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JUDUL: EXPERIMENTAL STUDY OF LASER BEAM CUTTING ON ACRYLIC SHEET

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EXPERIMENTAL STUDY OF THE LASER BEAM CUTTING ON ACRYLIC SHEET

MOHD AIMAN BIN ISMAIL

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

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NOVEMBER 2009

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical.

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STUDENT'S DECLARATION

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

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Dedicated to my beloved father and mother

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ABSTRACT

In this modern era, especially in advanced of engineering materials, it was realize to develop some of non-convectional machining methods known as advanced machining process (AMPs). Laser Beam Machining (LBM) is one of the AMPs that being used nowadays for shaping almost whole range of engineering materials. LBM are widely used for cutting, drilling, marking, welding, sintering, and heat treatment but for this project, this will focus only on cutting. This project is about experimental study of laser beam cutting on acrylic sheet. Cutting experiment will be done on acrylic sheet with thickness of 3mm using PCNC Laser Cutting Machine. The experiment held under some parameters such as cutting angle, cutting speed, laser power, nozzle gap, and air pressure. Response Surface Method (RSM) used to design the experiment which result 40 number of experiment with different values of parameters. The objective of this project is to find the parameter that produced best cutting quality of acrylic sheet. Cutting quality judged by measuring surface roughness of the specimen by using surface roughness tester, MahrSurf XR 20 with Perthometer S2. Two profile parameters that considered in order finding best cutting quality were Roughness Average, Ra and Maximum Roughness Depth, Rmax. From the experiment, the result analyzed and it was found the best cutting quality and parameters that produced that cut. Every parameter has their relationship between each other which affect the quality of cutting. In order to produce better surface, there are some recommendation that can be consider for future research.

ABSTRAK

Dalam zaman moden ini, terumtamanya dalam bidang kejuruteraan bahan yang lebih mendalam, wujudnya kesedaran untuk membangunkan salah satu daripada kaedah memesin yang dikenali sebagai Proses Kemajuan Mesin. Mesin Sinaran Laser adalah salah satu daripada proses kemajuan mesin yang digunakan pada masa kini untuk membentuk hampir seluruh bidang dalam kejuruteraan bahan. Mesin sinaran laser luas digunakan untuk proses memotong, menebuk, menanda, mengimpal, dan pemulihan haba tetapi untuk projek ini, ia hanya menumpukan kepada proses pemotongan. Projek ini adalah berkenaan kajian eksperimen tentang potongan sinaran laser keatas kepingan Acrylic. Eksperimen memotong akan dijalankan ke atas kepingan acrylic setebal 3mm dengan menggunakan Mesin Potongan Laser PCNC. Eksperimen dijalankan di bawah beberapa parameter seperti sudut dan halaju potongan, kuasa laser, jarak nozel, dan tekanan udara. Kaedah tindakbalas permukaan digunakan untuk merancang eksperimen dan sebagai keputusannya, 40 bilangan eksperimen telah dirancang dengan parameter yang berbeza. Objektif projek ini adalah untuk mendapatkan parameter yang menghasilkan kualiti potongan yang paling baik berdasarkan kekasaran permukaan. Kekasaran permukaan diukur dengan menggunakan mesin MahrSurf XR20 dengan Perthometer S2. Dua parameter profil diambil kira iaitu purata kekasaran dan kedalaman kekasaran maksimum. Daripada eksperimen, keputusan di analisis dan kualiti potongan tercantik boleh diketahui. Setiap parameter mempunyai kaitan antara satu sama lain dalam mempengaruhi kualiti potongan. Untuk menghasilkan potongan yang lebih baik, teradpat beberapa cadangan yang boleh diambil kira untuk kajian akan dating.

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LIST OF SYMBOLS

CO_2 : Carbon Dioxide

Ra : Average surface roughness

Rz : Average maximum height

RzJ : Japanese standard for average maximum height

Rq : Root mean square roughness

Rmax : Maximum roughness depth

LIST OF ABBREVIATIONS

LBC : Laser beam cutting

CNC : Computer numerical control

PCNC : Personal computer numerical control

HAZ : Heat affected zone

DOE : Design of experiment

RSM : Response surface methodology

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In this modern era, especially in advanced of engineering materials, it was realize to develop some of non-convectional machining methods known as advanced machining process (AMPs). Laser Beam Machining (LBM) is one of the AMPs that being used nowadays for shaping almost whole range of engineering materials. LBM are widely used for cutting, drilling, marking, welding, sintering, and heat treatment but for this project, this will focus only on cutting.

This project is about Experimental Study of the Laser Beam Cutting on Acrylic Sheet. The term laser is a short form of Light Amplification Stimulation Emission of Radiation (LASER) [1] and the Laser Beam Cutting (LBC) is a method of cutting metal utilizing a high intensity laser for melting and vaporizing material and related to laser beam machining [2].

A medium, either gaseous or solid, is excited to emit a monochromatic (single wavelength) coherent source of light. This light can be focused to a point source, called spot size, resulting in very high power, densities, capable of vaporizing various materials. By controlling the power density, through the laser power and spot size, and with the assistance of gases, laser cutting and welding can be achieved. The two most common types of industrial lasers are CO_2 and Nd:YAG. CO_2 use a gaseous medium for the lasing action while the Nd:YAG use a crystalline material. The CO_2 lasers are commercially available in powers up to 40 kW and Nd:YAG systems to 5 kW. The Nd:YAG were commonly used because of its high intensity, low mean beam power, good focusing characteristics, and narrow heat affected zone (HAZ). Laser beam cutting (LBC) also can be successfully used for the cutting of conductive and nonconductive difficult-to-cut advanced engineering materials such as reflective metals, plastics, rubbers, ceramics and composites.

Apart from cutting difficult-to-cut materials, LBC is most widely used in industries to achieve complex shapes/profiles with close tolerances for cutting of steel sheets [3].

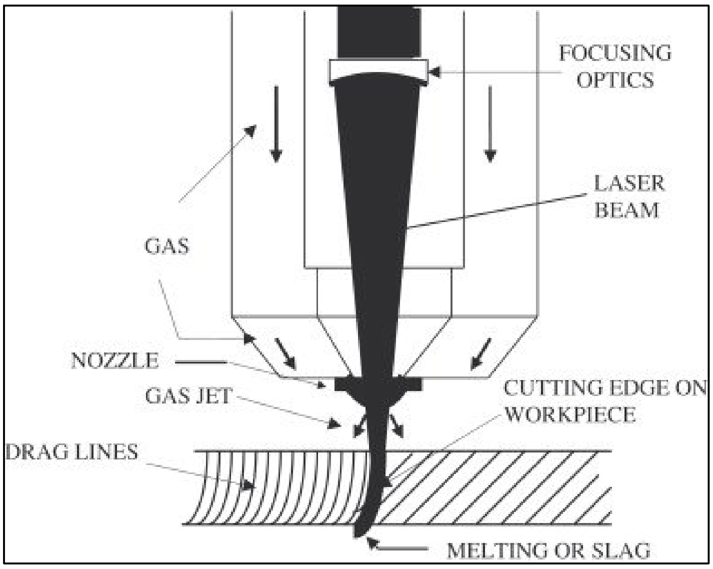

Figure 1.1: Schematic of Laser Beam Cutting (LBC)

Laser beam cutting (LBC) is achieved by the radiation emitted by a focused beam of coherent light with the assistance of a high pressure gas. An assist gas is used to remove the melted and volatilized materials from the beam path. Both metallic and non-metallic materials can be cut by the laser beam process. The output beam is often pulsed to very high peak powers in the cutting process. Pulsing generally increases the travel speed of the cutting operation [4].

It is a thermal energy based non-conventional cutting method in which sheet material is cut mainly due to melting and vaporization [5]. The quality of cut solely depends on the setting of process parameters such as laser power, type and pressure of assist gas, sheet material thickness and its composition, cutting speed, and mode of operation (continuous wave or pulsed mode).

Advantages of LBC include:

- complex figures can easily be cut by incorporating CNC motion equipment
- high cutting speeds
- low distortion
- low dross
- minimal heat affected zones
- very high edge cut quality
- very narrow kerf width

1.2 PROBLEM STATEMENT

In the industry sector, they are various ways to cut materials. One of them is using laser machine that is Laser Beam Cutting. This project is to help the industry to cut the various type of material that used in the industry by using laser machine. By using this method, they can cut any shape that they want easily where it is hard to use another machine or method to cut it. So practically, this method can help the industry in cutting their materials.

There were some problems that need to be tackled such as using the Microsoft Excel Software to analysis data or to find pattern in data. Besides that, the type of materials that need to used in this project also has to determine and have to produce the finest and the most quality of cut. There are some parameters that have to consider such as laser power, type and pressure of assist gas, cutting materials thickness and its composition, cutting speed, and mode of operation (continuous or pulsed) on process performance. All of these parameters have to be determined before doing an experimental study of laser beam cutting.

1.3 OBJECTIVE PROJECT

The aim of this project is generally to:

- To study of the Laser Beam Cutting (LBC) on Acrylic Sheet.
- To find the best parameters that can produce the finest and most quality of cutting quality on Acrylic sheet by analysis using Microsoft Excel.

1.4 PROJECT SCOPE

This project will focus mainly on one of the Laser Beam Machining function that is Laser Beam Cutting. In order to achieve the objective notified earlier, the following scopes have been recognized:

1. The machine that will used is PCNC Laser Cutting Machine (30 Watt)
2. Cutting parameters will be determined before doing the experiment and the quality of cut determined by doing surface roughness test.
3. The result will be analyzed by using Microsoft Excel and from that we can see the best quality of cutting.
4. Material that used is Acrylic sheet with thickness of 3 mm.

This project will be doing in Faculty of Mechanical Engineering (FKM) Laboratory in University Malaysia Pahang (UMP).

CHAPTER 2

LITERATURE REVIEW

2.1 LASER BEAM CUTTING

Laser light differs from ordinary light because it has the photons of same frequency, wavelength and phase. Thus, unlike ordinary light laser beams are high directional, have high power density and better focusing characteristics. These unique characteristics of laser beam are useful in processing of materials. The laser beams are widely used for machining and other manufacturing processes such as, cutting, drilling, micromachining, marking, welding, sintering, and heat treatment.

Laser beam cutting (LBC) can be successfully used for the cutting of conductive and non conductive difficult-to-cut advanced engineering materials such as reflective metals, plastics, rubbers, ceramics and composites. Apart from cutting difficult-to-cut materials, LBC is most widely used in industries to achieve complex shapes/profiles with close tolerances for cutting of steel sheets. In laser beam cutting (LBC) process, the thermal energy of laser beam is used for melting and vaporizing the sheet metal. The molten material is removed by using suitable assist gas at high pressure (figure 2.1). The most widely used lasers for sheet cutting are continuous wave (CW) CO2 and pulsed Nd:YAG [6]. Pulsed Nd:YAG laser cutting becomes an excellent cutting process because of high laser beam intensity, low mean beam power, good focusing characteristics, and narrow heat affected zone (HAZ) [7]. There has been growing interest in recent years in the use of pulsed Nd:YAG lasers for precision cutting of thin sheet metals and for applications that demand narrow kerf widths and intricate cut profiles. Due to its shorter wavelength (1.06_m) in comparison to CO2 (10.6_m), it is reflected to a lesser extent by metallic surfaces and this high absorptivity of the Nd:YAG laser enables cutting of even highly reflective materials with relatively less power [8].

