# STUDY THE APPLIED VOLTAGE AND WIRE SPEED INFLUENCES ON MACHINING ALUMINUM ALLOY 6061 USING WIRE- EDM PROCESS

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Report submitted in partial fulfillment of the requirements for the award of the degree of Bachelor Manufacturing Engineering

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5 JULY 2013

## ABSTRACT

This thesis deals with the investigation of the optimization parameters on the surface roughness and hardness of aluminum alloy 6061 by using wire electrical discharge machining (WEDM). In this experiment, varying applied voltage and wire speed were done. The applied voltage that has been used to conduct this experiment are 30V, 40V and 50V. While the wire speed was used are 5mm/min, 10mm/min and 15mm/min. The other machine parameters are fix to constant and only these two parameters were varied. The optimum machining parameters were determined by using Taguchi Method. Main effects, analysis of variance (ANOVA) and signal to noise ratio (S/N ratio) are used to analyze the data. The level of importance of the machining parameters on surface roughness and hardness can be determined by using ANOVA, while the optimum parameters combination was obtained by using analysis of S/N ratio. The wire breakage times also were taken and analyzed.

# ABSTRAK

Tesis ini menbentangkan penyelidikan tentang pengoptimuman parameter terhadap kekasaran permukaan dan kekerasan aloi aluminium 6061 dengan menggunakan mesin Mesin elektrik discas Wayar (WEDM). Dalam eksperimen ini, voltan dan kelajuan wayar yang berbeza digunakan. Voltan yang digunakan untuk menjalankan eksperimen ini adalah 30V, 40V dan 50V. Manakala kelajuan wayar yang digunakan adalah 5mm/min, 10mm/min dan 15mm/min. Pengoptimuman parameter ditentukan dengan menggunakan Kaedah Taguchi. Kesan utama, analisis varians (ANOVA) dan isyarat kepada nisbah bunyi (nisbah S / N) digunakan untuk menganalisis data. Tahap kepentingan parameter pada kekasaran permukaan dan kekerasan boleh ditentukan dengan menggunakan ANOVA, manakala kombinasi parameter optimum diperolehi dengan menggunakan analisis nisbah S / N. kekerapan wayar putus juga akan diambil dan dianalisis.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AA | Aluminum Alloy |
| ANOVA | Analysis of variance |
| CNC | Computer numerical control |
| EDM | Electric discharge machine |
| FKP | Faculty Kejuruteraan Pembuatan |
| HB | Hardness Brinell |
| HV | Hardness Vickers |
| IACS | International Annealed Copper Standard |
| SF | Surface finish |
| S/N | Signal to noise |
| WEDM | Wire electric discharge machine |

# CHAPTER 1

# INTRODUCTION

This chapter, discussed briefly about the project background, problem statement, objectives and scope of study. This chapter is a fundamental for the project and act as guidelines for project research.

## 1.1 PROJECT BACKGROUND

Aluminum alloy 6061 (AA6061) is a material that have various usage as structural material and it is one of the most widely used alloys in the 6000 Series. Nowadays, metal matrix composites based on AA 6061 are being used in several applications. The alloy shows a great promise for more applications. An aluminum alloy 6061 is a heat treatable, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables. It contains Magnesium, Silicon and chromium. For the aluminum alloy 6061, it contains 0.2% Chromium which provides improved corrosion resistance and prevent from rusting. While the silicon element improves the hardening response, Aluminum alloy 6061 is widely used in automotive and aerospace components, electrical fittings and connectors and couplings. Due to this requirement Wire Electrical Discharge Machining (WEDM) were chosen to produce all this components.

Wire Electrical Discharges Machining (WEDM), more commonly known as wire-cut EDM or wire cutting. Wire electrical discharge machine (WEDM) is an important 'non-traditional manufacturing method' which 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, having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion.

Wire electrical discharge machining (WEDM) is a process of metal removal by electro-thermal. The material is removed by a series of discrete electrical discharges between the wire electrode and the work piece. Wire-EDM is one of the machines which can produce high-precision parts. Apart of producing high-precision machining results, the machine also is capable of producing very fine surface finish. This could eliminate secondary process required such as surface finishing. The work material can be cut into complex 2D or 3D shapes in electrically conductive work material by using a wire electrode. The surface smoothness depends on the characteristic of the work materials and the parameters of the machine.

