REKABENTUK UJIKAJI PEMESINAN EDM UNTUK KEJURUTERAAN BAHAN TERMAJU

Experiment on EDM machining for advance engineering material using Taguchi Method

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ABSTRACT

Electro-discharge machining (EDM) technique is widely used for machining hard metals and for performing specific tasks which cannot be achieved using conventional technique. The most frequently used industrial application of die-sinking is mould fabrication. In this project, the main purpose is to optimize the quality of cut for tool steel (hardened) using Taguchi single response and multiple response performance characteristic. The orthogonal array, single and multi-response signal-to-noise ratio and analysis of variance are employed to study the cutting characteristic in EDM. The study needs to optimize three parameters; current, gap and pulse duration to get best surface roughness, material removal rate and electrode wear rate. The optimal combination of parameters obtained in both single response and multiple response performance characteristic shows significant improvement in cutting quality. Taguchi method is an effective approach to optimized process parameter with given cutting characteristic.

ABSTRAK

Electro-discharge machining (EDM) merupakan satu teknik yang biasanya digunakan untuk pemesinan besi keras dan mempunyai peranan tertentu yang mana tidak boleh dilakukan atau dimesin oleh pemesinan konvensional. EDM die-sinking kerap digunakan dalam industri untuk menghasilkan acuan dan die. Dalam projek ini, tujuan utama adalah untuk mengoptimumkan pemesinan tool steel (dikeraskan) dengan menggunakan kaedah Taguchi (single dan multiple response). O*rthogonal array, single and multi-response signal-to-noise ratio* dan *analysis of variance (ANOVA)* diketengahkan untuk mengkaji ciri-ciri pemotongan dalam EDM ini. Kajian ini perlu optimumkan tiga parameter input iaitu arus, jarak antara bahan kerja dan elektrod dan juga masa arcing untuk mendapatkan kekasaran permukaan, kadar penyingkiran bahan dan kadar nyah elektrod yang baik. Kombinasi parameter yang optimum diperolehi daripada kedua-dua single dan multiple response Taguchi yang signifikan ke atas kualiti pemotongan optimum. Oleh itu, kaedah Taguchi adalah satu pendekatan yang efektif untuk mengoptimumkan parameter proses dengan ciri pemotongan yang diberikan.

CHAPTER 1 : INTRODUCTION

1.1 Project Background

Electrical Discharge Machining or **EDM** is a method of working extremely hard materials or materials that are difficult to machine using alternative methods. It is limited, however, to electrically conductive materials. The EDM process can be used to cut small or odd-shaped angles, delicate cavities or intricate contours in extremely hard steel and exotic metals such as titanium, hastalloy, kovar, inconel, **hard tool steels**, and carbide. Sometimes referred to as spark machining, EDM is a nontraditional method of removing metal with a series of rapidly recurring electrical discharges between an electrode (the cutting tool) and the work piece. The machining is performed in presence of a dielectric field. The resulting chips are removed through melting and vaporization; they are washed away with a continuously flushing dielectric fluid. Consecutive electrical discharges produce a series of micro-craters in the work piece until the desired final product is achieved. The EDM process is most widely used by the mold-making tool and dies industries. It is also becoming a common method of creating prototype and production parts, especially when production quantities are relatively low. This project is a design of an experiment of cutting one of the tool steel using electrical discharge machining (EDM). The project should collect the data or the parameter that relate to the cutting process of **hardened tool steel** sample. Taguchi method of L9 Orthogonal Array which consists **Analysis of Variance (ANOVA)** used to analysis the data.

1.2 PURPOSE AND SCOPE

1.2.1 Objective

The objectives for this experiment are :

i. To understand the Electro Discharge Machining processing on a tool steel specimen

ii. To determine the process parameters for optimized cutting output.

iii. To observe other important parameter.

iv. To investigate the interaction between these three parameters; current, voltage gap and pulse-on time to the effects of the cutting material.

1.2.2 Project Methodology

The project's task will initially commence on the collection of data for EDM cutting through an extensive literature review. An analysis on the data of EDM cutting characteristics produced with various types of materials will be conducted to understand the critical processing parameters of the EDM. Then by using the data, multiple sets of parameters are constructed and the best cutting parameters are determined. Followed by analysis of the result and cutting performance. The satisfactory cutting condition obtained by this methodology is verified experimentally. Finally the cutting material is analyzed.