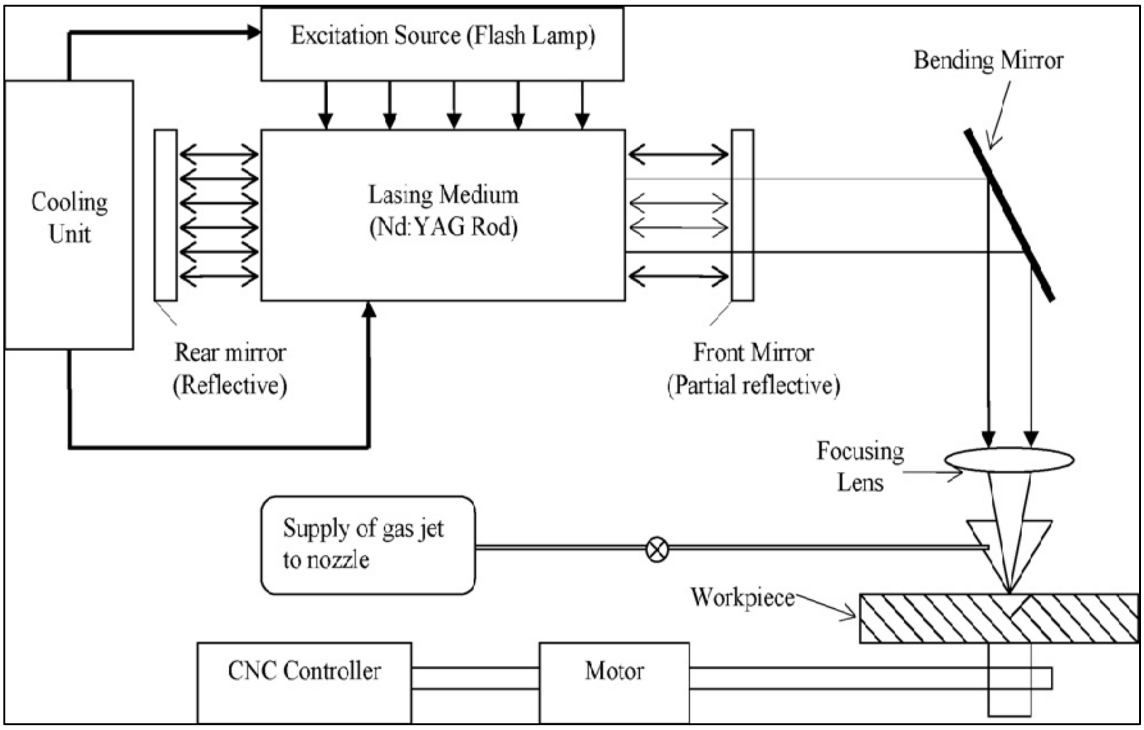

Figure 2.1: Schematic of Nd:YAG laser beam cutting system.

LBC has always been a major research area for getting the exceptionally good quality of cut. The quality of cut solely depends on the setting of process parameters such as laser power, type and pressure of assist gas, sheet material thickness and its composition, cutting speed, and mode of operation (continuous wave or pulsed mode). A lot of experimental investigation has been undertaken with the aim of analyzing the effect of process parameters on cut geometry, and cut surface quality. In most of the experimental investigations of the LBC process, researchers have varied one factor at a time to analyze the effect of input process parameters on output quality characteristics or responses. But this technique requires a large number of experimental runs because only one factor is varied in each run, keeping all other factors constant. Also, in this technique, the interaction effects among various input process parameters are not considered. To overcome these problems, some researchers have incorporated design of experiments methodologies such as the response surface methodology (RSM) and Taguchi methodology (TM) during experimental study of LBC process [9].

2.2 PARAMETERS

The experiments have been conducted by different researchers with the factors or process variables that are considered to be the most important without using any scientific method of experimental design. The results obtained are used to investigate the effect of each factor as well as the influencing mechanism on the observed quality characteristic.

Experiments on Nd:YAG laser beam cutting of metals and alloys have been reported by various authors. Grevey and Desplats (1994) have compared the cutting performance of continuous wave (CW) and pulsed Nd:YAG laser beam for cutting bare and coated metal plates (0.8–2.0mm thick) of car frame using oxygen assist gas. They have found that the cutting speed obtained was more in case of CW laser, bare metal and thinner plate. The highest cutting speed recorded was 5m/min at an optimum oxygen pressure of 3 bar [10].

Tahmouch et al. (1997) have performed the experimental study for cutting stainless steel sheets (up to 2 cm thick) from a long distance (1 m) without using any assist gas in pulsed mode taking pulse frequency (100–200 Hz), peak power (2–5 kW) and cutting velocity (0.05–0.5 m/min) as process variables. Their study revealed that less power density is required to cut without assist gas in comparison to classical cutting and sheets up to 2 cm thick can be cut successfully at a long distance. They have also found that low pulse frequencies and high peak powers were favorable for higher cutting speeds [11].

Kaebernick et al. (1999) have performed the experiments on mild steel and stainless steel sheets (0.5 and 0.9mm thick) in pulsed mode using oxygen assist gas at constant pressure of 700 kPa. Variation of kerf width was recorded by varying cutting speed (600–800 m/min) and pulse width (0.2–0.9 ms) keeping pulse energy (0.35 for 0.5mm sheet and 0.7 J for 0.9mm sheet) and frequency (170 and 100 Hz, respectively, for 0.5 and 0.9mmsheets) at constant values for each specimen. They have found that the kerf width increases slightly with increase in cutting speed up to a critical value then starts decreasing. This critical value depends on pulse width and increases with increasing pulse width [12].

Han et al. (2005) have performed the experiment in CW mode on H13 tool steel and stainless steel 304 substrates at different power levels (300–1000W) and processing speeds (6.3–17 m/s). Melt pool depth and width were found to be increased with increasing power while processing speed shows no significant effect. The maximum temperature was recorded at the middle of the melt pool geometry [13]. Effect of mechanical cutting and laser cutting on magnetic properties of nonoriented electrical steel sheets (300mm×100mm×0.5mm) have been experimentally investigated using pulsed Nd:YAG laser (Loisos and Moses, 2005). It was found that cutting at slow speed using special type of laser beam system of maximum average power 100W there was no change in magnetic properties while in mechanical cutting the magnetic flux density extends up to 5–6mm from each side of the cutting edge.

From the experiments that have been prove by the others researcher, it can be said all the parameters affected the LBC process. Cutting speed has to be more if the cutting mode is continuous wave. And if there was no assist gas use, less power density is required to cut the material from a long distance. For high cutting speed, it is suggested to use low pulsed frequencies and high peak power to obtain the good quality of cutting. But, increasing the cutting speed will increase the kerf width up to the critical value and then decrease. The pulse width was influence this critical value. It was also observed that smaller kerf width and smoother surface is obtained by increasing cutting speed and frequency while decreasing the power and gas pressure. The parameters that have to be considered are:

2.2.1 Laser Power

Laser power depends on the type of laser used. For this project, the laser that we used is continuous wave (CW) CO_2 type that have power maximum to 30 Watts. But the power only can be used until 95% to the maximum power. Meaning that, the maximum power that we can use is about ±28.5 Watts. So far, the machine that had in the FKM lab was only cut the PVC. It never been tested with other materials that harder or stronger materials such as aluminium. Then the suggested laser power is 25.5 Watt, 26.5 Watt, 27.5 Watt, and 28.5 Watt. Then we can determine what laser power will produce the best cutting quality.

2.2.2 Cutting Speed

Cutting speed for PCNC Laser Cutting Machine can be various depends on what we want to do. The speed is measured in pulse. For cutting, the best cutting speed for cutting PVC is 700 pulsed. But for materials aluminum and phosphorus (bone) we have to determine the best cutting speed. The cutting speed that will be used is 900, 1000, 1100, and 1200 pulse. Then the best cutting quality can be determined by which cutting speed.

2.2.3 Type and Pressure of Assist Gas

PCNC Laser Cutting Machine used the air as the assist gas. This assist gas is to help to move the molten materials at the surface of the materials. The gas also can suck the smell of the gas. The air pressure will be up to maximum 10 bars.

2.2.4 Cutting Material Thickness and its composition

This project will used acrylic as material that need to cut. Acrylic is a one of the types of PVC. Since this machine only cut PVC, the maximum PVC that successfully been cut is 15mm. And for this project, the thickness of the acrylic used Is only 3mm. so if should be no problem for PCNC Laser Cutting Machine with maximum power up to 30W to cut it.

2.2.5 Mode of Operation

Mode of operation for this machine is pulsed mode. This is mode for cutting materials. But the laser will operate in continuous wave (CW) mode.

2.2.6 Cutting Angle

The cutting angle that will be used in this experiment is 0^0, 2^0, 4^0, and 6^0. Then we have to determine what angle is the best angle that can be used to cut our materials.

2.2.7 Nozzle gap

One of the parameters that will influence the cutting quality is the gap between laser nozzle and the materials. Each distance will cause different effect on the materials that we are cutting. So in this experiment, the suggested gap was 1mm, 2.5mm, 4.5mm, and 6.0mm.

List of parameters :

- Laser Power = 25.5 Watt, 26.5 Watt, 27.5 Watt and 28.5 Watt
- Cutting Speed = 900,1000, 1100, 1200 pulse
- Type and pressure of assist gas = Air (0, 1, 2, 3 bar)
- Material thickness = Acrylic (3 mm)
- Mode of Operation = Pulsed
- Cutting Angle = 0^0, 2^0, 4^0, 6^0
- Nozzle gap = 1mm, 2.5 mm, 4.5mm, 6.0mm

2.3 CUTTING QUALITY

Also base on the experiment that have been done by the previous researcher, It was found that the laser cutting quality (dross adherence, kerf width, surface roughness and HAZ) depends mainly on the cutting speed, cutting mode, laser power, pulse frequency and focus position. Due to converging–diverging shape of laser beam profile (Fig. 3) the kerf taper always exist during LBC. Various researchers have experimentally studied the laser cut qualities such as kerf width and kerf taper in order to analyse the effect of various process parameters on these quality characteristics. Chen (1999), during his experimental investigation, found that kerf width increases with increasing laser power and decreasing the cutting speed during CO2 laser cutting of 3 mm-thick mild steel sheet [14]. He also observed that oxygen or air gives wider kerf while use of inert gas gives the narrow kerf.

Ghany and Newishy (2005) have observed the same variation of kerf width with cutting speed, laser power, and type of gas and pressure as above during experimental study of Nd:YAG laser cutting of 1.2 mm-thick austenitic stainless steel sheet. They have also found that on increasing pulse frequency the kerf width decreases [15].

The three main quality characteristics of laser cut kerf that decides the kerf geometry are kerf taper (Kt), kerf deviation (Kd) along the length, and kerf width (Kw). The schematic of laser cut kerf is shown in Fig. 4. The kerf qualities studied so far does not include the kerf unevenness or kerf deviation along the length of cut which is an important quality characteristic for achieving the stringent design requirements. TM- or RSM-based studies applied for LBC process were aimed to optimize a single quality characteristic at a time. But it is always desired to optimize the multiple quality characteristics of the product or process at the same time. Also, researchers have not tried for optimizing the kerf qualities during pulsed laser cutting
of aluminium/aluminium-alloy sheets, which are highly reflective and heat sensitive (thermally conductive) material and pose difficulty during LBC. Authors have found only one paper concerned with laser cutting of aluminium alloy sheet by Araujo et al. (2003) who have experimentally studied the microstructure in HAZ during LBC of 2024 aluminium alloy sheet by CW CO2 laser beam without using any of DOE techniques [16].

