. When the pulsed DC supply ~20,000-30,000 Hz, is switched off, the breakdown of plasma channel occurs, resulting in a sudden reduction in the temperature, allowing the circulating dielectric fluid to flush away the molten work material from the EDM machined surface in form of microscopic debris. Melting and vaporization of the work material dominates the material removal process in EDM, leaving tiny craters on the surface of the work material. EDM has no contact and no cutting force process, and therefore does not makes direct contact between tool electrode and the work material. This eliminates the chances of mechanical stress, chatter and vibration problems, as is prominent in traditional machining. Material removal rate (MRR) for EDM operation is somewhat slower than with traditional machining methods, where chips are produced mechanically. The rate of material removal is dependent upon the following factors: amount of pulsed current in each discharge, frequency of the discharge, electrode material, work material and dielectric flushing condition. Diameter overcut (dimensional accuracy) becomes important when close tolerance components are required to be produced for space application and also in tools, dies and moulds for press work, plastic molding and die casting. EDM does not induce any mechanical stresses during EDM thereby providing an additional advantage in the manufacture of intricate and complexshaped products [14]. Electrode wear takes place during the EDM operation when the electrode (i.e. the tool) gets eroded due to the sparking action. The rate at which the electrode wears is considerably less than that of the work material. In EDM, each electrical spark discharge produces a tiny spherical crater in the work material by local melting and vaporization. With high sparking frequencies the spark erosion gives substantial metal removal rates. The depth of the crater defines the surface finish which in turn depends on the current, frequency, and finish of the electrode. The metal removal rates and surface finish are controlled by the frequency and intensity of the spark. It has been found that high frequency and low amperage settings give the best surface finish. High amperage leaves a larger crater having large diameter and depth in a random location [14]. Surface finish produced on machined surface plays an important role in production. It becomes more desirable so as to produce a better surface when hardened materials are machined, requiring no subsequent polishing. Surface finish is also important in the case of tools and dies for molding as well as drawing operations. Surface roughness and dimensional accuracy of a spark-eroded work material depend on discharge currents, electrode materials and electrode polarity. With EDM processes, work piece surface modifications can be well controlled, [7] and highly accurate geometric predictions can also be made [8]. However, the machining characteristics of EDM remain unclear, especially in regard to the total energy of discharge pulses and tool electrode wear, since the energy is not only used to machine the work piece, but also degrades the tool electrode. Hence, the accuracy of the components machined by EDM is also influenced by the wear of the tool electrode [7, 8] From the literature survey, it has been observed that no extensive work has been done with different tool electrode materials on the work material steel (used for cold forming rolls, Knurling tools, press tools, lathe centre's, etc.). There exists a great need for investigating the effect of various electrode materials and pulsed discharge currents on material removal rate, diameter overcut, electrode wear and surface roughness in electric-discharge machining of tool steel.



Figure 2.1: EDM process [14]

(a) Schematic illustration of the electrical-discharge machining process. This is one of the most widely used machining processes, particularly for die-sinking applications.

(b) Examples of cavities produced by the electrical-discharge machining process, using shaped electrodes. Two round parts (rear) are the set of dies for extruding the aluminium piece shown in front (see also Fig. 19.9b).

(c) A spiral cavity produced by EDM using a slowly rotating electrode similar to a screw thread.

(d) Holes in a fuel-injection nozzle made by EDM; the material is heat-treated steel.

Source: (b) Courtesy of AGIE USA Ltd

# 2.5 ELECTRIC DISCHARGE MACHINE (EDM) CAPABILITIES

There are a lot of benefits when using electrical discharge machine (EDM) when machining. This is due to its capabilities and advantage. To summarize, these are the electric discharge machine (EDM) capabilities compare to other method [9]:

- Material of any hardness can be cut
- High accuracy and good surface finish are possible
- No cutting forces involved
- Intricate-shaped cavities can be cut with modest tooling costs
- Holes completed in one "pass"

# 2.6 ELECTRIC DISCHARGE MACHINE (EDM) LIMITATIONS

But, when using electric discharge machine (EDM) when machining there are a few limitation. These are electric discharge machine (EDM) limitation [9]:

- Limited to electrically conductive materials
- Slow process, particularly if good surface finish and high accuracy are required
- Dielectric vapour can be dangerous
- Heat Affected Zone (HAZ) near cutting edges
- Die sinking tool life is limited.

## 2.7 OPTIMIZATION PERFORMANCE

The complexity EDM and the number of the involved parameters require an accurate analysis for assessing the process performance. The effects of electrode material and flushing, in conjunction with electrode size and depth of cut, upon productivity, electrode wear and surface quality have been evaluated through a complete factorial experiment. The analysis has considered separately roughing and finishing regimes, by adopting the operative conditions usually recommended in industrial production. Productivity and electrode wear were measured by features especially and differently defined for roughing and finishing regimes. Surface quality

was assessed only for finishing, by adopting three height parameters and three form parameters. The experiment yields the following main conclusions [3]:

\*The electrode material has significant influence in finishing operations on wear and height roughness parameters.

\*In all the experiments the effect of the electrode size resulted relevant on productivity and electrode wear [3].

From the research of journals, the hypothesis can be made regarding machining performance is the wear ratio of the electrode becomes small for the electrode material with high boiling point, high melting point, and high thermal conductivity. The higher thermal conductivity of the electrode ensures a better spark discharge energy distribution during the EDM process. This will increase material removal rate (MRR) [10].

# 2.8 MACHINING PARAMETER SELECTION

In this research, electrode wear ratio (EWR) is important. Electrode tool wear is also used as a parameter to measure the ease of machining in the EDM processes, because the total energy of discharge pulses is not only used to machine the work piece, but also degrades the tool electrode [4]. Another important parameter is material removal rate (MRR). This two characteristic, electrode wear ratio (EWR) and material removal rate (MRR) is a major influence resulting the machining performance.

Tool Steel is actually, any grade of steel that can be used for a tool. Generally the term tool steel as applied in the steel industry is a grade of steel characterized by high hardness and resistance to abrasion coupled in many instances with resistance to softening at elevated temperatures. These properties are attained with high carbon and high alloy contents and the steel is usually melted in electric furnaces to assure cleanliness and homogeneity of the product.

Among the numerous parameters affecting the EDM performance, the dielectric fluid has a very important role. The physical properties of the fluid

influence the breakdown voltage and the ignition delay: however, the debris concentration in the fluid modifies these parameters, decreasing the dielectric strength by many orders of magnitude [5]. But this parameter is neglect due to limitation of scope of studies.