At present, Wire- EDM is a widespread technique used in industry for high precision cutting of all types of good conductivity metal. However, wire EDM only works with materials that are electrically conductive. The metals that can be machined with Wire EDM include mild steel, aluminum, carbide, copper and stainless steel. There are many parameters should be considered in wire-EDM cutting such as: structure of the material, electrical conductivity, residual magnetism, thickness of the work piece, discharges currents of the machine, pulse duration, pulse frequency, polarity, offset value, wire driving system, type of wire electrode, configuration of wire, wire diameters, length of wire between supports and coiling, tension and wire electrode speed. Figure 1.1 shows the schematic diagram of Wire EDM.

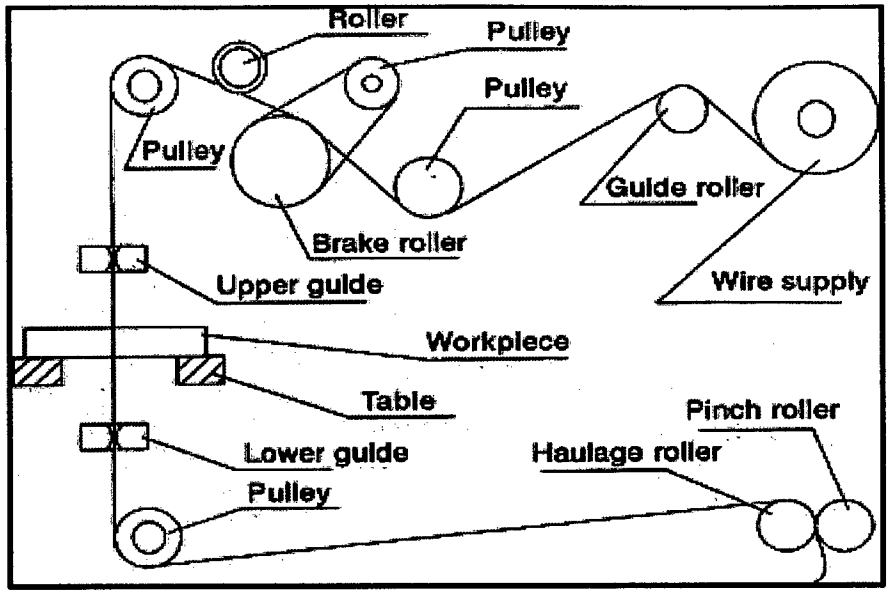


**Figure 1.1** Schematic diagram of WEDM

## 1.2 PROBLEM STATEMENT

The study of surface roughness characterization on aluminum alloy 6061 in wire-electrical discharge machining process can bring benefits to aerospace industries. Even a high skill technician also may have difficulty to set optimum parameters that will be used for WEDM process. It may take long time to set optimum parameters to get the fine surface roughness. Results obtained from this study might be useful in determining machining parameters especially in aerospace industries.

Several researches stated that the surface roughness or surface finish of the machined surface mainly depends on the applied voltage and the wire speed. Studies have shown that increasing of the applied voltage can increase the surface roughness of the products. However, there is no optimum value of applied voltage and wire speed to be combined with other parameters in machining the aluminum alloy 6061. This is serious or critical because aluminum alloy 6061 has being applicator in industry such as industries of aerospace and automotive. In additional, this material is lightweight compare to other steel materials. Due to this problem, the surface roughness has to be investigated further because this property will affect the performance of product in term of the surface finishing or finishing process.

There are studies done to examine relationship between parameters and surface roughness on other materials but parameters used are only limited to pulse current, pulse time, pulse pause time, open current voltage, discharge duration and pulse interval time. Therefore, the purpose for this research is to study the relation between voltage and wire speed of surface roughness on aluminum alloy 6061.

## 1.3 OBJECTIVES

The objectives of this project as below:

- To determine the optimal value of parameters between applied voltage and wire speed towards the surface roughness of aluminum alloy, AA6061.
- To study the hardness of the aluminum alloy 6061 by using different level of voltage and wire speed.