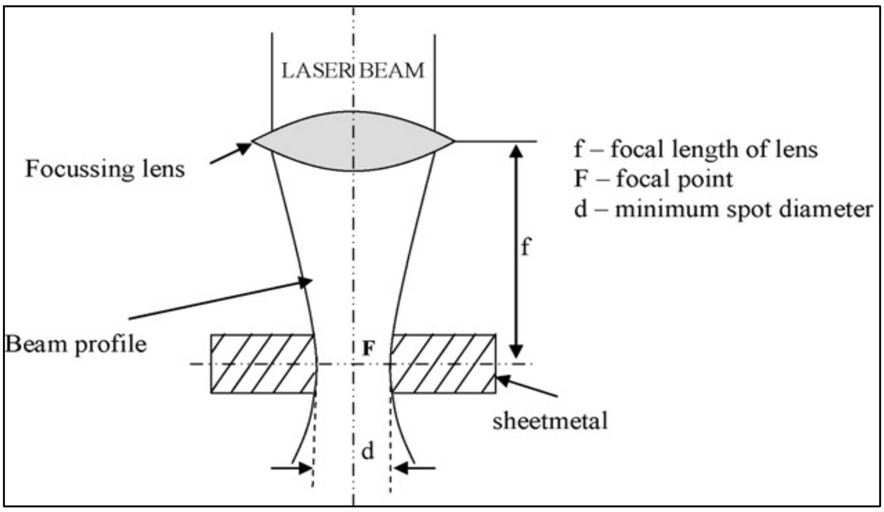

Figure 2.2: schematic of typical beam profile

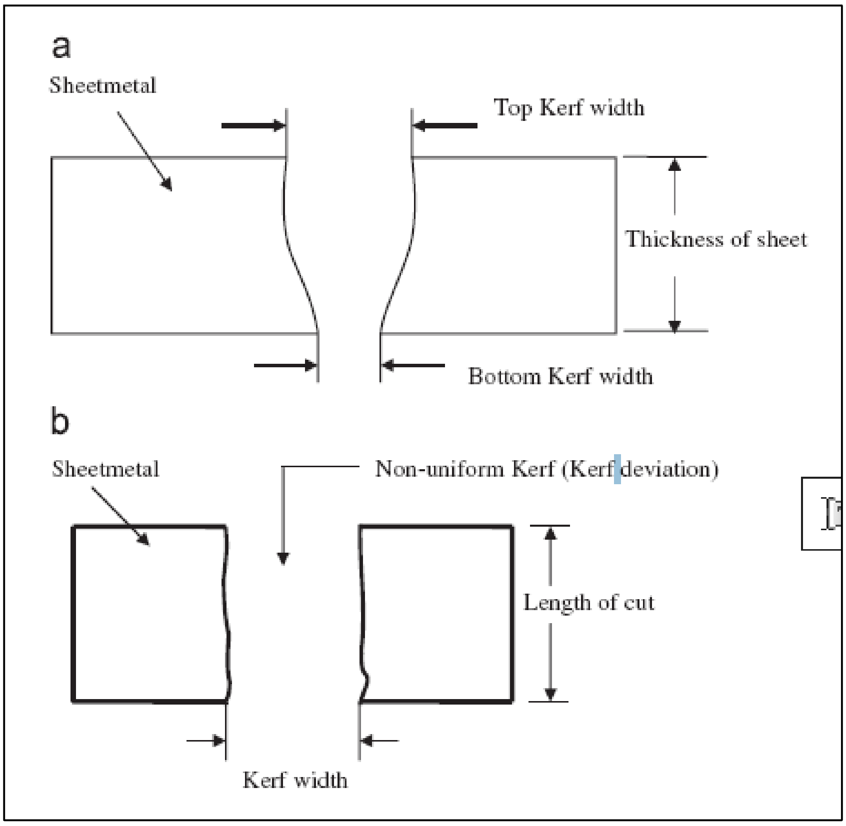

Figure 2.3: Schematic representation of laser cut kerf: (a) kerf taper and (b) kerf deviation.

Table 1 – Significant factors and their effects on various quality characteristics

Sr. no.	Quality characteristics	Significant factors	Variation of factors to keep minimum value of quality characteristics
1.	HAZ	Beam energy[1]	Low
		Feed rate[1]	High
		Pulse duration[2]	High
		Pulse frequency[2]	Moderate
		Gas pressure	More
		Material thickness	Low
2.	Taper	Beam energy[1]	Low
		Feed rate[2]	High
		Pulse frequency[2]	Low
		Pulse duration	High
		Material thickness[1,3]	More
		Focus position[3]	Above the work surface
3.	Surface roughness	Beam energy	Moderate
		Feed rate[1]	Moderate
		Pulse frequency[1]	Moderate
		Gas type[2]	Inert
		Gas pressure[2]	Moderate
4.	Recast layer	Beam energy	High
		Pulse duration[1,2]	Low
		Gas pressure	High
		Material thickness[1]	Low
		Focus position[2]	Above the work surface
5.	Dross adherence	Gas type[1]	Inert
		Gas pressure[1]	High
		Beam energy	High
		Feed rate[2]	High
		Pulse frequency[2]	Low
6.	Micro-cracks	Beam energy	High
		Pulse width	Low
		Gas pressure[1]	High
		Gas type[1]	Inert

Superscripts 1, 2, 3 show the interaction effect among factors.

Figure 2.4: Significant factor and their effects on various qualities characteristic.

2.4 ACRYLIC

In 1880 G. W. A. Kahlbaum reported the polymerization of methyl acrylate and at approximately the same time R. Fittig found that methacrylic acid and some of its derivatives readily polymerized. In 1932 J. W. C. Crawford discovered a new route to the monomer using cheap and readily available chemicals. Sheet polymethyl methacrylate (PMMA) became prominent during World War II for aircraft glazing [17].

Acrylic is a rigid plastic with a high degree of transparency. It is resistant to inorganic acids and alkalis but is attacked by a wide range of organic solvents. Acrylic's clarity and stability make it very suitable for the manufacture of burets and in sheet form it may be cemented to produce tanks, trays, racks etc. Acrylic may be used at temperatures up to 70°C continuously and to 90°C for short periods. 10mm thick Acrylic provides an effective barrier for Beta Radiation Protection. Dynalab Corp's acrylic fabrication shop fabricates thousands of catalog and custom acrylic products [18].

Acrylic Generics :

- Acrylic (PMMA)
- PMMA+PVC
- Acrylic, Unspecified
- Acrylic (SMMA)
- Acrylic (PMMI)
- SMMA+SBC

Acrylic are widely used in industry and it have many application that come benefit to human life such as in automotive, decorative, household, medical and healthcare, electrical and electronic, and optical applications.

Table 2.1: Advantages and disadvantages of Acrylic

Advantages	Disadvantages
- Weather Resistance, Good - Chemical Resistance, Good - Impact Resistance, Good - Clarity, High - UV Resistance, Good - Heat Resistance, High - Impact Resistance, High - Impact Modified - Flow, Good	- Poor solvent resistance - Subject to stress cracking - Low continuous service temperature - Flexible grades unavailable - Poor impact resistance

Table 2.2: Properties table of Acrylic in SI units [18]

Properties	**Acrylic (PMMA)**	**Acrylic (SMMA)**	**Acrylic, Unspecified**	**PMMA+PVC**
Density (*g/cm³*)	1.13 to 1.20	1.04 to 1.09	1.16 to 1.19	1.35 to 1.36
Melt Mass Flow Rate (*g/10 min*)	0.30 to 4.7	0.40 to 9.1	--	34
Flexural Modulus (*MPa*)	1120 to 3610	1820 to 3400	2210 to 3290	2020 to 2560
Tensile Strength (*MPa*)	36.7 to 80.8	5.00 to 64.2	38.8 to 70.9	39.8 to 42.4
Tensile Elongation (*%*)	0.0 to 7.3	2.0 to 59	2.7 to 250	55 to 170
Rockwell Hardness	31 to 105	61 to 76	93 to 95	87 to 114
Notched Izod Impact (*J/m*)	12.4 to 60.2	19.6 to 160	21.2 to 24.3	32.0 to 964
DTUL @ 66 psi (0.45 MPa) (*°C*)	78.9 to 105	77.8 to 92.8	75.0 to 111	82.2
DTUL @ 264 psi (1.8 MPa) (*°C*)	75.6 to 103	86.2 to 94.1	79.2 to 93.1	68.3 to 79.3
CLTE, Flow (*cm/cm/°C*)	0.000054 to 0.00012	--	0.000067 to 0.000081	0.000030 to 0.000081

2.5 SURFACE ROUGHNESS

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

Although roughness is usually undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application.

Roughness may be measured using contact or non-contact methods. Contact methods involve dragging a measurement stylus across the surface, these instruments include profilometers. Non-contact methods include:

- interferometry
- confocal microscopy
- focus variation
- structured light
- electrical capacitance
- electron microscopy and photogrametry

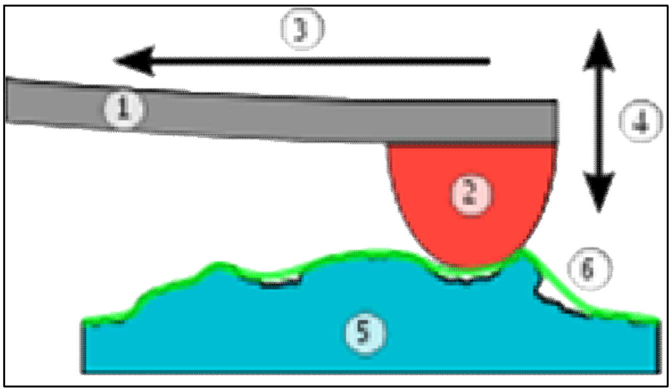

Figure 2.5: Principle of a contacting stylus instrument profilometer.

A cantilever (1) is holding a small tip (2) that is sliding along the horizontal direction (3) over the object's surface (5). Following the profile the cantilever is moving vertically (4). The vertical position is recorded as the measured profile (6) shown in light green.

2.5.1 Profile roughness parameters

Each of the roughness parameters is calculated using a formula for describing the surface. There are many different roughness parameters in use, but R_a is by far the most common. Other common parameters include R_z, R_q, and R_{sk}. Some parameters are used only in certain industries or within certain countries. For example, the R_k family of parameters is used mainly for cylinder bore linings, and the Motif parameters are used primarily within France.

Since these parameters reduce all of the information in a profile to a single number, great care must be taken in applying and interpreting them. Small changes in how the raw profile data is filtered, how the mean line is calculated, and the physics of the measurement can greatly affect the calculated parameter.

By convention every 2D roughness parameter is a capital R followed by additional characters in the subscript. The subscript identifies the formula that was used, and the R means that the formula was applied to a 2D roughness profile. Different capital letters imply that the formula was applied to a different profile. For example, Ra is the arithmetic average of the roughness profile, Pa is the arithmetic average of the unfiltered raw profile, and Sa is the arithmetic average of the 3D roughness.

Each of the formulas listed in the tables assumes that the roughness profile has been filtered from the raw profile data and the mean line has been calculated. The roughness profile contains n ordered, equally spaced points along the trace, and y_i is the vertical distance from the mean line to the i^{th} data point. Height is assumed to be positive in the up direction, away from the bulk material.

2.5.2 Amplitude parameters

Amplitude parameters characterize the surface based on the vertical deviations of the roughness profile from the mean line. Many of them are closely related to the parameters found in statistics for characterizing population samples. For example, R_a is the arithmetic average of the absolute values and R_t is the range of the collected roughness data points.

The amplitude parameters are by far the most common surface roughness parameters found in the United States on mechanical engineering drawings and in technical literature. Part of the reason for their popularity is that they are straightforward to calculate using a digital computer.

Table 2.3: Profile roughness parameters and its formula

Parameter	Description	Formula
R_a, R_{aa}, R_{yni}	arithmetic average of absolute values	$R_a = \frac{1}{n}\sum_{i=1}^{n}\lvert y_i\rvert$
R_q, R_{RMS}	root mean squared	$R_q = \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i^2}$
R_v	maximum valley depth	$R_v = \min_i y_i$
R_p	maximum peak height	$R_p = \max_i y_i$
R_t	Maximum Height of the Profile	$R_t = R_p - R_v$
R_{sk}	skewness	$R_{sk} = \frac{1}{nR_q^3}\sum_{i=1}^{n} y_i^3$
R_{ku}	kurtosis	$R_{ku} = \frac{1}{nR_q^4}\sum_{i=1}^{n} y_i^4$
R_{zDIN}, R_{tm}	average distance between the highest peak and lowest valley in each sampling length, ASME Y14.36M - 1996 Surface Texture Symbols	$R_{zDIN} = \frac{1}{s}\sum_{i=1}^{s} R_{ti}$, where s is the number of sampling lengths, and R_{ti} is R_t for the i^{th} sampling length.
R_{zJIS}	Japanese Industrial Standard for R_z, based on the five highest peaks and lowest valleys over the entire sampling length.	$R_{zJIS} = \frac{1}{5}\sum_{i=1}^{5} R_{pi} - R_{vi}$, where R_{pi} R_{vi} are the i^{th} highest peak, and lowest valley respectively.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology can be defined as design of experiment. In this chapter, preparation to run the experiment, experiment procedure and step after the experiment should be deliberated.

This experiment is to study about cutting selected materials by using Laser Beam Cutting Machine based on several selected parameters. The experiment was performed on a PCNC Laser Cutting Machine that has in FKM Laboratory. The air is used as an assist gas. The variable process parameters (or control factors) taken are: air pressure, nozzle gap, cutting angle, laser power, and cutting speed.