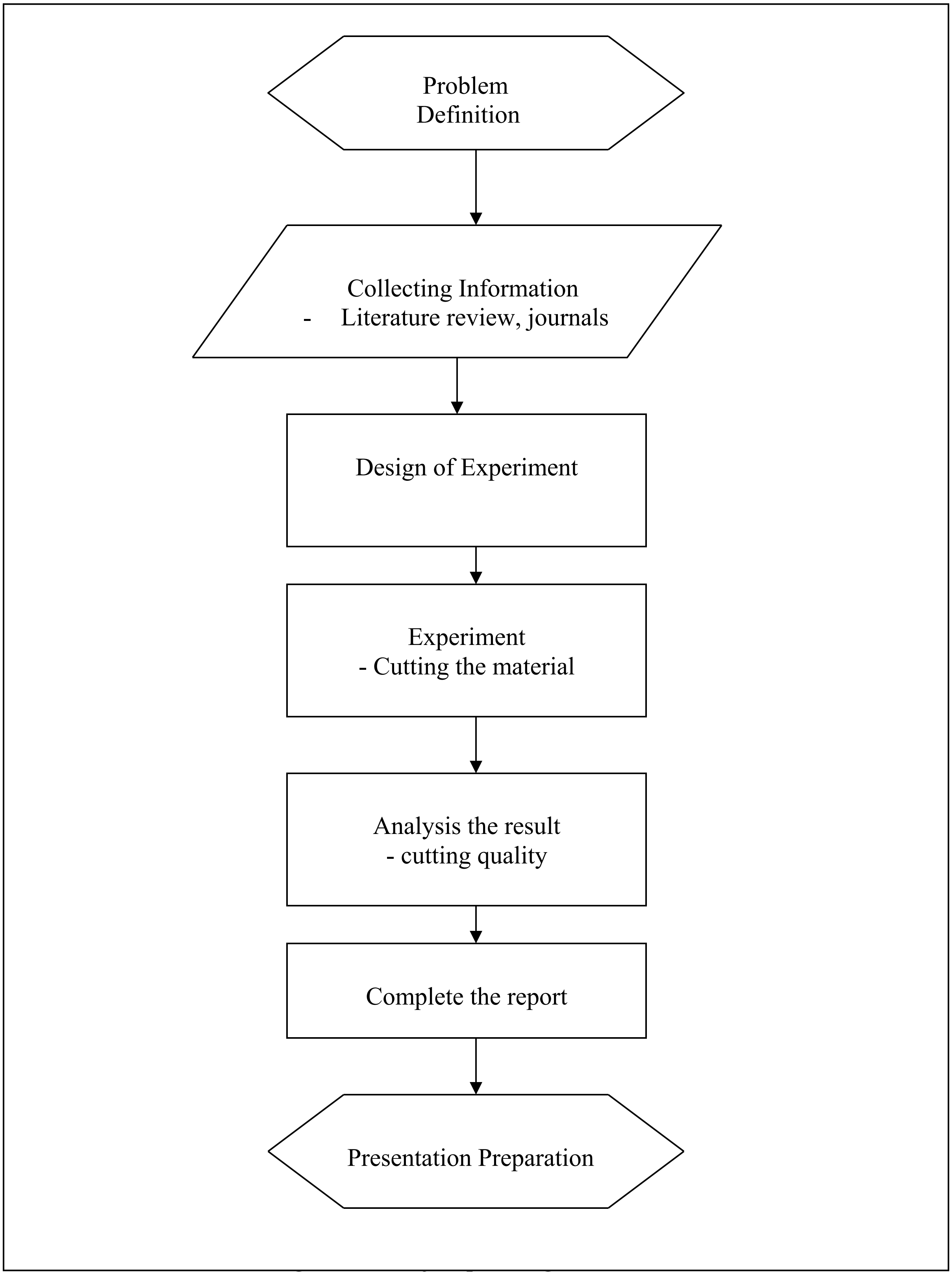

Figure 1.1 Project Planning Flow Chart

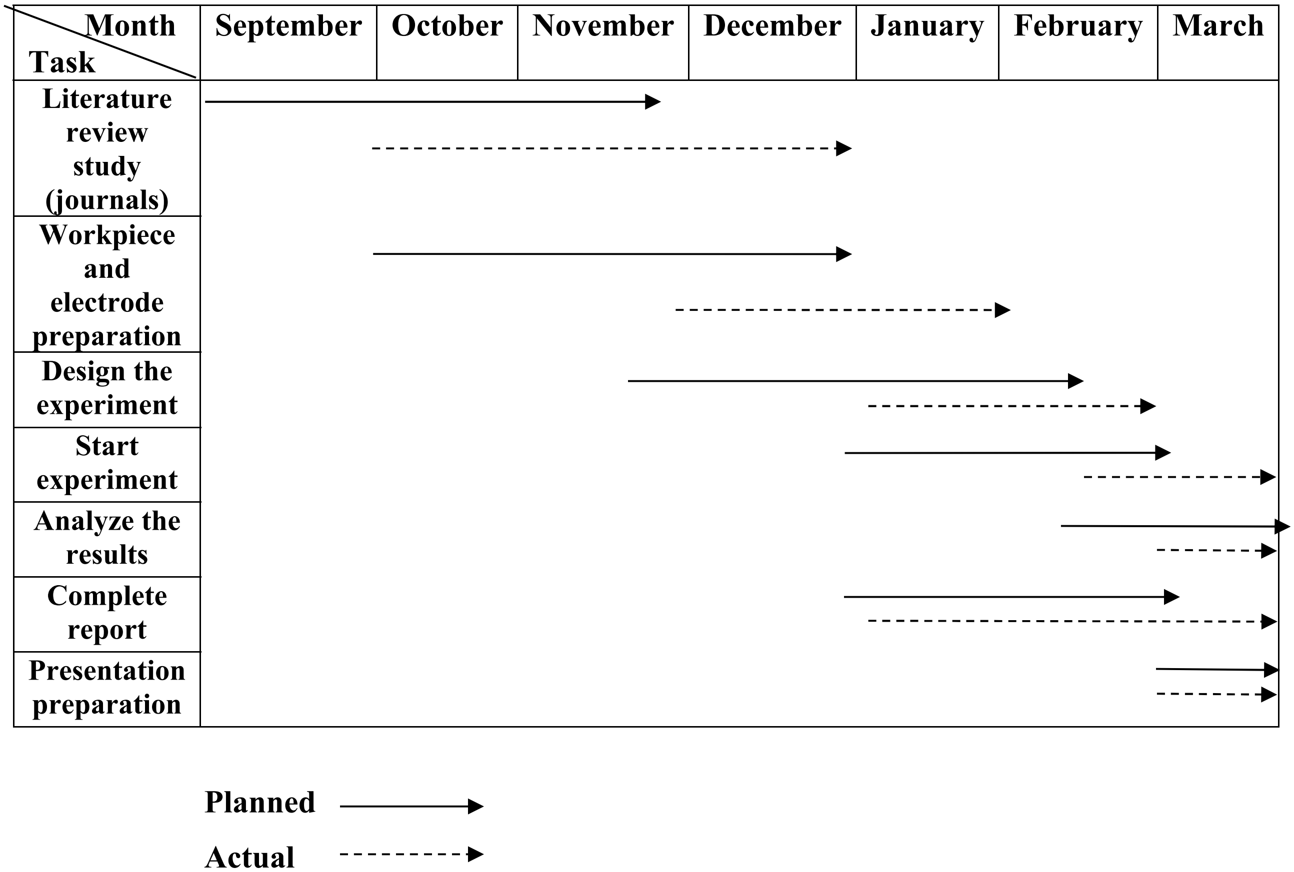

Table 1.1 Project Schedule

CHAPTER 2 : LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will introduce you into Electrical Discharge Machining (EDM) and several types of metal materials that is used in EDM cutting process. It also gives you a basic idea of how EDM works, the principles of EDM, the EDM components; electrodes, dielectric fluid and also the important types of EDM is regularly used in industry nowadays. The basic understanding will serve as a foundation for the detailed description of cutting process of the material in later chapter.

2.2 ELECTRICAL DISCHARGE MACHINING (EDM)

2.2.1 What is Electrical Discharge Machining (EDM)

Electrical Discharge Machining (EDM) operates by generating an electrical discharge between the machining electrodes and the workpiece (cutting material) to remove the surface layer of the workpiece. One example of this principle is found in the service life of an ordinary switch (H. Ramawsamy, 2002). Each time it is turned on, a small discharge is generated which consumes part of the contacts and eventually results in the total erosion of the contacts.

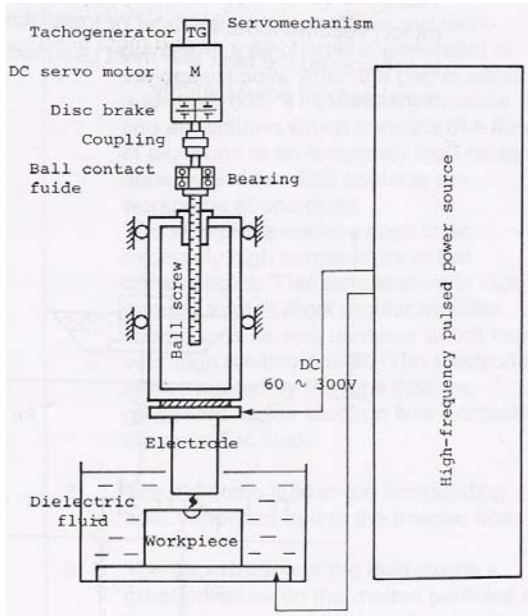

Figure 2.1 Electrical Discharge Machining

Source : NC-EDM SYSTEMS, J Series, 2nd Version, Mitsubishi Electric Corporation