## 1.4 PROJECT SCOPE

This experiment is conducted at Faculty Kejuruteraan Pembuatan (FKP) in UMP by using SODICK CNC Wire EDM; model VZ 300L with 0.2mm diameter of brass wire as the cutting tool. The material used in this experiment is aluminum alloy 6061. Discharge current, pulse duration, pulse frequency, wire tension and wire speed are set as fix parameters in this study, while voltage and wire speed are varied to act as the independent variables. The study is to measure the surface roughness of the cut material using surface roughness tester ZEISS brand (SURFCOM 130/480A) and hardness of the material using Vickers Hardness tester. The results are then analyzed using Taguchi method to find the optimum parameter of surface roughness and hardness.

# CHAPTER 2

# LITERATURE REVIEW

Literature review is one of the scope studies. It works as guide line to run out this experiment. It will give part in order to get the information about Wire electrical discharge machine (WEDM) and will give idea to operate the experiment. 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. Literature review section work as reference, to give information and guide based on journal and other source in the media.

## 2.1 HISTORY OF WIRE ELECTRICAL DISCHARGE MACHINE (WEDM)

The history of Wire EDM Machining techniques was discovered by an English Scientist in the earlier in the 1960s and there is not fully taken advantage. When it was observed by Joseph Priestly in 1770, the Wire EDM was very imprecise and riddled with failures and it was suitable for the tool and die, mold, and metalworking industries. The first numerical controlled wire EDM machine in the world was launched in Agie and the first CNC wire EDM machine was developed in 1972 and the first system was manufactured in Japan.

## 2.2 WIRE EDM (WIRE ELECTRICAL DISCHARGE MACHINE)

Wire EDM or wire cutting widely used in cutting precision dies and profiles that require a smooth surface finish. The Spark Theory on a wire EDM is basically the same as that of the vertical EDM process. In wire EDM, the conductive materials are machined with a series of electrical discharges (sparks) that are produced between an

accurately positioned moving wire (the electrode) and the work piece. High frequency pulses of alternating or direct current is discharged from the wire to the work piece with a very small spark gap through an insulated dielectric fluid (water). CNC wire cut EDM machine puts impulse voltage between electrode wire and work piece through impulse source, controlled by servo system, to get a certain gap, and realize impulse discharging in the working liquid between electrode wire and work piece.

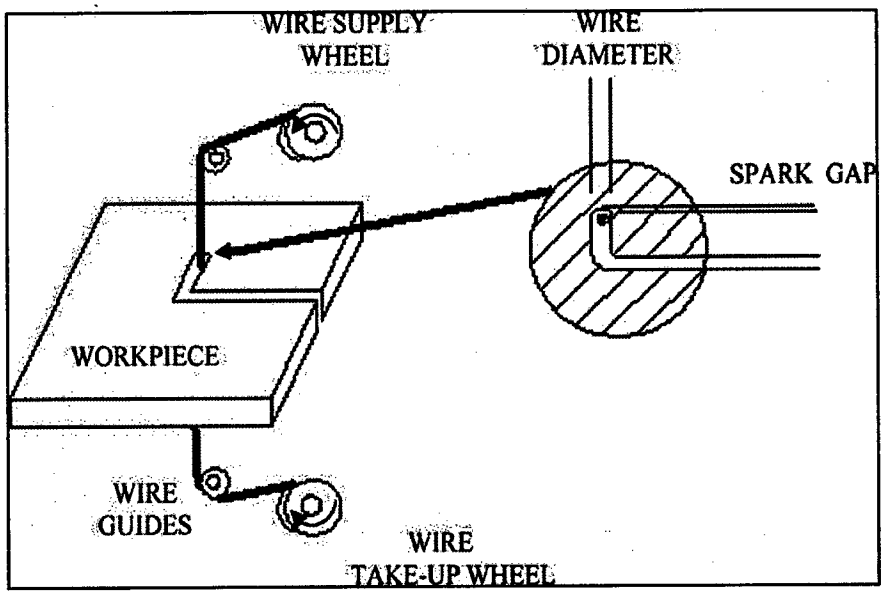


**Figure 2.1** Process Wire EDM

According to Treziseet al (1982), the fundamental limits on machining accuracy are dimensional consistency of the wire and the positional accuracy of the worktable and most of the uncertainties arise because the working region is an unsupported section of the wire, remote from the guides. The detailed section of the working region of the wire electrode is in Figure 2.1.