While the materials that used as specimen is acrylic with thickness of 3mm. The quality and characteristics of the cutting will be determined by surface roughness test using perthometer S2 (Mahr). Then all the result will be analyzed by using the Microsoft Excel software to find the finest cutting quality and relate between result and parameters used. Square shape (30mmx30mm) will be cut on acrylic plate in each experiment.

3.2 METHODOLOGY FLOWCHART

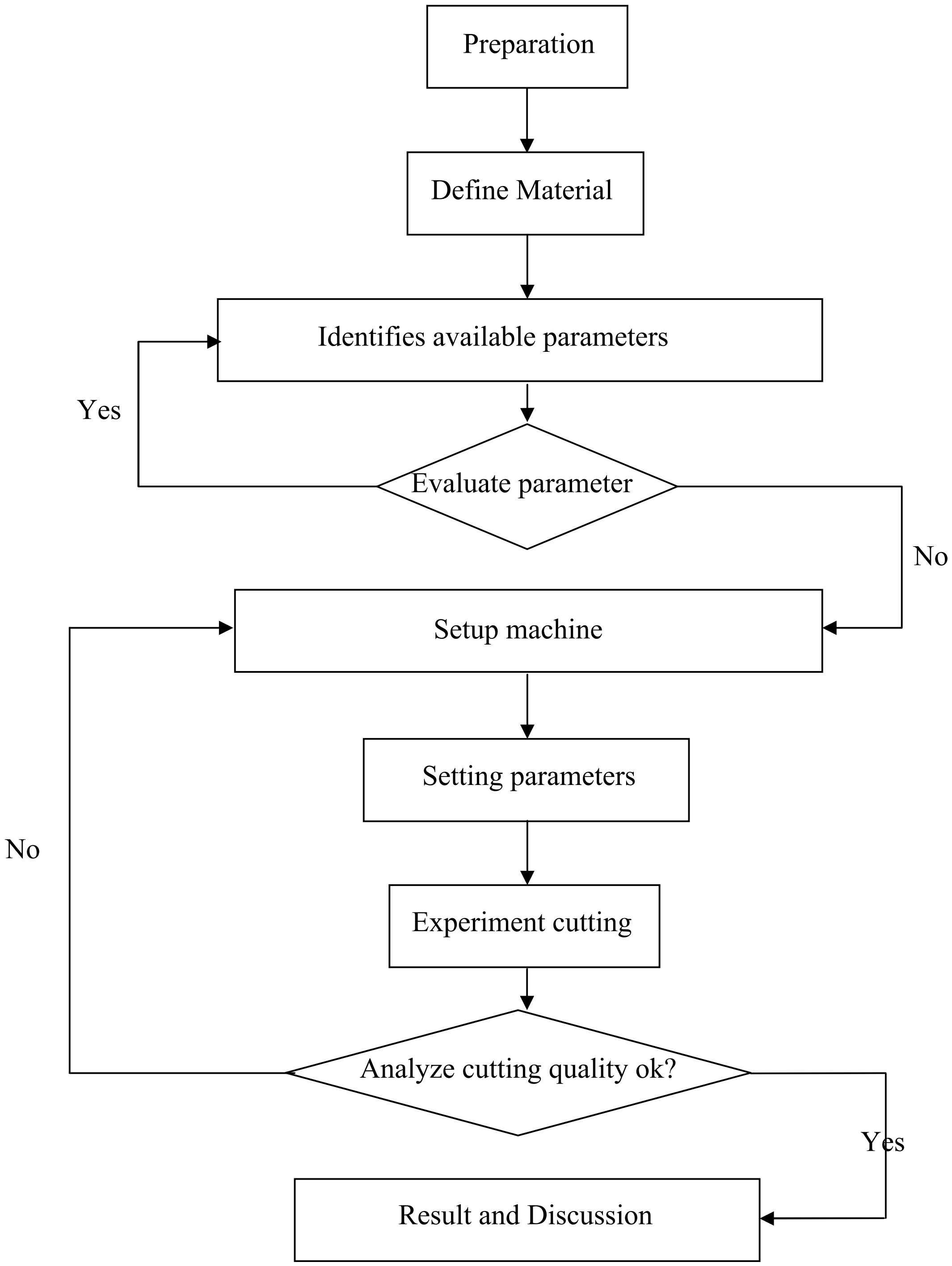

Figure 3.1: Methodology Flowchart

3.3 PREPARATION

Preparation is very important before doing everything especially in doing experiment. The most important is to know what experiment that has to do and what kind of apparatus that will be use. In this case, it is important to know what is PCNC Laser Cutting Machine and how it operates. PCNC is actually the same as CNC that stand for Computer Numerical Control but PCNC is stand for Personal Computer Numerical Control. It refers specifically to a computer "controller" that reads G-code instructions and drives the machine tool, a powered mechanical device typically used to fabricate metal components by the selective removal of metal. For this laser machine, it will used the same concept as CNC machine to cut the materials. It will read the G-code that has been generated to cut the shape that have been draw and convert to the G-code. Below is the example of the shape that has been draw and its G-code.

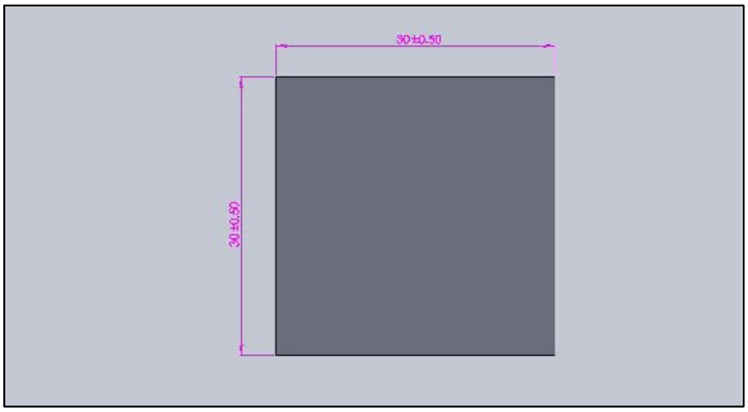

Figure 3.2

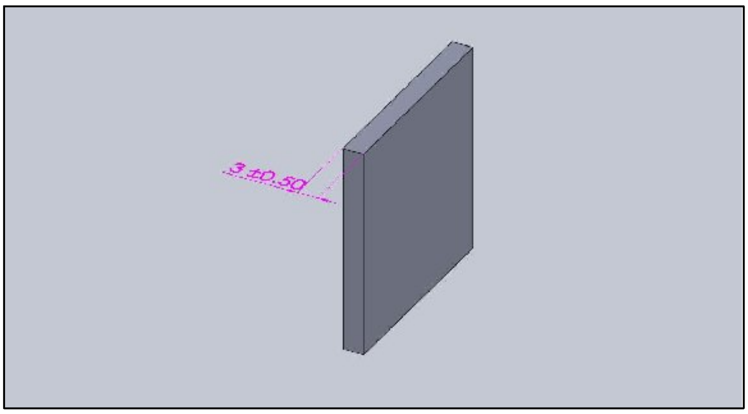

Figure 3.3

Figure 3.2 and 3.3: square shapes that want to cut

```
RAPID  X0.000 Y0.000 Z5.556 TOOL# 0
RAPID  X0.236 Y0.426 Z5.556
LINE   Z0.000 FEED 240.0
LINE X10.236   FEED 780.0
LINE   Y10.426
LINE  X0.236
LINE   Y0.426
RAPID    Z5.556
RAPID  X0.000 Y0.000
```

Figure 3.4: G-Code for the shape

In order to move the axis of the machine, it also used code or command that need to run in Microsoft Visual C++. It has its own code or command to make it move forward, backward, right or left. Below show the command for move the axis of the machine manually.

```
#include "iocpp.h"
#include <stdio.h>
#include <conio.h>
#include <iostream>
//using namespace std;
// 1,0 belakang (hala komputer)
//3,2 depan
//4,0 kanan
//12,8 kiri
int main()
{
int choice;
char respond;
long int i;
int LaserONOFF =0;;            //32 laser on 0 laser off
int laju =100 //kadar kelajuan
;;
do{
             LoadIODLL();
             cout<<"Please select your moving choice. \n\nPress Enter to Stop
Running!\n\n(1-Forward, 2-Backward 3-Left 4-Right): ";
             cin>>choice;
             cout<<endl;
             if(choice==1){
             while (!kbhit())
             {
             //LoadIODLL();
             printf("Running...\n");
             PortOut(888,3+LaserONOFF);  // kiri
             Delay(laju);
             PortOut(888,2+LaserONOFF);
             Delay(laju);
             //PortOut(888,0);
             //UnloadIODLL();
             }
```

```
            }
            if(choice==2){
            while (!kbhit())
            {
            //LoadIODLL();
            printf("Running...\n");
            PortOut(888,1+LaserONOFF);  // kiri
            Delay(laju);
            PortOut(888,0+LaserONOFF);
            Delay(laju);
            //PortOut(888,0);
            //UnloadIODLL();
            }
            }
            if(choice==3){
            while (!kbhit())
            {
            //LoadIODLL();
            printf("Running...\n");
            PortOut(888,12+LaserONOFF);  // kiri
            Delay(laju);
            PortOut(888,8+LaserONOFF);
            Delay(laju);
            //PortOut(888,0);
            //UnloadIODLL();
            }
            }
            if(choice==4){
            while (!kbhit())
            {
            //LoadIODLL();
            printf("Running...\n");
            PortOut(888,4+LaserONOFF);  // kiri
            Delay(laju);
            PortOut(888,0+LaserONOFF);
            Delay(laju);
            //PortOut(888,0);
            //UnloadIODLL();
            }
            }
            //else
                   //cout<<endl;
            PortOut(888,0);
            UnloadIODLL();
            cout<<"Do you wish to continue ? (Y/N): ";
      cin>>respond;
            cout<<endl;
}   while(respond=='Y'||respond=='y');
return 0;
}
//pulse cw+1 and ccw+1
//sign  cw-1 and ccw-1
```

3.4 DEFINE MATERIAL

The other important thing that has to know is what type of materials that want to use in this experiment. This experiment will be used Acrylic with thickness of 3mm, length 30mm and width 30mm.

3.5 PARAMETERS

In order to cut the materials, there are several parameters that have to be considered. In the beginning of this project, the suggested parameters that have to study are mode of operation, materials thickness, laser power, cutting speed, pressure of assist gas, cutting angle and nozzle gap. Two of the seven parameters were fixed its value that is mode of operation: pulsed, and materials thickness: Acrylic (3mm). For the others values of parameters, it has been set to: Laser power (25.5 Watt, 26.5 Watt, 27.5 Watt, and 28.5 Watt), Cutting speed (900 pulse/s, 1000 pulse/s, 1100 pulse/s, and 1200 pulse/s), pressure of assist gas (0 bar, 1 bar, 2 bar, and 3 bar), cutting angle (0^0, 2^0, 4^0 , and 6^0), and nozzle gap (1mm, 2.5mm, 4.5 mm, and 6mm). But after manually construct the table for those parameters, it show there so many experiment that have to do and also there have some repetition on the same parameters. This will affect the result of the experiment besides wasting time.

To make sure the parameters are not repeated and to get the precise result, it was suggested to use Response Surface Method (RSM) to optimize the parameters. It is very useful to use this method in optimizing the parameters. RSM is a collection of statistical and mathematical methods that are useful for the modeling and optimization of the engineering science problems. In this technique, the main objective is to optimize the responses that are influenced by various input process parameters. RSM also quantifies the relationship between the controllable input parameters and the obtained responses. In modeling and optimization of manufacturing processes using RSM, the sufficient data is collected through designed experimentation. In general, a second-order regression model is developed because first-order models often give lack-of-fit [19].

When using the RSM, we can reduce the number of experiment. At initial, there were 243 of experiment that have to test. That value is too many to do the test. So we have to identify/recognizes the best parameters that we have to use. It is difficult to do it manually. So, in this case, the RSM can help. But after we used RSM, if there still many number of experiment, we have to reverse to the previous step to identify and recognize the parameters.

After optimized the parameters using RSM, the number of experiment decreased from 243 to 40. This data shown there was decreased about 203 of the experiment. That is mean the experiment that has to do for one material is 40 experiments for various types of parameters. The table below showed the optimized parameters that had to test for one material and the number of test for 1 material with various parameters. The other material will use the same parameters (Muhamad, 2009).