Figure 2.1 shows the basic principles of electrical discharge machining. A machining electrode and workpiece are placed in container filled with dielectric fluid and are separated a minute distance by a servo-mechanism. The high-frequency pulsed power turns on/off a voltage impressed between the machining electrode and workpiece (from here on, referred to as the gap), as a switch turns on/off an electric current (Mitsubishi Electric Corporation Booklet). Each time the voltage is applied, a discharge is generated between gap and little by little the workpiece surface layer is removed. When the discharge is generated repeatedly, the workpiece surface layer facing the machining electrode is covered by spark erosion cavities, enlarging the space between gap. Accordingly, the servo-mechanism lowers the machining electrode to maintain constant the predetermined gap. Repeating of this operation results in machining of the workpiece according to the shape of the machining electrode. Since the high-frequency pulsed power turns on/off the voltage at 50,000 times/s (fine machining) to 1000 times/s (rough machining) per second, it appears as if a great number of discharges are generated concurrently (Mitsubishi ElectricCorp)

2.2.2 TYPES OF EDM

2.2.2.1. Cavity-Type or Die-sinking Electrical Discharge Machining

Cavity-type electrical discharge machining (EDM) is a thermal mass-reducing process that uses a shaped conductive tool to remove electrically conductive material (J.S. Soni at el. 1996). It does this by means of rapid, controlled, repetitive spark discharges. A dielectric fluid is used to flush the removed particles, to regulate the discharge, and to keep the tool and workpiece cool.