Electrical characteristics also affect the result of machining performance. High pulsed current and pulse time provide low surface finish quality. However, this combination would increase material removal rate and reduce machining cost. As a result, this combination (high pulsed current and pulse time) should be used for rough machining step of EDM process [6]. Generally, rough and finish machining steps require different level of machine power. For rough EDM application, the machine power should be one-fourth of the produced power with 16A of current, 6s of pulse time and 3s of pulse pause time. Finish machining should be carried out at one-half level of power at 8A of current as well as 6s of pulse time and 3 s of pulse pause time [8]. Unfortunately, this parameter is not discussed too much in this paper because the title is concentrated more on machining characteristics.

# 2.9 MACHINING PERFORMANCE EVALUATION

Material removal rate (MRR), surface roughness (SR), and electrode wear ratio are used to evaluate machining performance. The MRR increased when electrodes were used with positive polarity in all cases of semi-sintered electrodes. In the case of the copper electrode, EDM cannot be used when positive polarity was selected, due to no conductive layer being generated. The highest MRR and minimal wear were obtained using EDM-C3 with positive polarity. The copper electrode gave the highest electrode wear ratio. The results of electrode wear ratio relate to melting point; materials with higher melting points wear less. However, the wear ratio is inversely proportional to the MRR result. In the case of lower MRR, the electrode must spend more time to achieve machining. The positive polarity gives better MRR than negative polarity. This result is the same as for EDM on a conductive material. This can be explained by the fact that positive polarity gives better machining by causing a higher MRR under higher discharge energy. The material removal rate (MRR) is expressed as the work piece removal rate (WRW) under a period of machining time in minute (T), which is [1]:

MRR 
$$(g/min) = WRR/T$$

Generally, the electric discharge machine (EDM) process is a spark erosion method, eroding the work piece by high frequency spark discharges [12]. EDM has a high capability of machining the accurate cavities of dies and moulds. Nevertheless, electrode wear occurs during EDM process leading to a lack of machining accuracy in the geometry of work piece [13]. Furthermore, electrode wear imposes high costs on manufacturers to substitute the eroded complicated electrodes by new ones for die making. In order to increase the machining efficiency, erosion of the work piece must be maximized and that of the electrode minimized in EDM process [12]. Therefore, studying the electrode wear and related significant factors would be effective to enhance the machining productivity and process reliability. The electrode wear ratio (EWR) is define by the ratio of the electrode wear weight (EWW) to the work piece removal weight (WRW) and usually expressed as a percentage, that is [2]:

#### EWR (%) = $[EWW/WRW] \times 100$

However, electrode wear occurs during EDM process leading to a lack of machining accuracy in the geometry of work piece. To reduce the influence of the electrode wear, it is necessary either to feed electrode larger than the work piece thickness in the case of making through-holes, or to prepare several electrodes for roughing and finishing in the present state of technology [11]. Increasing wear on electrode surface is unavoidable during EDM process. Therefore, work piece surface roughness will be increasing due to wear rate on electrode [6].

Basically, the higher material removal rate in the EDM process, the better is the machining performance. However, the smaller the electrode wear ratio and surface roughness in EDM process, the better is machining performance. Therefore, the material removal rate is higher-the-better performance characteristic and the electrode wear ratio and the surface roughness are the lower-the-better performance characteristic.

# **CHAPTER 3**

## METHODOLOGY

# 3.1 INTRODUCTION

Current chapter generally discusses methodology of the project, with a focus on electric discharge machine (EDM) experiment and machining. Relevant data collection is done in order for further research analysis in subsequent chapter. This section contains the methodology to conduct this study. Methodology involves the problem identification and solving, Design of Experiment (DOE), and detail experimental design. Roughly, this project consists of two semesters. For semester 1 will be doing the proposal, literature review and methodology planning. The study of electric discharge machine (EDM) also include in semester one. This all gather in the semester one. The semester two conclude the preparation of experimental tools and work pieces, running experiment, get data collection do the analysis. The documentation and report writing will be done after that. The propose methodology is divide by 2 semester which for final year project (FYP) 1 and final year project (FYP) 2. The methodology flowchart is illustrated in figure 3.2.1 and 3.2.2.



Figure 3.2.1: Flow chart FYP 1



Figure 3.2.2: Flow chart FYP 2

# 3.3 MATERIAL SELECTION

Material selection is the most important to this experiment because different materials have different working parameters based of their properties. The right selection of the machining material is the most important aspect to take into consideration in processes related to the EDM. From the observation and discussion with partner and supervisor, the electrode material that has been selected is Aluminum, brass and cooper while the tools steels as their work pieces.

## 3.3.1 Tool Steels

Tool steels as work pieces are steels that are primarily used to make tools used in manufacturing processes as well as for machining metals, woods, and plastics. Tool steels are generally ingot-cast wrought products, and must be able to withstand high specific loads as well as be stable at elevated temperatures. The tool steels that used in this experiment is high speed tools steel (XW42 Tool Steel). High-Speed Tool Steels: High-speed alloys include all molybdenum (M1 to M52) and tungsten (T1 to T15) class alloys. High-speed tools steels can be hardened to 62-67 HRC and can maintain this hardness in service temperatures as high as 540 °C (1004°F), making them very useful in high-speed machinery. Typical applications are end mills, drills, lathe tools, planar tools, punches, reamers, routers, taps, saws, broaches, chasers, and hobs.

#### 3.3.2 Electrodes

The important factors in selecting aluminum, brass and cooper are their high strength-to-weight ratio, resistance to corrosion by many chemicals, high thermal and electrical conductivity, non-toxicity, reflectivity, appearance and ease of formability and of machinability; they are also nonmagnetic.

The important factors in selecting aluminum (Al) and its alloys are their high strength-to-weight ratio, resistance to corrosion by many chemicals, high thermal and electrical conductivity, nontoxicity, reflectivity, appearance and ease of formability and of machinability; they are also nonmagnetic. The principal uses of aluminum and its alloys, in decreasing order of consumption, are containers and packaging (aluminum cans and foil), building and other types of construction, transportation(aircraft, automobiles and aerospace), electrical applications (as an economical and nonmagnetic electrical conductor) and portable tools.

Brass is any alloy of copper and zinc; the proportions of zinc and copper can be varied to create a range of brasses with varying properties. In comparison, bronze is principally an alloy of copper and tin. Despite this distinction, some types of brasses are called bronzes. Brass is a substitutional alloy. It is used for decoration for its bright gold-like appearance; for applications where low friction is required such as locks, gears, bearings, ammunition, and valves; for plumbing and electrical applications; and extensively in musical instruments such as horns and bells for its acoustic properties.