Table 3.1: Optimized parameters by using RSM

No.	Parameter	A	B	C	D
1	Nozzle Gap (mm)	1	2.5	4.5	6
2	Air Pressure(bar)	0	1	2	3
3	Cutting Angle(degree)	0	2	4	6
4	Laser Power (Watt)	25.5	26.5	27.5	28.5
5	Cutting Speed(pulse/s)	900	1000	1100	1200

Table 3.2: Number of test for 1 material (A, B, C, and D represent the value of parameters)

No.	Nozzle gap	Air pressure	Cutting angle	Laser power	Cutting speed
1	D	D	D	D	D
2	C	C	A	D	D
3	D	A	B	C	D
4	A	B	D	B	D
5	B	D	C	A	D
6	D	D	A	B	B
7	A	D	B	D	A
8	C	D	D	C	C
9	B	A	D	D	B
10	D	C	D	A	A
11	D	B	C	D	C
12	B	B	A	C	A
13	C	A	C	B	A
14	A	C	C	C	B
15	C	B	B	A	B

16	B	C	B	B	B
17	A	A	A	A	C
18	B	C	B	B	C
19	C	D	B	C	A
20	A	B	B	A	D
21	A	D	C	B	C
22	D	B	C	C	B
23	A	C	D	C	C
24	C	C	C	A	D
25	C	B	D	B	A
26	C	A	B	D	C
27	B	D	A	C	D
28	A	C	A	D	A
29	A	A	D	A	B
30	D	D	A	A	C
31	B	A	C	A	A
32	D	A	B	B	A
33	B	B	D	D	C
34	C	D	A	B	B
35	B	D	C	D	B
36	A	A	C	B	D
37	D	C	C	D	A
38	B	D	D	A	A
39	B	B	A	B	C
40	D	C	D	B	D

3.6 THE EXPERIMENT

Before start the experiment, it is necessary to setup the machine first. The machine is including the cutting table, the axis that will move the laser, the air compressor and a computer that will use to control the machine. The air compressor is used to produce air pressure that help to suck the odor of the laser and to make sure the laser is not prevented by atmospheric impurities that will affect the quality of cutting.

All of the component must be connected correctly so that the machine will be performed. Make sure the laser power is off before experiment start for safety. Before can start the experiment, the shape of cutting have to determine first. The shape will be draw in the Artcam software and then converted to G-code. After that, the machine can read the shape of cutting. It was suggested to run the machine without turn on the laser power to see the movement of the machine first. If the machine ran smoothly, the next step can be proceed.

For testing the experiment, the acrylic 3mm of thickness was used. The parameters used are laser power 28.5 Watt, Cutting speed 1200 pulse/s, cutting angle 60, air pressure 3 bar and nozzle gap 6mm. To set the laser power to 28.5 Watt, we have to adjust at the laser power controller that has been connected to the laser and the computer. For cutting angle and nozzle gap, we have to set it up manually at the machine. For the air pressure, we have to set up at the air compressor to 3 bars. But for cutting speed, we have to use command to change the value. To set it up to 1200 pulse/s, it shown by the command below:

```
#ifndef PCLINE__H

#define PCLINE__H

__inline double lXFUN(double u, double cx1,double cx2){return cx1+(cx2-cx1)*u;}

__inline double lYFUN(double u, double cy1,double cy2){return cy1+(cy2-cy1)*u;}

__inline double lZFUN(double u, double cz1,double cz2){return cz1+(cz2-cz1)*u;}

__inline double lXFUN_1ST(double u, double cx1,double cx2){return cx2-cx1;}

__inline double lYFUN_1ST(double u, double cy1,double cy2){return cy2-cy1;}

__inline double lZFUN_1ST(double u, double cz1,double cz2){return cz2-cz1;}

void pcline(int on,double cx2,double cy2,double cz2);

void pcline(int on,double cx2,double cy2,double cz2)

{

	double cx1 = 0.0;

	double cy1 = 0.0;

	double cz1 = 0.0;

	double X = cx1;

	double Y = cy1;

	double Z = cz1;
```

```
double x = cx1;
double y = cy1;
double z = cz1;
double xp,yp,zp;
double xDist,yDist,zDist;
double u = 0.0;
int XF,YF,ZF,GF1,GF2;
int SelectedPlane;
int SX1,SY1,SZ1,SX2,SY2,SZ2;
double DX,DY,DZ,INC_X,INC_Y,INC_Z;
unsigned long TP = 0;
int valout_pulse = 0, valout_dir=0, sigout=0;
unsigned prnport = 0x378;
while ( u <= 1.0 )
{
xp = lXFUN_1ST(u,cx1,cx2);
yp = lYFUN_1ST(u,cy1,cy2);
zp = lZFUN_1ST(u,cz1,cz2);
  if (xp >= 0){xDist = fabs(x - X - STEP);XF = 10000;}
      else {xDist = fabs(x - X + STEP); XF = 0;}
  if (yp >= 0){yDist = fabs(y - Y - STEP); YF = 1000;}
      else {yDist = fabs(y - Y + STEP);YF = 0;}
  if (zp >= 0){zDist = fabs(z - Z - STEP);ZF = 100;}
      else {zDist = fabs(z - Z + STEP); ZF = 0;}
if ( fabs(yp*xDist) >= fabs(xp*yDist) ) GF1 = 10;
      else GF1 = 0;
if ( SQR(zp)*(SQR(xDist)+SQR(yDist)) >=
SQR(zDist)*(SQR(xp)+SQR(yp)) ) GF2 = 1;
      else GF2 = 0;
SelectedPlane = XF + YF + ZF + GF1 + GF2;
  switch (SelectedPlane)
{
```

```
      case (11000):case (11100):case (10100):case (10000): u = u +
(xDist/xp); break;      //Plane 1

      case (11010):case (1110):case (11110): u = u + (yDist/yp); break;
      //Plane 2

        case (1100):case (1000):case (100):case (0): u = u - (xDist/xp);
break;      //Plane 3

        case (10110):case (10010):case (1010):case (110):case (10): u = u
- (yDist/yp); break; //Plane 4

      case (11111):case (11101):case (10111):case (10101):case
(1111):case (1101):case (1011):

        case (1001):case (111):case (101): u = u + (zDist/zp); break;
      //Plane 5

      case (11001):case (10011):case (10001):case (11):case (1):case
(11011): u = u - (zDist/zp); break;//Plane 6

      default     : u = 1000; break;

      }

       x = lXFUN(u,cx1,cx2);

       y = lYFUN(u,cy1,cy2);

       z = lZFUN(u,cz1,cz2);

       DX = x - X;

       DY = y - Y;

       DZ = z - Z;

       INC_X =    NEXT_STEP(DX);INC_Y = NEXT_STEP(DY);INC_Z =
NEXT_STEP(DZ);

       X = X + INC_X;Y = Y + INC_Y;Z = Z + INC_Z;

       if (INC_X > 0.0) {SX1=1;SX2=0;} else if (INC_X < 0.0)
{SX1=3;SX2=2;} else {SX1=0;SX2=0;}

       if (INC_Y > 0.0) {SY1=4;SY2=0;} else if (INC_Y < 0.0)
{SY1=12;SY2=8;} else {SY1=0;SY2=0;}

       if (INC_Z > 0.0) {SZ1=0;SZ2=0;} else if (INC_Z < 0.0)
{SZ1=0;SZ2=0;} else {SZ1=0;SZ2=0;}

       valout_pulse = SX1+SY1+SZ1;

       valout_dir = SX2+SY2+SZ2;

       PortOut(prnport,valout_pulse+on);

       Delay(1200);     //200 utk engrave, 700 utk potong

       PortOut(prnport,valout_dir+on);

       Delay(1200);     //200 utk engrave, 700 utk potong
```

```
        TP++;
        }
return;
}
#endif
```

After setting all the parameters following the table constructed before for test 1, we can run the experiment of cutting the acrylic. The laser power is turn on and the cutting process begun. The command for parameter of cutting speed is saved and compiled first and then the cutting process can be run. To run the experiment, there has another command that have to compile first. The command represented all the command that have run before. When done with this last command, the machine can be run after we order it to proceed by pressing key ‘y’ on the keyboard which mean ‘yes’ when the system ask to continue or not. The command is shown below:

```
#include "stdafx.h"
#include "iocpp.h"
#include <conio.h>
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include "tgen.h"       //ubah scale
#include "gcode.h"
#include "pcline.h"     //ubah engrave or cutting
int main()
{
      const unsigned long int maxsize = 10000;
      double XP[maxsize]={0.0};
      double YP[maxsize]={0.0};
      double ZP[maxsize]={0.0};
   int laser[maxsize]={0};
```

```
        unsigned long int codeline;
        unsigned long int k;
        char a;
        codeline = gcode(laser,XP,YP,ZP);
        printf("Confirmac. running the program...(Y or N)\n");
        a='\n';
        a=getch();
        switch (a)
        {
              case 'Y':{break;}
              case 'y':{break;}
              case 'N':{printf("Thank you. Exiting...\n");exit(1);}
              case 'n':{printf("Thank you. Exiting...\n");exit(1);}
              default:{printf("Thank you. Exiting...\n");exit(1);}
        }
        LoadIODLL();
        for (k=1;k<=codeline;k++)
        {
              printf("%d\t%d\t%d\t%f\t%f\t%f\t\n",k,codeline,laser[k-
1],XP[k]-XP[k-1],YP[k]-YP[k-1],ZP[k]-ZP[k-1]);
              pcline(laser[k-1],XP[k]-XP[k-1],YP[k]-YP[k-1],ZP[k]-ZP[k-1]);
 //     getch();
        }
        printf("Program completed.\n");
   getch();
        UnloadIODLL();
        return 0;
}
```

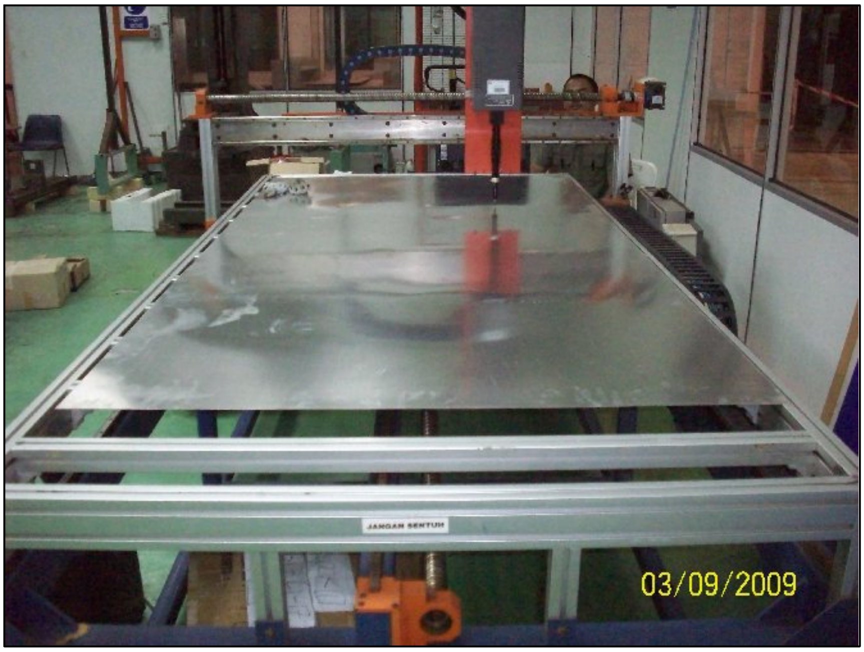

Figure 3.5: Laser machine that used in this project

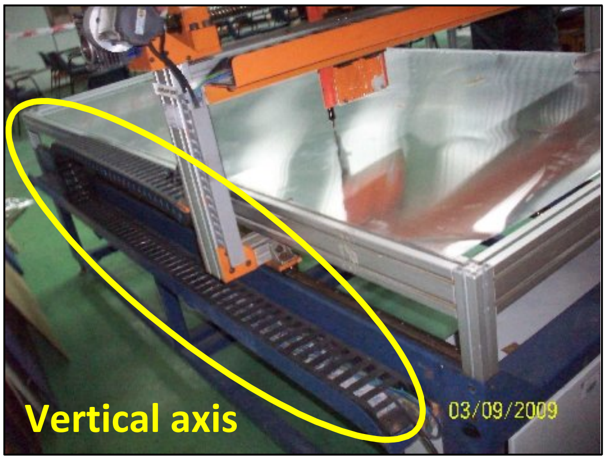

Figure 3.6: Figure showed the axis that controlled the movement of the head of the laser to move vertical or horizontal.