## 2.3 SUMMARY OF RESEARCHER'S OUTCOME

Several researches has been conducted in identifying the parameters that affect the quality of the work piece as tabulated in Table 2.1, these are some of those researches.

**Table 2.1:** Summary of researcher's outcome

| Year | Author | Outcome |
|---|---|---|
| 2011 | PujariSrinivasa et al | Pulse on time, pulse off time, current, flushing pressure of dielectric fluid, feed rate, wire tension, applied voltage, and servo were affect the quality of the workpiece. |
| 2009 | H.Singh and R. Garg | The MRR and SF increases with increase the applied voltage and peak current of the machine. |
| 2009 | U. Esme et al | Applied voltage is the major factor affecting the surface roughness. While increase the pulse duration, applied voltage, and wire speed were increase the surface roughness whereas increase the flushing were decrease the surface roughness. |

| | | |
|---|---|---|
| 2009 | C V S Parameswara et al | The effect of discharge current, job thickness and material composition were influences cutting speed, spark gap and MRR. |
| 2008 | F.R.M Romlay et al | The wire speed, wire tensions and wire voltage will affect the wire EDM process and cutting time. |
| 2006 | Ahsan Ali Khan et al | Surface finish was rougher by increasing voltage and current. |
| 2006 | S.S.Mahapatra and A.Patnaik | Discharge current, pulse duration, pulse frequency, wire speed, wire tension, dielectric flow rate were influences the MRR, SF and kerf of the workpiece. |

However, the most significant outcome has shown that surface roughness or surface finish of the machined surface are highly depends on the applied voltage and wire speed. The smoothness of the machined surface depends on the depth of cavities produced during a series of sparks and the depth and size of these cavities depend on the intensity of the sparks while the intensity of the sparks are mainly depends on current and voltage used during cutting process. As stated by Ahsan Ali Khan et al (2006) the applied voltage were affect the surface roughness due to the surface roughness were become rougher when using higher voltage.

Based on Scott et al. (1991) the method used to determine the optimal combination of control parameters in WEDM is factorial design, he was found that the discharge current, pulse duration, pulse frequency and voltage were influence the surface roughness. The parameters wire tension and voltage are observed as significant parameters in obtaining better surface finish and the increase of voltage means that the electric field becomes stronger and the spark discharge takes place more easily under the same gap and a coarse surface is always obtained. The spark erosion of the work material makes use of electrical energy or voltage, converting them into thermal energy through a series of repetitive electrical discharges between the tool electrode and the work material electrode. Regarding to PujariSrinivasa Rao et al. (2011) the increase of voltage means that the electric field becomes stronger and the spark discharge takes place more easily under the same gap. he also found that applied voltage is the major factor affecting the surface roughness. According to Y.S Liao et al. (2003) machining in smaller voltage cannot give fine surface roughness because small voltage needs closer gap between wire and work piece to ensure the occurrence of discharging spark and when the wire is close to the work piece the electrostatic force between the anode and cathode will increase.

Regarding to Tosun et al. (2004) the cutting speed in WEDM will affect the surface roughness of the work piece and the performance measures. They also determined the effect of machining parameters on cutting speed and surface roughness based on Taguchi method. Tang et al. (1995) developed a neural network system to determine wire speed for estimation of cutting speed and surface finish. Based on the U. ESME et al. (2009) research, the surface roughness will increase when the pulse duration, voltage and wire speed are increase. They also found that wire speed is the second factor that affecting the surface roughness.

## 2.4 TYPES OF WIRE ELECTRODE

Wire types also give effect to the performance of the process and also towards the quality of the machined surface. There are several types of wire electrode can be used to cut the work piece such as copper, zinc, brass and coated wire. Table 2.2 shows the types of wires that were used in the wire EDM cutting process.