Copper is a chemical element with the symbol Cu (Latin: cuprum) and atomic number 29. It is a ductile metal with excellent electrical conductivity. Copper is rather supple in its pure state and has a pinkish luster which is (beside gold) unusual for metals, which are normally silvery white. It is used as a heat conductor, an electrical conductor, as a building material and as a constituent of various metal alloys. Copper is malleable and ductile, a good conductor of heat and, when very pure, a good conductor of electricity. Copper is malleable and ductile, a good conductor of heat and, when very pure, a good conductor of electricity.

<b>Table 3.1:</b>	Table	e materia	l properties
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Material	Material Thermal		Melting point (K)
	conductivity		
	(W/m-K)		
Copper	401	2835.15	1357.77
Aluminum	237	2792.15	933.47
Brass	109	2624	900

# 3.4 MACHINE AND EQUIPMENT

The following equipments were used in this experimental works:

1) CNC EDM die sink. This machine was used to drill hole on the tool steel for experiment in the electrical discharge machining process.

Brand : Sodick CNC EDM die sink

Model : AQ55L

No of axis : 3 axes (X, Y & Z)



Figure 3.4.1: EDM machine

# 2) BALANCE

Brand : Precisa

Model : 92SM - 202A DR

Resolution : 10 nanogram

Precision balance was used to measure the weigh of the work piece and electrode before ands after the machining process.



Figure 3.4.2: Balance machine

# 3.5 EXPERIMENT METHOD

In machining any material using wire Electro Discharge Machine (EDM), there are still have many problem for this machine mentioned in chapter one. In order to investigate this study, the design of experiment will be create to solving the parameters problem. This section also discuss about material that must be selected for this study.

# 3.5.1 Experimental Set-up

Before run the experiment, the electrode and work piece is cut regarding their dimension. The electrode needs to be cut its diameter same for all material. The lathe machine is used to cut the electrode. For the work piece, the wire cut EDM machine is used for cutting all specimens in same dimension. This picture refers all the material dimension that should cut and shape.



Figure 3.5.1: Material dimension

## 3.5.2 Experiment Procedure

The electric discharge machine, model SODICK AQ55L (die sinking type) with servo-head (constant gap) and positive polarity for electrode (reverse polarity) will used to conduct the experiment. Kerosene will used as dielectric fluid. These are the procedure of this experiment:

- Experiment will conducted with positive polarity of electrode. The electrode aluminum is taken. The diameter of electrode is measured with a micrometer. Make sure its dimension is according to specification.
- An initial mass is measured with Precisa balance model 92SM 202A DR. Take the electrode mass value and the work piece mass value.
- 3) The work material (tool steel) was mounted on the T-slot table and positioned at the desire place and clamped. The electrode was clamped on the V-block, and its alignment was checked with the help of the try square.
- 4) Set the parameters of the experiment regarding table 1.1
- A depth of cut of 1 mm was set for the machining of all work materials.
   Finally, switches 'ON' for operating the desire discharge current values.
- After machining operation, the electrode was taken out and weight again on Precisa balance. Also take the mass value of work piece after machining.
- 7) The same experiment was repeated with other different electrode materials. This experiment is done by 5 times. The data will take and the average data calculated. This is to make sure the data more accurate.

#### 3.5.3 Machining Parameters

The parameters that are involved in this study are shown in Table 3.2

Electrode	Voltage	Current	Depth of cut	Dielectric
material	(V)	(A)	(mm)	fluid
Aluminum	3	0.2	1	kerosene
Brass	3	0.2	1	kerosene
Cooper	3	0.2	1	kerosene

 Table 3.2: Parameters table

#### **3.6 DATA COLLECTION**

The data that will be taken is:

- 1) Machining time, t
- 2) Mass of work piece before and after, g
- 3) Work pieces removal rate (WRR), g
- 4) Electrode wear weight (EWR), g

## 3.6.1 Analyzed Method

The present work highlights the development of mathematical solution to calculate the EDM machining parameters such as: mass of electrode, pulse duration and voltage on the metal removal rate, wear ratio and surface roughness. This work has been established based on the mathematical equation (3.0). The MRR of the work piece was measured by dividing the weight of work piece before and after machining (found by weighing method using balance) against the machining time that was achieved. After completion of each machining process, the work piece was blown by compressed air using air gun to ensure no debris and dielectrics were present. A precise balance (Precisa 92SM - 202A DR) was used to measure the

weight of the work piece required. Similar procedure for measuring the weight of work piece was used to determine the weight of the electrode before and after machining. The equation (3.1) will used for determine the EWR value:

MRR (g/min) = WRR/T .....equation 3.0

EWR (%) = 
$$[EWW/WRW] \times 100$$
 .....equation 3.1

The higher material removal rate in the EDM machine, the better is the machining performance. While, the lower electrode wear ratio in the EDM machine is the better and accurate performance characteristic. Due to the result, the best electrode material for EDM machining process can be determined.

# 3.7 SUMMARY

The electric discharge machine (EDM) process experiment has been done under experimental set up and procedure. Graph is used to observe tool wear growth after each experiment. Then from the graph we can determine the best selection and proper electrode. Afterwards, the results were compared at the same material parameters from journal. The results obtained are following graph patterns if compared with the literature study. These results would further being interpret in Chapter 4- Results and Discussion.

# **CHAPTER 4**

# **RESULTS AND DISCUSSIONS**

# 4.1 INTRODUCTION

Chapter four is generally discuss the results obtained throughout the experimental research analysis on the material removal rate (MRR) and electrode wear ratio (EWR) after a period of machining process.

# 4.2 DATA COLLECTION

EXP	ELECTRODE	MASS	MASS	MASS W/P	MASS	TIME		
		ELECTRODE	ELECTRODE	BEFORE (g)	W/P			
		BEFORE (g)	AFTER (g)		AFTER (g)			
1	cooper	11.1402	11.1266	11.1402	142.7020	25m 17s		
2	cooper	11.2121	11.2082	143.4450	143.1936	25m 20s		
3	cooper	11.1260	11.1237	143.2495	143.0096	25m 46s		
4	cooper	11.1217	11.1143	142.8812	142.6335	25m 33s		
5	cooper	11.1237	11.1220	142.2405	141.9867	25m 3s		
6	aluminum	10.5560	10.3952	143.0000	142.9462	18m 58s		
7	aluminum	3.1011	3.0742	142.9121	142.8357	18m 33s		
8	aluminum	10.3952	10.2345	142.0301	141.9393	18m 31s		
9	aluminum	3.0145	2.9847	142.7999	142.221	18m 49s		
10	aluminum	10.2345	10.0761	143.0359	142.9481	18m 45s		
11	brass	3.1350	3.1033	142.5420	142.4239	2h 58s		
12	brass	10.4444	10.2757	142.9789	142.4239	2h 1s		
13	brass	3.1033	3.0754	143.0378	142.9099	1h 52m 43s		
14	brass	10.8689	10.7212	143.0000	142.6781	2h 2m 4s		
15	brass	3.0754	3.0500	142.1770	142.0460	1h 51m 17s		
	Total time							