Figure 3.7: Head of laser

3.7 RESULT AND DISCUSSION

After done with the experiment, we have to investigate the quality of cutting on the material. There were several aspects that have to study such as surface roughness of the cut material, HAZ, taper, recast layer, dross adherence, and micro cracks. The study will determine the quality of the cutting is good or not. From that, we can know whether the result is acceptable. If not, we have to start the experiment back from the optimizing steps. That is mean we had to optimize the other parameters value to get better quality of the cutting.

For this project, it will be focus on surface roughness to determine the quality of cut. To measure the specimen's surface roughness, surface roughness tester, Mahrsurf XR 20 with Perthometer S2 will be used. Each 4 side of the specimen's cut surface will be measure on its surface for distances of 5.6mm. The average value will be considered for the 4 sides that have been measured. The profile roughness parameters that measured for this project are average roughness (Ra), maximum roughness depth (Rmax), root mean square roughness (Rq), average maximum height of profile (Rz), and Japanese industrial standard for Rz (RzJ). But to analyze the cutting quality, it will refer on average roughness (Ra) only. It means, when analyze the result, it will consider the smaller Ra is the finest surface roughness.

Figure 3.8: Perthometer S2 with surface roughness tester Mahrsurf XR 20

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, it will discuss briefly or more details in result and discussion of the experiment. The result for this experiment or project is surface roughness and from the result, it showed what really happen in the experiment. Besides that, it also will show what have been found in the experiment. Discussion is important for a research to know what the result of the experiment mean. From discussion of the result, it will help to understand what really happen, cause and effect of the experiment, and finally a conclusion can be made.

This experiment is about to cut a selected material under some parameters and to find the best quality of cutting. The material that used is Acrylic with thickness of 3mm which cut into square shape with dimension of 30mm x 30mm. The result is measured through the roughness of the cutting surface. Since the material is cut into square shape, it means there are four sides of cutting surfaces which have to measure the roughness for 1 specimen. There were 40 test with different parameters used which give 40 specimen that have to test. The profile roughness parameter that considered is Roughness Average, Ra which measured in micrometer (μm). The result then analyzed to find the best parameters that produced the finest and the best cutting quality.

Through out this chapter, the relationship between experiment parameters (cutting speed, cutting angle, laser power, nozzle gap, and air pressure) and cutting quality (surface roughness) will be created.

4.2 RESULT OF EXPERIMENT

From the methodology, preparation of the experiment made before do the experiment. The study about the laser machine has been made through the literature before selected the material that want to use that is Acrylic. There are five parameters in this project which each parameter have 4 different values. Table below show the parameters used in this project.

Table 4.1: Parameters that used in the experiment

Parameter	A	B	C	D
Nozzle Gap (mm)	1	2.5	4.5	6
Air Pressure(bar)	0	1	2	3
Cutting Angle(degree)	0	2	4	6
Laser Power (Watt)	25.5	26.5	27.5	28.5
Cutting Speed(pulse/s)	900	1000	1100	1200

There are 40 number of experiment (based on selected parameters) which have been design using Response Surface Method (RSM). The laser machine has to setup according to the parameters for each number of tests. Each test used different value of parameters (refer to table 3.2 in Methodology). Experiment can be done after setting all the parameters according to the table 3.2 and the cut specimen tested using Perthometer to see the surface roughness as the result. Then the result will be analysis to figure out the best parameter. The next figure showed the part of the machine that controls the value of the parameters that used in the experiment.

Figure 4.1: Air compressor that used to help the cutting process.

It is control by controller that shown in the figure above. It can produce air up to 3 bars to assist the cutting process. It connected to the laser nozzle to assist the cutting process.

Figure 4.2: Nozzle of the Laser Machine.

The laser will come out from this nozzle. The nozzle gap can be control by adjusting the height of the nozzle. The nozzle gap is measured from the surface of the material until the tip of the nozzle.

Figure 4.3: Laser controller of the laser machine.

This controller used to control the power of the laser that came out trough the nozzle. This controller also used to turn on or off the laser. That mean, when to move the head of laser forward, backward, right or left, we do not have to on the laser. So the laser must be in off condition for safety. On the laser if only the laser is in ready position to run the cutting process.

4.2.1 Result of Surface Roughness

To measure the surface roughness, surface roughness tester MahrSurf XR 20 with Perthometer S2 will be used. There are five types of profile roughness parameters that used to consider in measured roughness of specimen's surface that is average roughness (Ra), maximum roughness depth (Rmax), root mean square roughness (Rq), average maximum height of profile (Rz), and Japanese industrial standard for Rz (RzJ). But to analysis the result in order to find the best cutting parameters that produced the finest and best cutting quality, its only refer to roughness average, Ra and maximum roughness depth, Rmax.

Maximum roughness depth, Rmax is average distance between the highest peak and lowest valley in each sampling length. It means, the highest value of Rmax, more rough the surface will be. Roughness average, Ra is average of surface along the measured surface. The type of surface roughness tester that used is a contacting stylus instrument (refer figure 6 in chapter 2) which have to touch and move along the surface to measure its roughness. The tip of the tester will move along the contact surface for 5.6mm since it was set (it can be set how long we want the tip to move along the surface), in order to measure the roughness. So roughness average, Ra in this case is average among the 5.6mm surfaces. While the average of roughness average, Ra is average of 4 different value of roughness average, Ra that have been measured at 4 different surfaces, that is each 4 sides of each specimen. By that, an average data for Ra can be produced.

Table 5 shows the result of surface roughness for 40 specimens in roughness average, Ra for 4 sides for each specimen and the average value of roughness average, Ra. Table 6 shows the result of surface roughness for 40 specimens in five profile roughness parameters: roughness average (Ra), maximum roughness depth (Rmax), root mean square roughness (Rq), average maximum height of profile (Rz), and Japanese industrial standard for Rz (RzJ).

Table 4.2: Result for average roughness, Ra for 4 sides for each specimen and the average value of average roughness, Ra.

Test Number and experiment parameters		Roughness Average, Ra (µm)				Average of Roughness Average, Ra (µm)
		Side 1	Side 2	Side 3	Side 4	
1	Nozzle gap : 6 mm Air pressure : 3 bar Cutting angle : 6^{o} Laser power : 28.5 watt Cutting speed : 1200 pulse/s	9.300	11.264	8.613	8.203	9.345
2	Nozzle gap : 4.5 mm Air pressure : 2 bar Cutting angle : 0^{o} Laser power : 28.5 watt Cutting speed : 1200 pulse/s	10.115	12.594	16.796	17.015	14.130
3	Nozzle gap : 6 mm Air pressure : 0 bar Cutting angle : 2^{o} Laser power : 27.5 watt Cutting speed : 1200 pulse/s	0.933	0.851	0.728	0.832	0.836
4	Nozzle gap : 1 mm Air pressure : 1 bar Cutting angle : 6^{o}	9.180	11.404	10.935	12.121	10.910

	Laser power : 26.5 watt Cutting speed : 1200 pulse/s					
5	Nozzle gap : 2.5 mm Air pressure : 3 bar Cutting angle : 4^o Laser power : 25.5 watt Cutting speed : 1200 pulse/s	5.657	5.004	5.034	4.005	4.925
6	Nozzle gap : 6 mm Air pressure : 3 bar Cutting angle : 0^o Laser power : 26.5 watt Cutting speed : 1000 pulse/s	0.882	0.480	1.056	1.462	0.970
7	Nozzle gap : 1 mm Air pressure : 3 bar Cutting angle : 2^o Laser power : 28.5 watt Cutting speed : 900 pulse/s	0.754	0.688	0.635	0.823	0.725
8	Nozzle gap : 4.5 mm Air pressure : 3 bar Cutting angle : 6^o Laser power : 27.5 watt Cutting speed : 1100 pulse/s	0.627	0.470	0.512	0.519	0.532
9	Nozzle gap : 2.5 mm Air pressure : 0 bar Cutting angle : 6^o Laser power : 28.5 watt Cutting speed : 1000 pulse/s	0.943	0.654	0.581	0.694	0.718
10	Nozzle gap : 6 mm Air pressure : 2 bar Cutting angle : 6^o Laser power : 25.5 watt Cutting speed : 900 pulse/s	0.833	0.900	0.852	0.823	0.852
11	Nozzle gap : 6 mm Air pressure : 1 bar Cutting angle : 4^o Laser power : 28.5 watt Cutting speed : 1100 pulse/s	0.644	0.718	0.910	0.836	0.777
12	Nozzle gap : 2.5 mm Air pressure : 1 bar Cutting angle : 0^o Laser power : 27.5 watt Cutting speed : 900 pulse/s	0.993	0.928	1.217	1.334	1.118
13	Nozzle gap : 4.5 mm Air pressure : 0 bar Cutting angle : 4^o Laser power : 26.5 watt	1.196	1.052	1.517	1.311	1.269

	Cutting speed : 900 pulse/s					
14	Nozzle gap : 1 mm Air pressure : 2 bar Cutting angle : 4^o Laser power : 27.5 watt Cutting speed : 1000 pulse/s	0.752	0.788	1.054	0.650	0.811
15	Nozzle gap : 4.5 mm Air pressure : 1 bar Cutting angle : 2^o Laser power : 25.5 watt Cutting speed : 1000 pulse/s	1.114	0.703	0.838	0.813	0.867
16	Nozzle gap : 2.5 mm Air pressure : 2 bar Cutting angle : 2^o Laser power : 26.5 watt Cutting speed : 1000 pulse/s	0.876	0.627	1.420	0.789	0.928
17	Nozzle gap : 1 mm Air pressure : 0 bar Cutting angle : 0^o Laser power : 25.5 watt Cutting speed : 1100 pulse/s	0.555	0.645	0.744	0.676	0.656
18	Nozzle gap : 2.5 mm Air pressure : 2 bar Cutting angle : 2^o Laser power : 26.5 watt Cutting speed : 1100 pulse/s	0.428	0.681	0.733	0.814	0.664
19	Nozzle gap : 4.5 mm Air pressure : 3 bar Cutting angle : 2^o Laser power : 27.5 watt Cutting speed : 900 pulse/s	2.109	2.132	1.725	2.130	2.024
20	Nozzle gap : 1 mm Air pressure : 1 bar Cutting angle : 2^o Laser power : 25.5 watt Cutting speed : 1200 pulse/s	0.798	0.931	0.780	0.779	0.822
21	Nozzle gap : 1 mm Air pressure : 3 bar Cutting angle : 4^o Laser power : 26.5 watt Cutting speed : 1100 pulse/s	0.651	0.517	0.400	0.564	0.533
22	Nozzle gap : 6 mm Air pressure : 1 bar Cutting angle : 4^o Laser power : 27.5 watt	0.741	0.899	1.159	1.053	0.963

	Cutting speed : 1000 pulse/s					
23	Nozzle gap : 1 mm Air pressure : 2 bar Cutting angle : 6^o Laser power : 27.5 watt Cutting speed : 1100 pulse/s	0.537	0.465	0.582	0.500	0.521
24	Nozzle gap : 4.5 mm Air pressure : 2 bar Cutting angle : 4^o Laser power : 25.5 watt Cutting speed : 1200 pulse/s	0.540	0.603	0.497	0.516	0.539
25	Nozzle gap : 4.5 mm Air pressure : 1 bar Cutting angle : 6^o Laser power : 26.5 watt Cutting speed : 900 pulse/s	0.472	0.491	0.628	0.777	0.592
26	Nozzle gap : 4.5 mm Air pressure : 0 bar Cutting angle : 2^o Laser power : 28.5 watt Cutting speed : 1100 pulse/s	0.511	0.480	0.478	0.483	0.488
27	Nozzle gap : 2.5 mm Air pressure : 3 bar Cutting angle : 0^o Laser power : 27.5 watt Cutting speed : 1200 pulse/s	0.431	0.406	0.380	0.447	0.416
28	Nozzle gap : 1 mm Air pressure : 2 bar Cutting angle : 0^o Laser power : 28.5 watt Cutting speed : 900 pulse/s	0.805	0.821	0.927	0.751	0.826
29	Nozzle gap : 1 mm Air pressure : 0 bar Cutting angle : 6^o Laser power : 25.5 watt Cutting speed : 1000 pulse/s	0.764	0.719	0.763	0.990	0.809
30	Nozzle gap : 6 mm Air pressure : 3 bar Cutting angle : 0^o Laser power : 25.5 watt Cutting speed : 1100 pulse/s	0.522	0.470	0.638	0.534	0.541
31	Nozzle gap : 2.5 mm Air pressure : 0 bar Cutting angle : 4^o Laser power : 25.5 watt	0.667	0.725	0.852	0.620	0.716