Process Characteristics.

- Advances a shaped tool to within sparking (arcing) distance of the workpiece
- Tools and workpiece must be electrically conductive
- Removes material by rapid, controlled, repetitive spark discharge
- Uses a dielectric fluid to flush removed particles, control discharge, and cool tool workpiece
- Surface finish is affected by gap voltage, discharge current, and frequency

Process Schematic

The tool and workpiece are submerged in a nonconductive dielectric fluid, usually a hydrocarbon oil. A very small gap of about 0.001 in. is maintained between the tool and the workpiece by means of a servo-system (Y.S.Wong et al. 1995). Thousands of spark discharges occur each seconds, vaporizing small particles of the workpiece and slowly producing the desired cavity shape. A dielectric fluid is circulated by a pump, and workpiece particles are removed from the dielectric fluid by filtering system.

Workpiece Geometry

In theory, any conductive material can be cut by electrical discharge machining; however, the effectiveness of the process varies very widely, depending on the workpiece material and surface finish requirements. **Workpiece hardness** is not a concern because hard materials are machined easily as soft ones. The process results in relatively burr-free parts.

Setup and Equipment

The electrode can be held with various toolholders. Hand wheels move the table to position the workpiece under the electrode. A servo-controlled mechanism feeds the electrode into the workpiece. Some high production machines currently in use have eight or more parallel heads, each equipped with an indexing turret electrode holder. The dielectric fluid covering the workpiece and electrode is contained in a tank attached to the X-Y table.

Typical Tools and Geometry Produced

Many intricate shapes can be made with EDM, as long as the material is electrically conductive. Because the electrode has no contact with the workpiece, it can be made of a soft, easily machined material, such as brass. The wear rate of the electrode depends on its material. Common electrode materials include copper-tungsten alloys, graphite, copper, brass and zinc alloys. Tool and workpiece wear rates of 1 to 3 or more are common.

Geometrical Possibilities

The geometrical possibilities are limited by such factors as electrode shape, workpiece material, required accuracy, and amount of material to be removed. Depth of cut may typically vary from 0.1 in. to 2 in., although deeper cuts are possible. Workpiece length typically ranges from 0.25 in. to 2 in., or more, depending on the machine.

Tolerances and Surface Finish

EDM is widely used to machine dies and molds that require strict adherence to specified tolerances and surface finish. At maximum removal rate, tolerances range from ± 0.005 in. to 0.002 in.

Tool Style

Virtually any shape of conductive tool that can be made and held in a toolholder can serve as the electrode. Three basic shape of tools are straight stock shapes, multistaged and irregularly shaped tools. Stock shapes commonly used for simple shapes (e.g. extrusion die blocks, punching die blocks). Multistaged commonly for multistaged cavities (e.g. forging dies) and irregularly shaped for complex cavities (e.g. coining dies).

2.2.2.2. Electrical Discharge Machining Grinding

Electrical Discharge Machining (EDM) grinding is a mass-reducing process that uses a rotating conductive wheel to remove electrically conductive material by means of controlled, repetitive spark discharges (Hwa-Teng Lee, 2004). A dielectric fluid is used to flush away the chips, regulate the discharge, and cool the wheel and the workpiece.

Process characteristics.

- Uses a slowly rotating conductive wheel that is kept within sparking (arcing) distance of the workpiece
- Wheels and workpieces must be electrically conductive
- Fragile and thin parts can be processed without distortion
- Can process very hard or difficult to machine metals
- Removes material by controlled spark erosion

Typical tools and geometry produced.

The conductive wheel is rotated at 100 to 600 surface feet per minute. Too high a speed causes splashing, and too low a speed may result in out-of-roundness. The power supply and the dielectric fluid are similar to cavity-type EDM, but lower amperage is used because the cutting area is usually small, and this method is used to achieve accuracy and a smooth finish.

2.2.2.3. Electrical Discharge Machining Wire Cutting

Electrical discharge machining wire cutting (EDM-WC) is a thermal mass-reducing process that uses a continuously moving wire to remove material by means of rapid, controlled, repetitive spark discharges. A dielectric fluid is used to flush the removed particles, regulate the discharge, and keep the wire and workpiece cool. The wire and workpiece must be electrically conductive(Robert H. Todd et. Al, 1994).

Process characteristics.

- Utilizes a traveling wire that is advanced to within arcing distance of the workpiece (0.001 in)
- Removes material by rapid, controlled, repetitive spark discharges
- Uses dielectric fluid to flush removed particles, control discharge, and cool wire and workpiece
- Is performed on electrically conductive workpieces
- Can produce complex two-dimensional shapes

Typical tools and geometry produced.

A traveling copper or brass wire from 0.001 in. to 0.002 in. in diameter is used for the electrode. Tension in the wire and controlled positioning produce a very narrow kerf. This arrangement permits the cutting of intricate openings and tight radius contours, both internally and externally, without a specially shaped tool. Because the wire is inexpensive, it is generally used only once.