# **Table 4.1: Data collection**

From table 4.1 we can see the total number of experiment and its data result. Overall for experiment, the total time is taken to finish the machining is 13 hours 24 minutes and 3 second. This time is just the time of machining process and not including the time set-up for the experiment. This experiment looks fairly suitable for the limits of scope project due to the lack of time. In other words, more experiment can be done if there is no limited time and more accurate result can be obtained. But, this experiment is quite accurate because the experiment had done five times. Hence, the data from the table 4.1 can be used and analyze. The experiment is done with three electrode material which is brass, copper and aluminum. Every electrode is running experiment by five times. Means every electrode done machining a work piece (tool steel) and overalls the number of electrodes and tool steels is 15 each. If we think again, more time are spend and waste on set up the material than machining because every experiment needs another electrode and work piece. But finally, the experiment done successfully and the data have been collected. The data collections that are taken are the mass of electrode before and after, mass of work piece before and after and time taken of every experiment. Roughly, from table 4.1 we can see the time taken for the brass material electrode is more compare with other electrode materials. The machining time is more for electrode brass followed by copper and brass. From the table 4.1 also we can easily find the less mass of electrode material which aluminum. Aluminum is less in weight due to its properties followed by brass and copper. But, this only the rough data that cannot be make as conclusion. So, this data need to analyzed first in order to meet the objective of this project.

### 4.3 ANALYSIS OF MATERIAL REMOVAL RATE (MRR)

There are many factor need to be consider during operating the machine to make sure the results produce are in good condition and increase productivity. The most important factor in making the production run faster is the time taken for machining product. The time taken for machining can be express in term of material removal rate (MRR). Material removal rate (MRR) is a value of time that calculated to determine the rate of production in industries.

#### 4.3.1 Data Collection Of Material Removal Rate (MRR)

The material removal rate (MRR) of the work piece was measured by dividing the weight of work piece before and after machining (found by weighing method using balance) against the machining time that was achieved. The data from the experiment is collect and put into table 4.2, 4.3 and 4.4 in order to analyze the material removal rate (MRR).

Copper	1st	2nd	3rd	4th	5th
Before (g)	142.9590	143.4450	143.2495	142.8812	142.2405
After (g)	142.7020	143.1936	143.0096	142.6335	141.9867
Different	0.2570	0.2514	0.2399	0.2477	0.2538
Mass (g)					
111111111111111111111111111111111111111					
	05 17	25 20	25 16	25 22	25 2
Time	25m 17s	25m 20s	25m 46s	25m 33s	25m 3s

 Table 4.2: Data collection by using copper electrode

The table 4.2 is showing about experiment with copper electrode material and its data. The data is including the mass value of work piece (tool steel) before and after, and also the time taken to complete machining each experiment. The mass of tool steel before and after is analyzed and then the different mass is obtained by minus the mass tool steel before against mass tool steel after. Then, we can know the different mass of the work piece that had machining by using the copper electrode. The average of work piece (tool steel) mass when using copper as electrode is 0.2g something.

Brass	1st	2nd	3rd	4th	5th
Before (g)	142.5420	142.9789	143.0378	143.0000	142.1770
After (g)	142.4239	142.8467	142.9099	142.6781	142.0460
Different	0.1181	0.13211	0.1279	0.13219	0.131000
Mass (g)					
time	2h 58s	2h 1s	1h 52m 43s	2h 2m 4s	1h 51m 17s

Table 4.3: Data collection by using brass electrode

The table 4.3 is showing about experiment with brass electrode material and its data. The data is including the mass value of work piece (tool steel) before and after, and also the time taken to complete machining each experiment. The mass of tool steel before and after is analyzed and then the different mass is obtained by minus the mass tool steel before against mass tool steel after. Then, we can know the different mass of the work piece that had machining by using the brass electrode. The average of work piece (tool steel) mass when using brass as electrode is 0.1g something.

Aluminum	1st	2nd	3rd	4th	5th
Before (g)	143.0000	142.9121	142.0301	142.7999	143.0359
After (g)	142.9462	142.8357	141.9393	142.221	142.9481
Different	0.0538	0.0764	0.0908	0.0778	0.0878
Mass (g)					
time	18m 58s	18m 33s	18m 31s	18m 49s	18m 45s

Table 4.4: Data collection by using aluminum electrode

The table 4.4 is showing about experiment with aluminum electrode material and its data. The data is including the mass value of work piece (tool steel) before and after, and also the time taken to complete machining each experiment. The mass of tool steel before and after is analyzed and then the different mass is obtained by minus the mass tool steel before against mass tool steel after. Then, we can know the different mass of the work piece that had machining by using the aluminum electrode. The average of work piece (tool steel) mass when using aluminum as electrode is in range of 0.04g to 0.09g.

#### 4.3.2 Calculation of Material Removal Rate (MRR)

Although other ways of measuring material removal rate (MRR) and electrode wear ratio (EWR) do exist, in this work the material removal rate and electrode wear values have been calculated by the weight difference of the sample and electrode before and after undergoing the electric discharge machine (EDM) process. The present work highlights the development of mathematical solution to calculate the electric discharge machine (EDM) machining parameters such as: mass of electrode, pulse duration and voltage on the metal removal rate, wear ratio and surface roughness. This work has been established based on the mathematical equation. The material removal rate (MRR) of the work piece was measured by dividing the weight of work piece before and after machining against the machining time that was achieved. The material removal rate (MRR) is expressed as the work piece removal rate (WRR) under a period of machining time in minute (T), that is [1]:

MRR (g/min) = WRR/T

Where;

WRR = Work Piece Removal Rate (g) T = time (minutes)

The material removal rate (MRR) is calculate and can be refers to the table 4.5.

Electrode	1st	2nd	3rd	4th	5th	Average
						MRR
						(g/min)
Cooper	0.01021	0.00998	0.00942	0.00978	0.01003	0.00988
Brass	0.000978	0.00110	0.001137	0.00108	0.001178	0.00109
Aluminum	0.00289	0.00417	0.00495	0.00421	0.00475	0.00419

 Table 4.5: Calculation for MRR

The material removal rate (MRR) that calculated can be seeing in the table 4.5. Each machining using the selected electrode has their value of material removal rate (MRR) for the five experiments. From that table also we can also calculate the average of material removal rate (MRR) each machining using different electrode material. With that value, we can know the total average of material removal rate (MRR) if we using the selected electrode material in the machining process. By the way, the machining using copper material as an electrode give the highest average of material removal rate (MRR), followed by aluminum and brass.