	Cutting speed : 900 pulse/s					
32	Nozzle gap : 6 mm Air pressure : 0 bar Cutting angle : 2^o Laser power : 26.5 watt Cutting speed : 900 pulse/s	0.524	0.712	0.693	0.715	0.661
33	Nozzle gap : 2.5 mm Air pressure : 1 bar Cutting angle : 6^o Laser power : 28.5 watt Cutting speed : 1100 pulse/s	0.877	0.846	0.738	0.895	0.839
34	Nozzle gap : 4.5 mm Air pressure : 3 bar Cutting angle : 0^o Laser power : 26.5 watt Cutting speed : 1000 pulse/s	0.653	0.544	0.618	0.581	0.599
35	Nozzle gap : 2.5 mm Air pressure : 3 bar Cutting angle : 4^o Laser power : 28.5 watt Cutting speed : 1000 pulse/s	0.619	0.712	0.695	0.786	0.703
36	Nozzle gap : 1 mm Air pressure : 0 bar Cutting angle : 4^o Laser power : 26.5 watt Cutting speed : 1200 pulse/s	0.911	0.887	0.798	0.868	0.866
37	Nozzle gap : 6 mm Air pressure : 2 bar Cutting angle : 4^o Laser power : 28.5 watt Cutting speed : 900 pulse/s	0.466	0.532	0.521	0.445	0.491
38	Nozzle gap : 2.5 mm Air pressure : 3 bar Cutting angle : 6^o Laser power : 25.5 watt Cutting speed : 900 pulse/s	0,922	0.867	1.144	0.859	0.948
39	Nozzle gap : 2.5 mm Air pressure : 1 bar Cutting angle : 0^o Laser power : 26.5 watt Cutting speed : 1100 pulse/s	0.653	0.615	0.756	0.636	0.665
40	Nozzle gap : 6 mm Air pressure : 2 bar Cutting angle : 6^o Laser power : 26.5 watt Cutting speed : 1200 pulse/s	0.507	0.474	0.481	0.506	0.492

Table 4.3: Result of surface roughness in five profile roughness parameters

Test Number and experiment paramenters		Ra-Average roughness (µm)	Rq-Root Mean Square Roughness (µm)	Rz-Average maximum height of profile (µm)	RzJ-Japanese Industrial Standard for Rz (µm)	Rmax-Maximum roughness depth (µm)
1	Nozzle gap : 6 mm Air pressure : 3 bar Cutting angle : 6^{o} Laser power : 28.5 watt Cutting speed : 1200 pulse/s	9.345	11.280	48.700	29.300	53.800
2	Nozzle gap : 4.5 mm Air pressure : 2 bar Cutting angle : 0^{o} Laser power : 28.5 watt Cutting speed : 1200 pulse/s	14.130	17.19	69.000	46.800	76.900
3	Nozzle gap : 6 mm Air pressure : 0 bar Cutting angle : 2^{o} Laser power : 27.5 watt Cutting speed : 1200 pulse/s	0.836	1.048	4.790	3.050	6.340
4	Nozzle gap : 1 mm Air pressure : 1 bar Cutting angle : 6^{o} Laser power : 26.5 watt Cutting speed : 1200 pulse/s	10.910	13.160	54.500	34.400	64.700
5	Nozzle gap : 2.5 mm Air pressure : 3 bar Cutting angle : 4^{o} Laser power : 25.5 watt Cutting speed : 1200 pulse/s	4.925	6.017	27.600	16.200	33.600
6	Nozzle gap : 6 mm Air pressure : 3 bar Cutting angle : 0^{o} Laser power : 26.5 watt Cutting speed : 1000 pulse/s	0.970	1.197	5.130	3.020	7.53
7	Nozzle gap : 1 mm Air pressure : 3 bar Cutting angle : 2^{o} Laser power : 28.5 watt Cutting speed : 900 pulse/s	0.725	0.832	2.280	-	3.790
8	Nozzle gap : 4.5 mm	0.532	0.680	3.370	1.690	4.350

	Air pressure : 3 bar Cutting angle : 6^o Laser power : 27.5 watt Cutting speed : 1100 pulse/s					
9	Nozzle gap : 2.5 mm Air pressure : 0 bar Cutting angle : 6^o Laser power : 28.5 watt Cutting speed : 1000 pulse/s	0.718	0.875	3.980	2.420	4.720
10	Nozzle gap : 6 mm Air pressure : 2 bar Cutting angle : 6^o Laser power : 25.5 watt Cutting speed : 900 pulse/s	0.852	10.80	4.440	2.700	5.750
11	Nozzle gap : 6 mm Air pressure : 1 bar Cutting angle : 4^o Laser power : 28.5 watt Cutting speed : 1100 pulse/s	0.777	0.939	4.010	2.550	4.620
12	Nozzle gap : 2.5 mm Air pressure : 1 bar Cutting angle : 0^o Laser power : 27.5 watt Cutting speed : 900 pulse/s	1.118	1.396	7.680	4.490	9.930
13	Nozzle gap : 4.5 mm Air pressure : 0 bar Cutting angle : 4^o Laser power : 26.5 watt Cutting speed : 900 pulse/s	1.269	1.641	7.890	4.740	10.300
14	Nozzle gap : 1 mm Air pressure : 2 bar Cutting angle : 4^o Laser power : 27.5 watt Cutting speed : 1000 pulse/s	0.811	0.978	4.390	2.660	4.780
15	Nozzle gap : 4.5 mm Air pressure : 1 bar Cutting angle : 2^o Laser power : 25.5 watt Cutting speed : 1000 pulse/s	0.867	1.044	4.760	3.090	5.040
16	Nozzle gap : 2.5 mm Air pressure : 2 bar Cutting angle : 2^o Laser power : 26.5 watt Cutting speed : 1000	0.928	1.164	5.070	3.350	5.950

	pulse/s					
17	Nozzle gap : 1 mm Air pressure : 0 bar Cutting angle : 0° Laser power : 25.5 watt Cutting speed : 1100 pulse/s	0.656	0.812	3.950	2.220	4.660
18	Nozzle gap : 2.5 mm Air pressure : 2 bar Cutting angle : 2° Laser power : 26.5 watt Cutting speed : 1100 pulse/s	0.664	0.839	3.840	2.320	4.860
19	Nozzle gap : 4.5 mm Air pressure : 3 bar Cutting angle : 2° Laser power : 27.5 watt Cutting speed : 900 pulse/s	2.024	2.479	10.400	7.450	12.700
20	Nozzle gap : 1 mm Air pressure : 1 bar Cutting angle : 2° Laser power : 25.5 watt Cutting speed : 1200 pulse/s	0.822	1.162	4.660	3.000	10.900
21	Nozzle gap : 1 mm Air pressure : 3 bar Cutting angle : 4° Laser power : 26.5 watt Cutting speed : 1100 pulse/s	0.533	0.689	4.530	2.390	7.860
22	Nozzle gap : 6 mm Air pressure : 1 bar Cutting angle : 4° Laser power : 27.5 watt Cutting speed : 1000 pulse/s	0.963	1.222	4.670	3.300	7.350
23	Nozzle gap : 1 mm Air pressure : 2 bar Cutting angle : 6° Laser power : 27.5 watt Cutting speed : 1100 pulse/s	0.521	0.694	3.790	1.970	4.830
24	Nozzle gap : 4.5 mm Air pressure : 2 bar Cutting angle : 4° Laser power : 25.5 watt Cutting speed : 1200 pulse/s	0.539	0.705	5.830	2.640	7.670
25	Nozzle gap : 4.5 mm Air pressure : 1 bar Cutting angle : 6°	0.592	0.743	3.590	2.270	4.620

	Laser power : 26.5 watt Cutting speed : 900 pulse/s					
26	Nozzle gap : 4.5 mm Air pressure : 0 bar Cutting angle : 2^o Laser power : 28.5 watt Cutting speed : 1100 pulse/s	0.488	0.603	2.830	1.760	3.260
27	Nozzle gap : 2.5 mm Air pressure : 3 bar Cutting angle : 0^o Laser power : 27.5 watt Cutting speed : 1200 pulse/s	0.416	0.520	2.630	1.570	3.010
28	Nozzle gap : 1 mm Air pressure : 2 bar Cutting angle : 0^o Laser power : 28.5 watt Cutting speed : 900 pulse/s	0.826	1.127	4.920	2.860	7.190
29	Nozzle gap : 1 mm Air pressure : 0 bar Cutting angle : 6^o Laser power : 25.5 watt Cutting speed : 1000 pulse/s	0.809	1.040	5.530	3.200	8.240
30	Nozzle gap : 6 mm Air pressure : 3 bar Cutting angle : 0^o Laser power : 25.5 watt Cutting speed : 1100 pulse/s	0.541	0.691	4.070	2.430	5.280
31	Nozzle gap : 2.5 mm Air pressure : 0 bar Cutting angle : 4^o Laser power : 25.5 watt Cutting speed : 900 pulse/s	0.716	0.889	4.810	2.730	6.680
32	Nozzle gap : 6 mm Air pressure : 0 bar Cutting angle : 2^o Laser power : 26.5 watt Cutting speed : 900 pulse/s	0.661	0.806	3.550	2.090	4.010
33	Nozzle gap : 2.5 mm Air pressure : 1 bar Cutting angle : 6^o Laser power : 28.5 watt Cutting speed : 1100 pulse/s	0.839	1.076	6.270	3.910	7.420
34	Nozzle gap : 4.5 mm	0.599	0.744	4.010	2.220	5.200

	Air pressure : 3 bar Cutting angle : 0^o Laser power : 26.5 watt Cutting speed : 1000 pulse/s					
35	Nozzle gap : 2.5 mm Air pressure : 3 bar Cutting angle : 4^o Laser power : 28.5 watt Cutting speed : 1000 pulse/s	0.703	0.924	6.140	3.370	8.830
36	Nozzle gap : 1 mm Air pressure : 0 bar Cutting angle : 4^o Laser power : 26.5 watt Cutting speed : 1200 pulse/s	0.866	1.391	7.000	3.940	17.200
37	Nozzle gap : 6 mm Air pressure : 2 bar Cutting angle : 4^o Laser power : 28.5 watt Cutting speed : 900 pulse/s	0.491	0.623	3.640	2.110	5.410
38	Nozzle gap : 2.5 mm Air pressure : 3 bar Cutting angle : 6^o Laser power : 25.5 watt Cutting speed : 900 pulse/s	0.948	1.146	5.250	3.570	8.060
39	Nozzle gap : 2.5 mm Air pressure : 1 bar Cutting angle : 0^o Laser power : 26.5 watt Cutting speed : 1100 pulse/s	0.665	0.832	5.370	2.830	10.900
40	Nozzle gap : 6 mm Air pressure : 2 bar Cutting angle : 6^o Laser power : 26.5 watt Cutting speed : 1200 pulse/s	0.492	0.634	3.230	1.790	4.200