2.2.3 PROCESS OF METAL MACHINING BY DISCHARGE AND DIELECTRIC FLUID

The electrical discharge machining is performed by repeating the discharge during the operation. This single discharge should be studied thoroughly as it is the basis of the machining process. The EDM process begins by melting a single discharge and then returns to its initial state. There are five steps performed within an extremely short period of time, which ranges from 0.05 to 1.0 ms (Mitsubishi Electric Corporation).

1. The electrode approaches the workpiece and a discharge is generated at the closest point when the gap is within a few microns. The discharge makes a fine arc column which consists of a flow of electrons at an extremely high current density, and this flow contacts the workpiece at one point. The workpiece surface rises to an extremely high temperature is high enough to melt most regular metallic compounds as well as those which have very high melting points. The electrode is also heated by the ions that are generated as the electron flows contacts the dielectric fluid.
2. The dielectric fluid is surrounding area vaporizes due to the intense heat.
3. The vaporization of the fluid exerts a great pressure on the melted particles of the workpiece and the machining electrode. Although this pressure is relatively small compared to the entire workpiece and electrode, it is quite substantial when calculated in relation to the contact surface area.
4. The melted metallic particles are dispersed in the dielectric fluid. Some particles remain on the edges and adhere to the workpiece and electrode, forming raised areas. These areas form subsequent discharge point for the following sparks caused by the electrical discharge.
5. The cold dielectric fluid that surrounds the discharge point enters the area where the melted metal was dispersed and rapidly absorbs the remaining heat.

2.2.4 ELECTRICAL DISCHARGE STABILIZER

The electrical discharge stabilizer moves the electrode up and down at set intervals so that the machining chips can be removed from the gap. These procedures a pumping action as the dielectric fluid enters and leaves the machining area. The discharge stabilizer is not used independently. It is used with the emission, suction and injection flushing method.

2.2.5 ELECTRODES

2.2.5.1 Selecting the Electrode Material

Table below are lists of the electrode materials that are frequently and infrequently used in electrical discharge machining.

Frequently used materials	Infrequently used materials
Copper (Cu) Graphite (Gr) Copper Graphite (Cu-Gr) Silver tungsten (Ag-W) Copper Tungsten (Cu-W) Steel (St)	Brass (Bs) Aluminum (Al) Zinc (Zn) Tungsten (W)

Table 2.1 Frequently and infrequently used electrode, source : Mistsubishi Electric Corp.

Although brass is used less frequently for many machining applications, it is still used for through-hole machining of pinions because of its excellent cutting characteristics and the fine finished surface it produces. Its greatest disadvantage is the high rate of electrode consumption. Aluminum, zinc and tungsten were used extensively in the past, but these metals have rarely been used since the development of the transistorized power supplies due to their excessive electrode wear compared to the copper and graphite. The essential criteria for selecting electrode materials are based on its manufacturing properties and discharge machining characteristics. The possible materials should be investigated thoroughly so the optimal material can be selected.

Manufacturing Properties :

- Cuttability
- Size limitation
- Ease of handling
- Manufacturing method
- Price

Discharge machining characteristics :

- Electrode consumption
- Clearance
- Surface coarseness
- Machining speed

2.2.6 Dielectric Fluid

Electrical discharge machining is generally performed in dielectric fluid, which is a type of oil. Dielectric fluid is used in electrical discharge machining for the following purposes:

1. The fluid disperses the melted metal produced during discharge machining.
2. It removes the scattered machining chips from the gap.
3. It cools the section that was heated by the discharge machining.
4. It also provides insulation in the gap between the electrode and the workpiece.

The dielectric fluid is an essential element in the discharge machining process.

The dielectric fluid that is generally used is a mineral oil with a paraffin type of hydrocarbon base that was developed exclusively for electrical discharge machining and is produced by all major petroleum manufacturers. The six criteria must be fulfilled when a dielectric fluid is selected :

1. Adequate viscosity
2. Having good electrical discharge efficiency
3. Low cost
4. Minimum odor
5. Good oxidation stabilization
6. High flush point

2.3 MATERIAL

2.3.1 Introduction to Tool Steel

Tool steels are either carbon or alloy steels, capable of being hardened and tempered. They are usually melted in electric furnaces and produced under tool steel practice to meet special requirements. They may be utilized for application in certain tools used by hand, or in mechanical fixtures for cutting, shaping, forming and blanking of materials at either ordinary or elevated temperatures (S. Koshiba, and M. Kikuta, 1954). They are also used for other applications when wear resistance is important. For the purpose of this manual section, the foregoing description of tool steels is not intended to include that type of "mass production open hearth steel" that is used in the manufacture of hollow drill steel, or of such products as mechanic's hand tools, hammers, picks, mining bits, large mill rolls and low alloy die blocks. Thus it is arbitrarily established that many common tools are not made from tool steel. The principal distinction is that tool steel is manufactured under carefully controlled conditions so that the steel that is ultimately shipped to the consumer is of highest quality (Peter Payson, 1962).