#### **4.3.3** Graff For Material Removal Rate (MRR)

Regarding to the table 4.5, the graph for the material removal rate (MRR) can be plot. The value of all five experiments using selected electrodes material is transfer into graph to make the analyzed more clearly and easy. Figure 4.1 show about the material removal rate (MRR) when machining of three electrode material; brass, copper and aluminum. By this graph also we can see the highest of material removal rate (MRR) when doing machining using the copper as an electrode material compared to others electrode material. These mean every experiment or machining process that using copper material as electrode will give the higher material removal rate (MRR) compared to brass and aluminum electrode. The graph from figure 4.1 has proved.





Figure 4.1: Graph of MRR



Figure 4.2: Graph of average MRR

Figure 4.2 show the average of material removal rate (MRR) graph after the machining process of tool steel work piece using different electrode materials. From this graph it shows that machining electric discharge machine (EDM) using electrode material of copper give higher average material removal rate (MRR) than using electrode brass or aluminum. From is graph also, we can determine the best electrode

for machining electric discharge machine (EDM) is copper. These prove from the higher value average of material removal rate (MRR) from graph from figure 4.1. For material removal rate (MRR) in machining process electric discharge machine (EDM) the proper selection for electrode material is copper. The next choice should be aluminum due to fairly good value material removal rate (MRR). But the brass electrode showed very poor value of material removal rate (MRR) compare to others electrode material.

# 4.4 ANALYSIS OF ELECTRODE WEAR RATIO (EWR)

Electrode wear imposes high costs on manufacturers to substitute the eroded complicated electrodes by new ones for die making. In order to increase the machining efficiency, erosion of the work piece must be maximized and that of the electrode minimized in EDM process. Therefore, studying the electrode wear and related significant factors would be effective to enhance the machining productivity and process reliability. Furthermore, in electric discharge machine (EDM), improper selection of material as electrode when machining process is running will decrease the accuracy of the product because influence of the electrode wear ratio (EWR) characteristic. The wear ratio defined as the volume of metal lost from the tool divided by the volume of metal removed from the work material, varies with the tool and work materials used. If the rate of tool wear is high means that the material is easy to wear and not good for machining performance.

## 4.4.1 Data Collection Of Electrode Wear Ratio (EWR)

Electrode wear occurs during electric discharge machine (EDM) process leading to a lack of machining accuracy in the geometry of work piece. In industries or engineering, electrode wear also known as electrode wear ratio (EWR). Due to important of this characteristic against the machining process, the analyzed for optimize performance is necessary.

#### 4.4.2 The Formula Of Electrode Wear Ratio (EWR)

Therefore, studying the electrode wear and related significant factors would be effective to enhance the machining productivity and process reliability. The electrode wear ratio (EWR) is define by the ratio of the electrode wear weight (EWW) to the work piece removal weight (WRW) and usually expressed as a percentage, that is: [2]

EWR (%) =  $[EWW/WRW] \times 100$ 

Where;

EWW = Electrode Wear Weight

WRW = Work Piece Removal Weight

# 4.4.3 Calculate Electrode Wear Ratio (EWR)

In this paper, the data from the experiment is collect and put into table 4.6, 4.7 and 4.8 in order to analyze the electrode wear ratio (EWR). And then, the calculation of the electrode wear ratio (EWR) has calculated also and can be refers to the table 4.6.1, 4.7.1, 4.8.1.

Table 4.6: Dat	a of mass coo	per's electrod	le and mass	work piece
----------------	---------------	----------------	-------------	------------

Copper	1st	2nd	3rd	4th	5th
Before (g)	11.1402	11.2121	11.1260	11.1217	11.1237
After (g)	11.1266	11.2082	11.1237	11.1143	11.1220
EWW	0.0136	0.0039	0.0023	0.0074	0.0017

Work Piece	1st	2nd	3rd	4th	5th
Before (g)	142.9590	142.0000	143.2495	142.677	142.2405
After (g)	142.7020	141.7556	143.0096	142.427	141.9867
WRW	0.257	0.2444	0.2399	0.2499	0.2538

Table 4.6 shows the data collection of the experiment machining tool steel using electric discharge machine (EDM) with copper electrode. The data of copper electrode before and after is taken and also same with their work piece (tool steel). Then, the different mass of copper electrode is calculated by minus the mass before experiment against mass after experiment. The different mass value of this calculation is called electrode wear weight (EWR). Meanwhile, the different mass of work piece also calculated. The mass of tool steel after experiment then will minus by the mass of tool steel before the experiment to get the different masses. This different mass is called work piece removal weight (WRW).

 Table 4.6.1: EWR by using copper electrode

copper	1st	2nd	3rd	4th	5th
EWW	0.0136	0.0039	0.0023	0.0074	0.0017
WRW	0.257	0.2444	0.2399	0.2499	0.2538
EWR	0.0529	0.016	0.0095	0.030	0.0066

To make the table is clear and not complicated; the data calculation from table 4.6 is converting to table 4.6.1 in order to make the data more clearly. From this table (4.6.1), the electrode wear ratio (EWR) of machining tool steel using electric discharge machine (EDM) with copper as electrode can be determine. The formula of electrode wear weight (EWR) is:

Where;

EWW = Electrode Wear Weight

WRW = Work Piece Removal Weight

The electrode wear ratio (EWR) can be obtained by divide the value of electrode wear weight (EWW) against the value of work piece removal weight (WRW). We also use the same method to calculated electrode wear ratio (EWR) in every experiment. Means, each experiment from 1<sup>st</sup> to 5<sup>th</sup> have its own value of electrode wear ratio (EWR). The value of the electrode wear ratio (EWR) when machining electric discharge machine (EDM) using copper electrode now can be determine. All the value of electrode wear ratio (EWR). All the (EWR) value then can be analyze and discuss. The value of the electrode wear ratio (EWR) had been kept in and get from the table 4.6.1.

Brass	1st	2nd	3rd	4th	5th
Before (g)	10.5560	10.4444	10.3952	10.8689	10.2345
After (g)	10.3952	10.2757	10.2345	10.7212	10.0761
EWW	0.1608	0.1687	0.1607	0.1477	0.1584
Work piece	1st	2nd	3rd	4th	5th
Before (g)	143.0000	142.0212	142.0301	142.1289	143.0359
After (g)	142.9462	141.9442	141.9393	142.0612	142.9481
WRW	0.0538	0.0770	0.0908	0.0677	0.0878

Table 4.7: Data of mass brass's electrode and mass work piece

Table 4.7 shows the data collection of the experiment machining tool steel using electric discharge machine (EDM) with brass electrode. The data of copper electrode before and after is taken and also same with their work piece (tool steel). Then, the different mass of brass electrode is calculated by minus the mass before experiment against mass after experiment. The different mass value of this calculation is called electrode wear weight (EWR). Meanwhile, the different mass of work piece also calculated. The mass of tool steel after experiment then will minus by the mass of tool steel before the experiment to get the different masses. This different mass is called work piece removal weight (WRW).