**Table 2.2:** Characteristics of the wire electrode

| Type of wire | characteristics |
|---|---|
| Zinc | • minimum of wire breakage<br>• can prevent short circuits<br>• able to cooling the interface of work piece<br>• ability to cut the high metal removal rate<br>• good electrical conductivity |
| Brass | • combination of copper and zinc<br>• higher tensile strength<br>• lower melting point<br>• higher vapor pressure rating<br>• high electrical conductivity |

To get the desirable of wire material for WEDM electrode should base on following properties such as adequate tensile strength with high fracture toughness, high electrical conductivity [% IACS - International Annealed Copper Standard, a unit of electrical conductivity for metals and alloys relative to a standard annealed copper conductor; an IACS value of 100% refers to a conductivity of $5.80 \times 10^7$ Siemens per meter (58.0 MS/m)], low melting point and Low energy requirement to melt and vaporize.

Jennes et al (1984) reported that the machining rates increase with increase in Zinc content in the wire and the higher Zinc content allows lower servo voltage (mean machining voltage), thereby reduce the short circuit condition. The machined surface will become smooth because of cooling, due to zinc evaporation and also because the Zinc coating on the surface helps to prevent short circuits.

Zinc wire electrode used when the speed of the wire increase. The evaporation of the zinc produces a 'heat-sink' effect in the wire and thus cooling the core material. This 'heat-sink' effect on the wire results in the improvement of the efficiency of the

WEDM process by reducing the wire temperature, and therefore allowing a more thermal flow, leading to an increase of the cutting speed by up to 50% has determine by Sho. H et al (1989). So, the different wire composition would determine their final performance.

Surface finish and tolerance control are related strongly to the quality of the electrode, which must possess electrical conductivity, close size tolerance and sufficient strength to allow tensioning and to avoid breakage. The thermo physical properties of the wire are associated with its thermal conductivity and its melting and evaporation temperatures. Zinc wire electrode has this thermo physical property.

The cost of the wire contributes about 10 % of the operating cost of the wire EDM process, it is very cost effective to examine and evaluate the properties of the wire used in order to be able to optimize the overall performance of the process. Brass and zinc wire electrode are used because it is cheaper than other type of wire electrode. Any types of wire that we use will impact overall cost and performance. Standard brass wires are used because the margin of using this type of wire is 80 percent compare with using other wires [Kalpakjian.Schmid (sixth Edition)]. The more important is total time as it relates to part of quality.

## 2.5 TYPES OF WORK MATERIAL

Han et al (2007) have conducted the experiments on different material namely aluminum alloy, brass, alloy steel, cemented carbide which have different hardness at the same condition to obtain surface roughness. They found that the significant factors which affect the surface roughness are the rigidity of the work material. The surface roughness decreases accompanying an increase in material rigidity. Therefore, they found out that high rigidity materials will produce finer surfaces and low rigidity materials will produces rough surface roughness. So, that means the higher hardness of the material will give the fine surface roughness to the work piece.

However, aluminum alloy is widely used in aerospace and automotive industry because of its lightweight and its corrosion resistance as to be compared with other

materials. Very few metals have a lower density than aluminum and they are not in common usage. This aluminum mostly used for bright trim applications, including automotive trim. In aluminum alloy the typical alloying elements are copper, magnesium, silicon and zinc. (Mechanical engineers handbook, MYER KUTZ, 2006)

There are many types of aluminum alloy with their properties and aluminum alloy 6061 has been chosen. This is because the strength and the hardness of aluminum alloy 6061 is suitable for heavy duty industry. Alloy 6061 are the workhorses from the structural standpoint, with increasing higher strength associated with the higher Mg content and it offer the best combination of strength and corrosion resistance of all aluminum alloys. (Mechanical engineers handbook, MYER KUTZ, 2006) Aluminum alloy 6061 is combination of aluminum, Magnesium, Silicon, Iron, Copper, Zinc, Titanium, Manganese, Chromium and others. Alloy 6061 widely used in the construction of aircraft structures for example wings and fuselages, yacht construction, including small utility boats, construction of bicycle frame and components and the famous pioneer plaque was made of this particular alloy. The hardness of aluminum alloy 6061 is 95 HB (Hardness Brinell) or 107 HV (Hardness Vickers) which combination of aluminum and magnesium.