Even tool steel is not perfect, but it is far superior to so-called "tonnage" steel in freedom from internal porosity, sizable undesirable nonmetallic inclusions, serious chemical segregation, and surface defects(Peter Payson, 1962). Various physical methods are used for macro inspection, to assure that tool steels meet the minimum requirements set up by the consumer. The consumer is aware of the severity of the stresses to which tools are subjected in service and may insist on more rigid requirements for one application than for another. Some hand tools are subjected to relatively mild stresses in service, and it is for this reason that such tools need not be made from high-quality tool steels. However, most mechanically driven tools are subjected to very high stresses, and such tools must be as free as possible of internal defects that may start fatigue failures or cause the tool to break prematurely.

2.3.2 Compositions of tool steels

Tool steels differ from “tonnage” steels primarily in their wide ranges of composition, which cause these tool steels to have a tremendous variety of responses to heat treatment (Peter Payson, 1962). The American Iron and Steel Institute (AISI) lists 85 types of tool steels, and a number of tool steel manufacturers produce special types not shown in the Institute classification. Some types of steel are made by many manufacturers, and each manufacturer has a separate brand name for the steel. For example, there are over 30 brand names in USA for the popular oil-hardening steel, Type O1.

Iron is the most prominent element which is found in tool steels. Some of the water-hardening tool steels contain 98% or more iron, and even the most highly alloyed high-speed steels contain over 60% iron. It is the ability of iron to undergo the allotropic transformation from ferrite (alpha) to austenite (gamma) during heating, and back to ferrite again during cooling, which makes it possible for the tool steels to develop high hardness and wear resistance. The chemist reports all the other elements in the steel, and it is tacitly accepted that the balance of the composition is iron. Generally carbon, manganese, phosphorus, sulfur, silicon, nickel, chromium, vanadium, tungsten, molybdenum, and cobalt are reported in analyses of tool steels. There are several elements which are usually not reported and which may be present in minute quantities. Small amounts of aluminum, titanium, and zirconium may be added to the steel for the purpose of deoxidizing the melt and controlling the grain size of the steel.

Nitrogen, which may enter the melt from the atmosphere or from ferroalloy additions, may be present up to about 0.030% or may be purposely added in amounts up to about 0.10%.

Carbon. Carbon is the most important element in tool steels for the development of high hardness by heat treatment. When steels of different carbon content are heat-treatment so that the resultant microstructure is entirely martensite, as measured by conventional hardness testers, increases with increasing carbon content. Carbon is present in tool steels in amounts from as little as about 0.05% to as much as 2.35%. The very low carbon steels are actually not used as tools without augmentation of their carbon content by a carburizing heat treatment. The very low carbon content makes it possible for the steel to be annealed to a very soft condition suitable for being processed into molds by a cold-hubbing operation.

Wear resistance of steel is generally proportional to the hardness of the steel. Since most tools are expected to be wear resistant, they are heat-treated to develop high hardness, that is, from about Rockwell C58 to Rockwell C68. Generally, the higher the hardness of steel, the lower is its resistance to cracking or chipping in service. Therefore it is sometimes necessary to compromise between wear resistance and so-called “toughness”; under these circumstances, tools are put into service at hardness values as low as Rockwell C35 to C40.

Manganese and Silicon. Manganese and silicon are found in all tool steels in quantities from about 0.15 to 3.0%. In small quantities these elements are primarily effective in deoxidizing the steel in the final stages of melting. Manganese also combines with the sulfur in the steel to form the relatively innocuous nonmetallic inclusion, manganese sulfide. In quantities higher than 0.30%, both manganese and silicon increase the hardenability of the steel, but manganese is much more effective than silicon.

Nickel. Relatively few tool steels contain nickel in amounts over approximately 0.5%. However, most steels contain small quantities of nickel, which enter the melt from scrap. Nickel is effective in increasing the hardenability of steel, therefore, in the manufacture of very shallow hardening, carbon tool steels only specially selected scrap low in nickel content is used in the charge. In high-alloy steels, nickel usually increases annealing difficulties.

Chromium. Chromium is used in many tool steels in amounts from about 0.2% to 12%. It is effective in raising the hardenability of steel. It is also a carbide-forming element, and in the high-carbon, high-chromium steels, remarkable wear resistance is imparted by the presence of numerous chromium carbide particles embedded in the matrix of the hardened steel.

Vanadium. Vanadium is used in tool steel principally as a carbide former. It is an important element in the high-speed tool steels for the development of red hardness, that is, the ability of the steel to retain a great deal of its hardness even when the steel is heated to relatively high temperatures. Small amounts of vanadium, about 0.20% are effective in inhibiting grain growth in heat-treated steel.

Tungsten and Molybdenum. Tungsten has been one of the most important alloying elements in tool steels since about 1890, but the quantity of tungsten used in the tool steel industry has diminished appreciably since about 1950. Tungsten is used in tool steels in quantities from about 0.5 to 20.0 %, and molybdenum from about 0.15 to 10.0%. Both are carbide-forming elements and contribute red hardness and wear resistance to the heat-treated steel. Molybdenum is also quite effective, and much more so that tungsten, in increasing the hardenability of steel.

Cobalt. The last element of importance in tool steels is cobalt, and it is used almost exclusively in high-speed steels. Steels containing cobalt have been available since about 1910, but although it is known that cobalt contributes to the red hardness of high-speed steels, the mechanism involved is still not understood. Cobalt is generally used in relatively large quantities, that is, from about 5.0 to 12.0% (Peter Payson, 1962).