Brass	1st	2nd	3rd	4th	5th
EWW	0.1608	0.1687	0.1607	0.1477	0.1584
WRW	0.0538	0.0770	0.0908	0.0677	0.0878
EWR	2.988	2.1910	1.769	2.1830	1.804

Table 4.7.1: EWR by using brass electrode

To make the table is clear and not complicated; the data calculation from table 4.7 is converting to table 4.7.1 in order to make the data more clearly. From this table (4.7.1), the electrode wear ratio (EWR) of machining tool steel using electric discharge machine (EDM) with copper as electrode can be determine. The formula of electrode wear weight (EWR) is:

#### EWR = [EWW/WRW]

Where;

EWW = Electrode Wear Weight

WRW = Work Piece Removal Weight

The electrode wear ratio (EWR) can be obtained by divide the value of electrode wear weight (EWW) against the value of work piece removal weight (WRW). We also use the same method to calculated electrode wear ratio (EWR) in every experiment. Means, each experiment from 1<sup>st</sup> to 5<sup>th</sup> have its own value of electrode wear ratio (EWR). All the (EWR) value then can be analyze and discuss. The value of the electrode wear ratio (EWR) when machining electric discharge machine (EDM) using brass electrode now can be determine. All the value of electrode wear ratio (EWR) had been kept in and get from the table 4.7.1.

Aluminum	1st	2nd	3rd	4th	5th
Before (g)	3.1350	3.1011	3.1033	3.0145	3.0754
After (g)	3.1033	3.0742	3.0754	2.9847	3.0500
EWW	0.0317	0.0269	0.0279	0.0298	0.0254
Work piece	1st	2nd	3rd	4th	5th
Before (g)	142.5420	142.6664	143.0378	143.6442	142.1770
After (g)	142.4239	142.5497	142.9099	143.5092	142.0460
WRW	0.1181	0.1167	0.1279	0.1350	0.131

Table 4.8: Data of mass aluminum's electrode and mass work piece

Table 4.8 shows the data collection of the experiment machining tool steel using electric discharge machine (EDM) with brass electrode. The data of aluminum electrode before and after is taken and also same with their work piece (tool steel). Then, the different mass of brass electrode is calculated by minus the mass before experiment against mass after experiment. The different mass value of this calculation is called electrode wear weight (EWR). Meanwhile, the different mass of work piece also calculated. The mass of tool steel after experiment then will minus by the mass of tool steel before the experiment to get the different masses. This different mass is called work piece removal weight (WRW).

Aluminum	1st	2nd	3rd	4th	5th
EWW	0.0317	0.0269	0.0279	0.0298	0.0254
WRW	0.1181	0.1167	0.1279	0.1350	0.131
EWR	0.2684	0.2310	0.2181	0.2210	0.1938

 Table 4.8.1: EWR by using aluminum electrode

Same technique like before, to make the table is clear and not complicated; the data calculation from table 4.7 is converting to table 4.7.1 in order to make the data more clearly. From this table (4.7.1), the electrode wear ratio (EWR) of machining tool steel using electric discharge machine (EDM) with copper as electrode can be determine. The formula of electrode wear weight (EWR) is:

EWR = [EWW/WRW]

Where;

EWW = Electrode Wear Weight

WRW = Work Piece Removal Weight

The electrode wear ratio (EWR) can be obtained by divide the value of electrode wear weight (EWW) against the value of work piece removal weight (WRW). We also use the same method to calculated electrode wear ratio (EWR) in every experiment. Means, each experiment from  $1^{st}$  to  $5^{th}$  have its own value of electrode wear ratio (EWR). All the (EWR) value then can be analyze and discuss. The value of the electrode wear ratio (EWR) when machining electric discharge machine (EDM) using aluminum electrode now can be determine. All the value of electrode wear ratio (EWR) had been kept in and get from the table 4.7.1.

Electrode	1st	$2^{nd}$	3 <sup>rd</sup>	$4^{\text{th}}$	5th	average
cooper	0.0529	0.016	0.0095	0.030	0.0066	0.023
brass	2.988	2.1910	1.7690	2.1830	1.8040	2.187
aluminum	0.2684	0.2310	0.2181	0.2210	0.1938	0.226

 Table 4.9: Calculations of EWR

The electrode wear ratio (EWR) that calculated can be seeing in the table 4.9. Each machining using the selected electrode has their value of electrode wear ratio (EWR) for the five experiments. From that table also we can also calculate the average of electrode wear ratio (EWR) each machining using different electrode material. With that value, we can know the total average of electrode wear ratio (EWR) if we using the selected electrode material in the machining process. By the way, the machining using copper material as an electrode give the lowest average of electrode wear ratio (EWR), followed by aluminum and brass.

#### 4.4.4 Graph For Electrode Wear Ratio (EWR)

Regarding to the table 4.9, the graph for the electrode wear ratio (EWR) can be plot. The value of all five experiments using selected electrodes material is transfer into graph to make the analyzed more clearly and easy. Figure 4.3 show about the electrode wear ratio (EWR) when machining of three electrode material; brass, copper and aluminum. By this graph also we can see the lowest of electrode wear ratio (EWR) when doing machining using the copper as an electrode material compared to others electrode material. These mean every experiment or machining process that using copper material as electrode will give the less electrode wear ratio (EWR) compared to brass and aluminum electrode. The graph from figure 4.3 has proved.



Figure 4.3: Graph of EWR



Figure 4.4: Graph of average EWR

Figure 4.2 show the average of electrode wear ratio (EWR) graph after the machining process of tool steel work piece using different electrode materials. From this graph it shows that machining electric discharge machine (EDM) using electrode material of copper less average electrode wear ratio (EWR) than using electrode

brass or aluminum. From is graph also, we can determine the best electrode for machining in electric discharge machine (EDM) is copper. These prove from the less value average of electrode wear ratio (EWR) from graph from figure 4.1. For electrode wear ratio (EWR) in machining process electric discharge machine (EDM) the proper selection for electrode material is copper. The next choice should be aluminum due to average value electrode wear ratio (EWR). But the brass electrode showed very high value of electrode wear ratio (EWR) compare to others electrode material.