# CHAPTER 3

# METHODOLOGY

Current chapter generally discusses methodology of the project, with a focus on wire electric discharge machine (WEDM) 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 how to start an experiment, the problem identification and solving and detail experimental design. Roughly, this project consists of two semesters. For the semester one which are doing the proposal, literature review and methodology planning. While for the semester two which is prepare the experimental tools and work pieces, running the experiment, get the data collection and do the analysis. For this research, the methodology flow chart is illustrated as Figure 3.1.

## 3.1 FLOW CHART

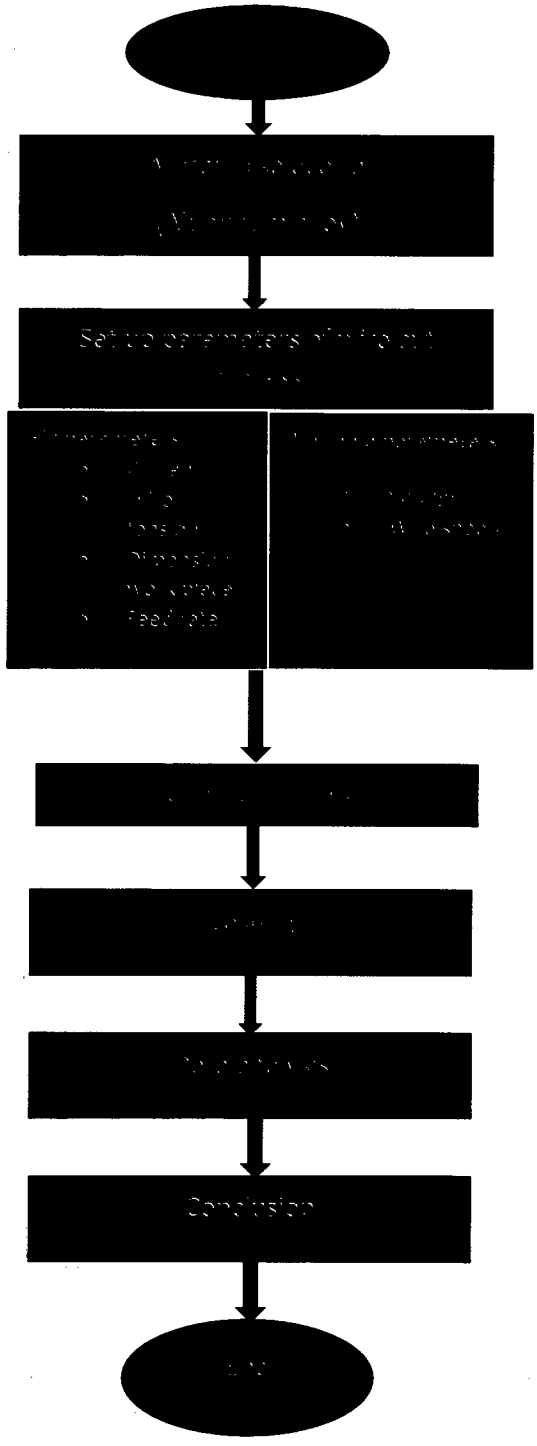


**Figure 3.1** Flow Chart

## 3.2 MATERIAL SELECTION

Material selection is the most important to this experiment because different work 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 WEDM. Aluminum alloy is widely used in industries. The principal uses of aluminum and its alloys, in decreasing order of consumption, building and other types of construction, transportation(aircraft, automobiles and aerospace), electrical applications (as an economical and nonmagnetic electrical conductor), consumer durables (appliances, cooking utensils and furniture) and portable tools.

The work material that has been selected is aluminum alloy 6061. The important factors in selecting this aluminum because it has 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 and last they are also nonmagnetic.

## 3.3 SET UP PARAMETERS OF WIRE CUT PROCESS

To carry out this experiment, the parameter needs to be setting up on the machine. The parameters for the wire cut process were separated into two groups which are fixed parameters and varied parameters.

### 3.3.1 Fixed parameters

The parameters such as current, wire tension, feed rate and dimension of the work pieces are fixed before the experiments has been carried out. Table 3.1 shows the value of the parameters that were fixed. These parameters are fixed because in this experiment the relation between voltage and wire speed has been investigated only. The wire tension is fixed to 1000g because the increase of wire tension automatically will increase the wire speed and accuracy of the machine. Thus, the wire tension is fixed to this value.