2.3.3 Types of Tool Steels

There are 7 major groups to classify the tool steels, and each major group consist subgroups based on characteristic composition or heat-treatment variations. Admittedly, this classification is not perfect, but it has satisfactorily given some order to the tremendous variety of compositions by to steel manufacturers (Peter Payson, 1962).

The AISI (American Iron and Steel Institute) classification is as follow :

1. High-Speed Tool Steels: molybdenum-base types (symbol M)
2. High-Speed Tool Steels: tungsten-base types (Symbol T)
3. Hot-Work Tool Steels: chromium-base types (symbol H)
4. Hot-Work Tool Steels: tungsten-base types (symbol H)
5. Hot-Work Tool Steels: molybdenum-base types (symbol H)
6. Cold-Work Tool Steels: high-carbon, high-chromium types (symbol D)
7. Cold-Work Tool Steels: medium-alloy, air-hardening types (symbol A)
8. Cold-Work Tool Steels: oil-hardening types (symbol O)
9. Shock-Resisting Tool Steels (symbol S)
10. Mold Steels: low-carbon types (symbol P)
11. Special Purpose Tool Steels: low-alloy types (symbol L)
12. Special Purpose Tool Steels: carbon-tungsten types (symbol F)
13. Water-Hardening Tool Steels (symbol W)

The compositions listed in the AISI classification are by no means all of the tool steel types produced. Basically, not all types listed are made by all the tool steel producers. For example, many of the producers make the W1, S5, O1, A2, D2, H12, T1, M1, and M2 types, whereas relatively few make the W7, S3, A5, D1, H20, T9, M6, and F3 types (American Iron and Steel Institute).

CHAPTER 3 : EXPERIMENT METHODOLOGY

3.1 INTRODUCTION

Electrical Discharge Machining or EDM is one of the precision machining which requires all the metrology and measurements are precise. Its tolerance should only be between 2-5 microns only. The experiments begin with the preparation of the workpiece which is tool steel and its properties as shown in the next page. Then Taguchi method L9 Orthogonal Array is used in the design of the experiment and the input and output parameters are defined. Before cut the material, the EDM machine must be set up first. The flow chart of the experiment methodology is shown in the next page.