# 4.5 FINAL RESULTS

After the experiment (machining tool steel with electric discharge machine (EDM) using different electrode material) the final result is obtained. This result obtained from the calculation of material removal rate (MRR) and electrode wear ratio (EWR). The summary of the result can be shown from table 4.10. If we refer to table 4.10, we can determine the average value of material removal rate (MRR) and electrode wear ratio (EWR) every electrode material. From table 4.10 also, we can find the higher material removal rate (MRR) is by using electrode copper followed by aluminum and brass while for electrode wear ratio (EWR) the higher value is come from material brass followed by aluminum and copper.

Electrode	Average MRR	Average EWR	
Cooper	0.00988	0.023	
Brass	0.00109	2.187	
Aluminum	0.00419	0.226	

 Table 4.10: Average of MRR and EWR

#### 4.5.1 **Result Comparison With Journals**

To make sure the result of the experiment is right; compare result with another relevant journal is a great method to do so. The result that obtain should be compare to some journal in order to know whether that experiment we run is correct or not. In this case study, the journal that wants to compare must be including material removal rate (MRR), electrode wear ratio (EWR) and the same materials used as electrode in their experiment.

After a few researches, the journal that wants to compare is from Shankar Singh, S. Maheshwari and P.C. Pandey title; some investigations into the electric discharge machining of hardened tool steel using different electrode materials. From this journal, their result about material removal rate (MRR) can be seeing from the figure 4.5.



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Fig. 1. Variation of material removal rate with discharge current.

Figure 4.5: MRR result from journal

The figure 4.5 tell us about the result of machining work piece in electric discharge machine (EDM) using four different electrode; which is copper, copper tungsten, brass and aluminum. Meanwhile, the journal's result about electrode wear ratio (EWR) also can be seeing from the figure 4.6. The figure 4.6 tell us about the result of machining work piece in electric discharge machine (EDM) using four different electrode; which is copper, copper tungsten, brass and aluminum. For the value of electrode wear ratio (EWR) in journal's experiment can be refer in figure 4.6.



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Fig. 3. Variation of electrode wear with discharge current.

Figure 4.6: EWR result from journal

From the result in the journal, the highest material removal rate (MRR) is cooper electrode material followed by aluminum, copper tungsten and brass. Meanwhile, the result from the experiment we run obtain copper give the higher material removal rate (MRR) followed by aluminum and brass. In other words, the result is quite same with our experiment. This proved that the result of material removal rate (MRR) from this experiment is right. In case electrode wear ratio (EWR), the result from journal obtained that is cooper electrode material give the less electrode wear ratio (EWR) followed by aluminum, copper tungsten and brass. Meanwhile, the result from the experiment we run obtained copper give the less electrode wear ratio (EWR) followed by aluminum and brass. The result is quite same with our experiment. This also proved that the result of material removal rate (MRR) from this experiment is right. Refers table 4.11 and 4.12.

EXPERIMENT	MRR	JOURNAL
COPPER	BEST	COPPER
ALUMINUM	AVERAGE	ALUMINUM
BRASS	POOR	BRASS

Table 4.11: Comparison MRR result with journal

<b>Table 4.12:</b>	Comparison	EWR	result	with	journal
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EXPERIMENT	EWR	JOURNAL
COPPER	BEST	COPPER
ALUMINUM	AVERAGE	ALUMINUM
BRASS	POOR	BRASS

## 4.6 **DISCUSSION**

#### 4.6.1 The Theory

The selection material of electrode important because its influence most of the machining performance in electric discharge machine (EDM). This is due to the material's properties itself. The properties of the material will affect the machining characteristic like material removal rate (MRR) and electrode wear ratio (EWR) in electric discharge machine (EDM). The properties of material including thermal conductivity, boiling point, melting point and so on resulting differently depends on material selection itself. In this experiment, the material that chose to do machining is copper, brass and aluminum. The experiment's result of these material selections give different value of material removal rate (MRR) and electrode wear ratio (EWR) because that characteristic depends on material properties itself. The material properties of this material can be seeing in the table 4.12. From that table material property, we can see roughly that the copper material has high conductivity followed by aluminum and then brass.

Material	Thermal conductivity	Boiling point	Melting point (K)
	(W/m-K)	(K)	
Copper	401	2835.15	1357.77
Aluminum	237	2792.15	933.47
Brass	109	2624	900

**Table 4.12: Table of material properties** 

From the research of theory in many journal, we found that the electrode wear ratio (EWR) will less for electrode material with high boiling point, high melting point and high thermal conductivity. These means, material selection for use as electrode in electric discharge machine (EDM) should be high boiling point, high melting point and high thermal conductivity in case to make the value electrode wear ratio (EWR) is less.

As we know, the electrode wear ratio (EWR) of the electrode becomes small for the electrode material with high boiling point, high melting point, and high thermal conductivity. However, the electrode wear ratio (EWR) is inversely proportional to the material removal rate (MRR) result. In other words, material with high material removal rate (MRR) will have the less electrode wear ratio (EWR).

The material with high thermal conductivity must be considered to use as electrode in machining electric discharge machine (EDM). The theory says the material with higher thermal conductivity resulting better material removal rate (MRR). Actually, the higher thermal conductivity of the electrode ensures a better spark discharge energy distribution during the EDM process. When there is more spark discharge energy, this will make the machining run effectively and fast. Hence, the more spark discharge energy, the faster the machining can run. This will increase material removal rate (MRR).

As we know, the increase in the material removal rate (MRR) is due to the increase of spark discharge energy. The spark discharge energy high when the material is more thermal conductivity. So as result, the material with high thermal conductivity will increase material removal rate (MRR).

#### 4.6.2 Discussion Of Material Removal Rate (MRR)

## 4.6.2.1 Material Removal Rate

In industries, the production rate is a part that they consider most. The production rate is a rate or time taken to do a process in making product. If the production rate is slow, the profit flow is also slow. But if the production rate is high, the more profit can gain. To increase the production rate, we need to increase the material removal rate (MRR). When the material removal rate (MRR) is higher, the production also run faster.

#### 4.6.2.2 Results And Analysis Of Material Removal Rate (MRR)

Table 4.10 shows the effect of electrode material on material removal rate (MRR) for the tool steel work piece material. The copper electrodes achieve the best material removal rate (MRR) with the increase in discharge current, followed by aluminum electrode. Brass does not indicate significant increase in MRR. The average material removal rate (MRR) of cooper is 0.00988 g/min while aluminum is 0.00419 g/min and brass is 0.00109 g/min. Copper gives the best material removal rate (MRR) on tool steel work piece material. From the theory, the material with high thermal conductivity will result increasing the material removal rate (MRR). As we can see from table 4.10, the properties of all material in term conductivity; copper give the higher conductivity compare to aluminum and brass. The spark discharge energy also high when the material is more thermal conductivity. The increase in material removal rate (MRR) is due to the fact that the spark discharge energy is increased to facilitate the action of melting and vaporization, and advancing the large impulsive force in the spark gap, there by increasing the material removal rate (MRR). Experimental investigations have shown that material removal rate (MRR) is dependent upon the electrode material, work material and dielectric flushing. The material removal rate (MRR) is also controlled by the frequency of the sparks. It is observed that low discharge currents and higher frequencies correspond to low stock removal. Effective machining rate with brass electrode could not be achieved because the brass has low conductivity.

## 4.6.3 Results And Analysis Of Electrode Wear Ratio (EWR)

#### 4.6.3.1 Electrode Wear Ratio (EWR)

The high rate of tool wear is one of the main problems in electric discharge machine (EDM). Actually, the wear ratio defined as the volume of metal lost from the tool divided by the volume of metal removed from the work material, varies with the tool and work materials used. If the rate of tool wear is high means that the material is easy to wear and not good for machining performance. In industries, the

wear ratio is an important thing because it will cost the production. They are trying to optimize this factor to make sure no waste occur and reduce the purchasing the material with high wear.

#### 4.6.3.2 Results And Analysis Of Electrode Wear Ratio (EWR)

Table 4.10 shows that the copper electrodes have minimal wear. Brass and aluminum show a considerable increase in the electrode wear with the increase in the discharge current. The theory says an electrode material with higher melting point wears less. In other words, the electrode wear ratio (EWR) will less for electrode material with high boiling point, high melting point and high thermal conductivity. From the result of experiment, the copper give less electrode wear ratio followed by aluminum and brass. The average of electrode wear ratio (EWR) for cooper is 0.023 while aluminum is 0.226 and brass is 2.187. Electrode wear is mainly due to high-density electron impingement (electrical), thermal effect, mechanical vibrations (shocks) generated by metal particles from the work material and imperfections in the microstructure of electrode material.

#### 4.6.4 Summary

Electrical discharge machining, more commonly known as EDM or spark machining, removes electrically conductive materials by means of rapid, repetitive spark discharges from electric pulse generators with the dielectric flowing between the tool and the work piece. No physical cutting forces exist between the work piece and tool. Machining with electric discharge machine (EDM) sometimes faces problem with productivity rate and product finishing accuracy. The machining rate will be slow and low product finishing qualities if the not use the proper machining parameters. The most important parameters to solve this problem are electrode selection material. To optimize, the best electrode material for machining process in electric discharge machine (EDM) is need to determine.

There are many factors that influence machining process in electric discharge machine (EDM) especially its machining characteristics. Machining characteristics are material removal rate (MRR) and electrode wear ratio (EWR). This characteristic mostly depends on the material properties. The material properties like thermal conductivity, melting point and others. Moreover, it has been found from the experimental investigation that in case of material removal rate (MRR), electrical and thermal conductivity are the primary influencing factors. The high electrical conductivity facilitates the sparking process and increases effective pulses which increase material removal rate (MRR). On the other hand, higher thermal conductivity is useful to raise the temperature of the work piece above the melting point in a short time. These are the reasons why copper electrode material provide higher material removal rate (MRR) in the finishing. However, the melting point has a secondary effect on the material removal rate (MRR). It has been observed that copper electrode material provides better material removal rate (MRR) than brass. The reason could be the higher melting point (153.77 K) of copper compared to that of brass (900 K).

Moreover, the electrode wear ratio (EWR) of an electrode strongly depends on the electrical and thermal properties of the electrode material. The evaporation point, melting point, thermal conductivity and thermal diffusivity are the important properties that influence the electrode wear of an electrode. The basic requirement of an electrode material is the high melting and evaporation point in addition to high thermal conductivity. It has been found from the study that the electrode wear ratio (EWR) is almost inversely proportional to the melting point of the electrode material. From table 4.12 seen that for every experiment, the wear of copper electrode is the lowest due to its highest melting point among the three electrodes. The aluminum electrode has also good wear resistance due to its moderately high melting point and strong spark-resisting capacity. On the other hand, the brass electrode suffers the highest electrode wear ratio (EWR) in spite of its higher thermal and electrical conductivity among the three electrodes.

# 4.6.4.1 Selecting Electrode

When selecting an electrode material for using in machining in electric discharge machine (EDM), several factors must be considered, including the cost, strength, resistance to wear, and machinability. The machinability of a material is difficult to quantify, but can be said to posses the following characteristics:

- 1. Provides faster rate for production; higher material removal rate (MRR)
- 2. Promotes long tool life; less electrode wear ratio (EWR)
- 3. Easy to find, lower cost and available.
- 4. Results in a good surface finish; (finishing surface free from electrode that have wear)

## 4.6.4.2 Optimization

- 1. If to optimize production and faster rate, choose electrode material with high material removal rate (MRR).
- The costs of production also including the tool wear. Means, if possible try to select electrode with lowest electrode wear ratio (EWR) in order to make tool life long.
- 3. Select an electrode material that minimizes overall cost.

# **CHAPTER 5**

# CONCLUSION

# 5.1 INTRODUCTION

Chapter 5 summarizes all the main research points of this project. It concludes the crucial information and observation obtained during the project. Especially on the machining characteristic in machining electric discharge machine (EDM). These conclusions pay more attention at objective of project that want to find the proper electrode for machining tool steel. In that case, the investigation on material removal rate (MRR) and electrode wear ratio (EWR) is being done. In this chapter also, some recommendations have made for future research of this project.

#### 5.2 CONCLUSION

This experiment investigated the effects of machining characteristic on electric discharge machine using different electrode materials. As conclusion, the experiments of this paper conclude that the machining characteristics in machining process of electric discharge machine (EDM) influence the machining performance.

The higher material removal rate (MRR) will result in better machining performance rate. In this experiment, the higher material removal rate (MRR) obtained is come from electrode copper that is 0.0098 g/min followed by aluminum (0.00419g/min) and brass (0.00109 g/min).

Meanwhile, the less electrode wear ratio (EWR) will make the machining performance better. From this experiment, the best selection electrode for electrode wear ratio (EWR) is copper (0.023) followed by aluminum (0.026) and brass (2.187).

After the results obtained, the objective is excellently achieved. The best selection of electrode in machining tool steels is copper because it has high material removal rate (MRR) and less electrode wear ratio (EWR).

# 5.3 **RECOMMENDATION**

There are some recommendations to be considered in improving the details of this project. More electrode materials are highly recommended to be use as electrode for investigation its capabilities. This is crucial to see clearly the other material machining characteristic. Other than that, the experiments also can be conducted in different parameters. This is needed to investigate other parameters that influence machining performance in electric discharge machine (EDM).

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