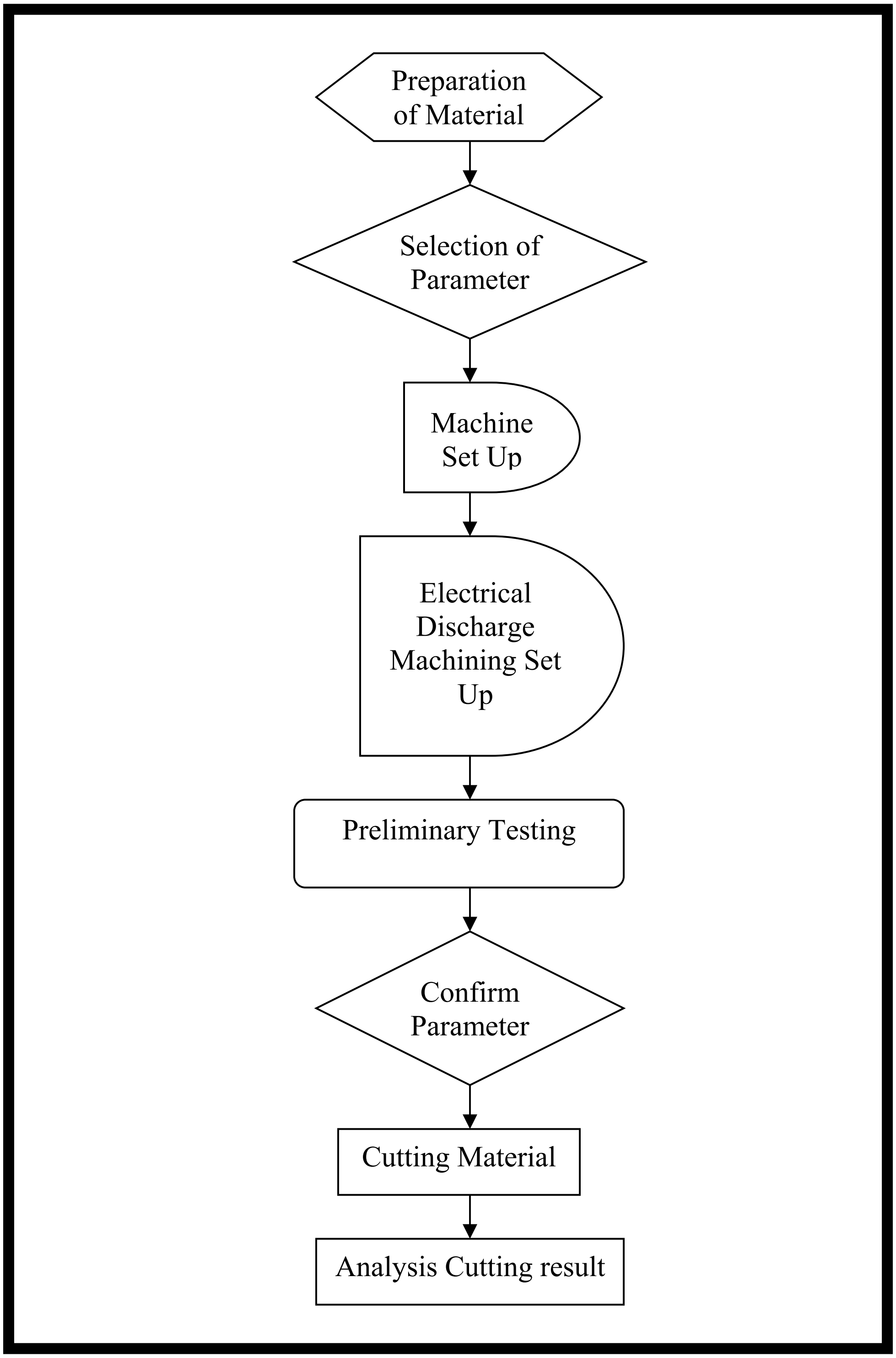

Figure 3.1 Experiment Flow Chart

3.2 MATERIAL PREPARATION

3.2.1 Material Properties

A rectangular tool steel bar, 130mm x 90mm with thickness of 15mm has been used in this experiment. The properties of the tool steel used shown as follow :

Figure 3.2 Material used

1. Work material and chemical composition
   a. Carbon – 0.93%
   b. Silicon – 0.25%
   c. Manganese – 1.10%
   d. Chromium – 0.60%
   e. Tungsten – 0.60%
   f. Vanadium – 0.10%

2. Work material hardness before hardened : 15 HRC
3. Work shape and size : 130mm x 90mm x 15mm
4. Nearest equivalent : AISI O1
5. Supplied condition : Annealed
6. Tensile strength : 850-900 MPa
7. Yield strength : 500 MPa
8. Modulus of elasticity : 215 GPa
9. Density : 7.64 g/cc
10. Melting temperature : 1100 C
11. Used in common components : Dies and Fixtures

- Source of data : The mechanical design process, David G. Ullman, 2nd edition, McGraw Hill International Editions.

3.2.2 Tool Steel Hardening

The original tool steel from manufacturer are low in hardness, 14-17HRC. To satisfy the needs of the experiment, the cutting material cannot be cut with other cutting machine such as milling, lathe, the hardness must be increase to 55-65HRC so that only can be cut by certain machine such as EDM. So tool steel hardening process involved to increase the hardness. The process begins with heating the material to 850C for 20 minutes in the furnace. Then the heated material is dipped into oil for cooling process. Finally the hardness of the material checked using Rockwell Hardness Tester with Diamond C, load up to 150kgs. The hardness are checked for both side A and side B with this method shown below :

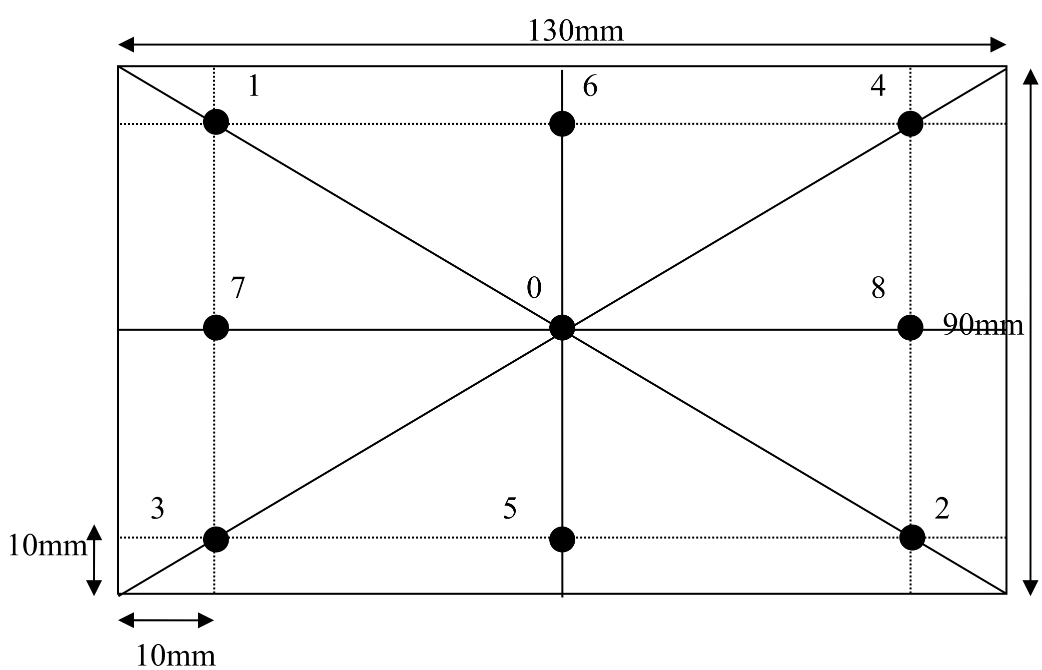

Figure 3.3 Hardness checking method