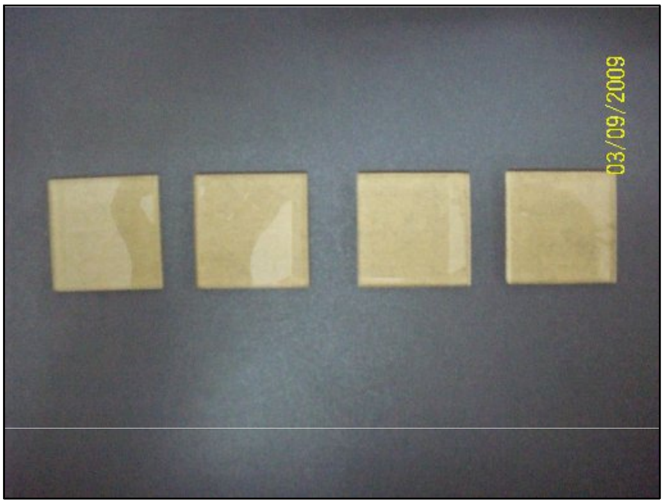

Figure 4.4: Sample of specimen that have been cut

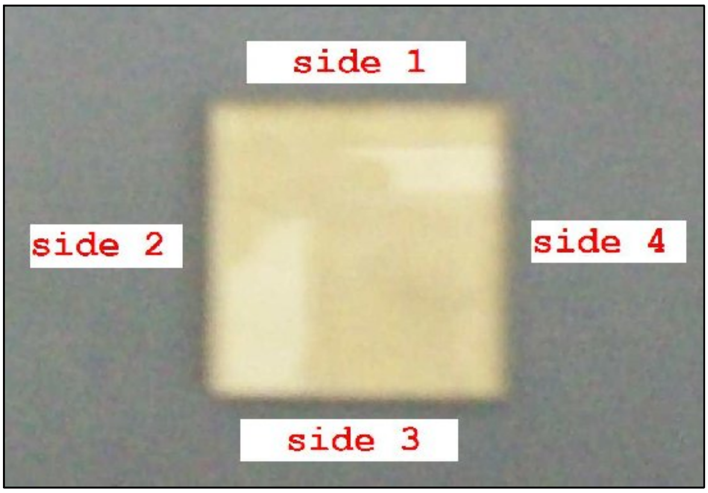

Figure 4.5: Four sides that have been measured its surface roughness

4.2.2 Analysis of the result

To analysis the result, Microsoft Office's software has been used that is Microsoft Office Excel 2007. From the table of result (table 4.2), a graph has been plotted to find the best cutting quality. The best and finest surface roughness has the lowest value of roughness average, Ra. So to find the best quality of cutting, it will refer to the number of test which has lowest average value of roughness average, Ra. Figure below shows the graph that have been plotted from table 4.2.

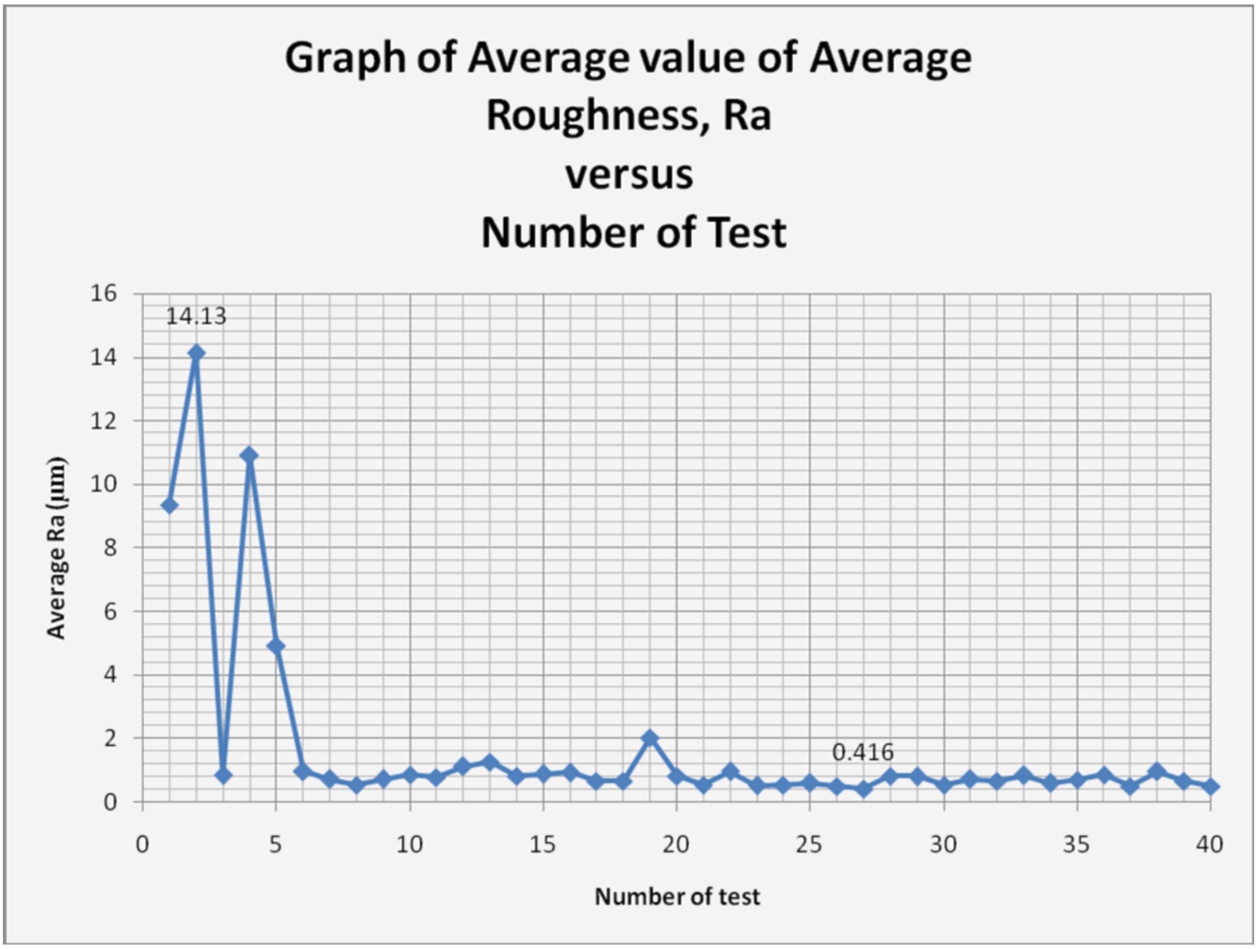

Figure 4.6: Graph of Average Ra (µm) versus Number of Test

From the graph, the lowest value of average of roughness average, Ra is 0.416 µm where get from test number 27. While the highest value of average of roughness average, Ra is 14.130 µm where get from test number 2. Its mean the test with the worse surface is test number 2 and the test with the best surface is test number 27.

In the other analysis, it done based on maximum roughness depth, Rmax. From the table of result (table 4.3), a graph have been plotted to see pattern in data between Rmax and number of test. The test with lower Rmax will have better cutting quality while the test with higher Rmax will have worse cutting quality. The graph below show the analysis from table 4.3 based on Rmax.

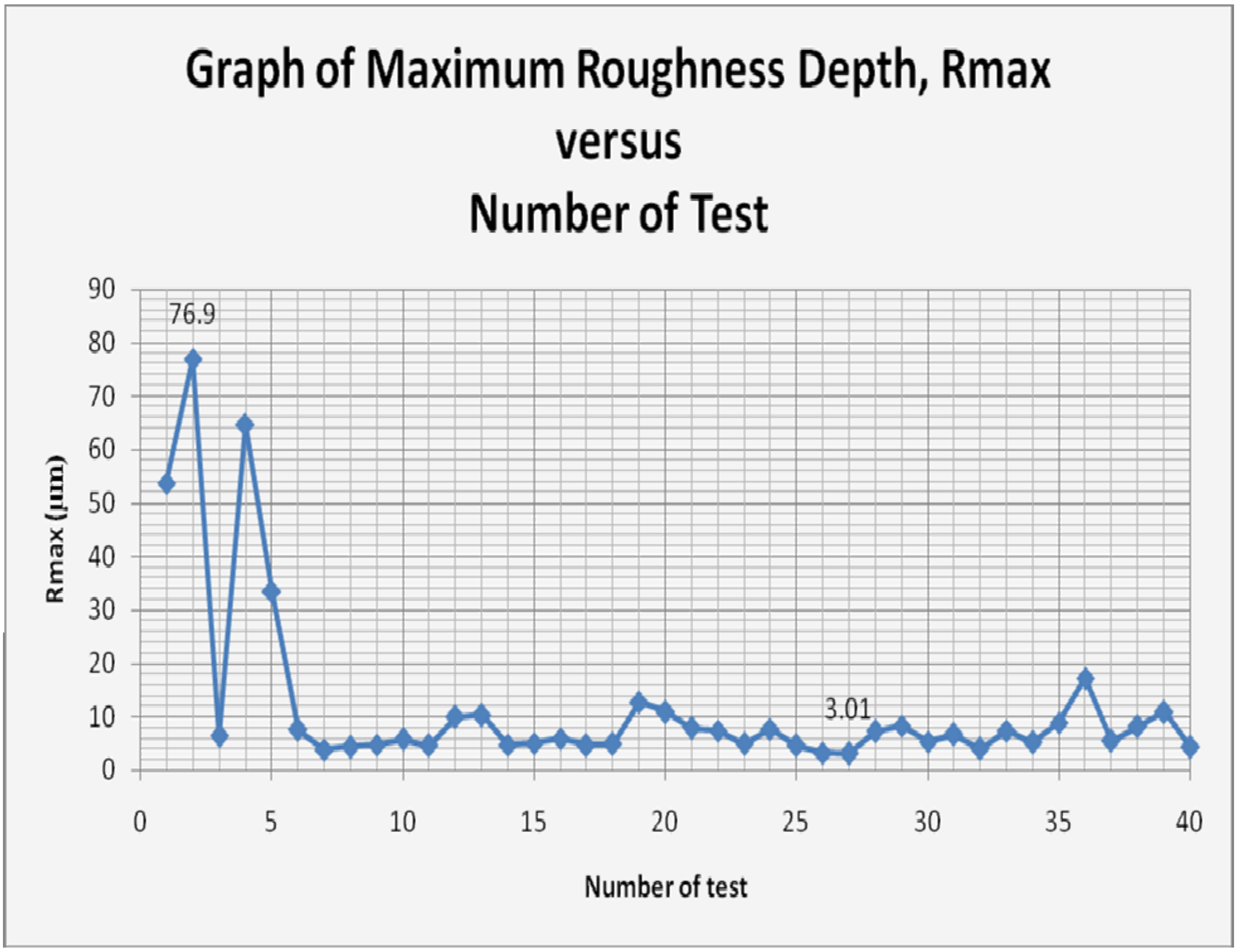

Figure 4.7: Graph of Maximum Roughness Depth, Rmax (µm) versus Number of Test

From the graph above, again test number two give the highest result of maximum roughness depth, Rmax which is 76.9 µm. While the lowest value also come from test number 27 which have maximum roughness depth, Rmax of 3.01 µm. Since Rmax is measured between highest peak of the surface and lowest valley of the specimen's surface, its mean surface of specimen from test number 27 is smoother than the other surface of the other specimen.

From the both graph above, graph of average value of roughness average, Ra (figure 4.6) and graph of maximum roughness surface, Rmax (figure 4.7), it shows that test number 27 is the best test which produced finest surface roughness with value of Ra is 0.416 µm and Rmax is 3.01 µm. But oppositely with test number two which have the greatest value for both Ra and Rmax that is 14.13 µm for Ra and 76.9 µm for Rmax.

Based on this data, the best parameter that produces the best cutting quality can be determined. Parameters that used in test number 27 is the best parameter in this experiment which produces lowest roughness average, Ra and lowest roughness maximum height, Rmax. Below shows the parameters that used in test number 27, also test number 2 which give the worse cutting quality in this experiment.

Test 27		Test 2	
Nozzle Gap	= 2.5 mm	Nozzle Gap	= 4.5 mm
Air Pressure	= 3 bar	Air Pressure	= 2 bar
Cutting Angle	= 0^0	Cutting Angle	= 0^0
Laser Power	= 27.5 Watt	Laser Power	= 28.5 Watt
Cutting Speed	= 1200 Pulse/sec	Cutting Speed	= 1200 Pulse/sec

4.3 EXPERIMENTAL DISCUSSION

From the result and collected data, there was some interested outcome that should be discussed in this chapter. In this discussion, it will go details in effect of different parameters used in each experiment on quality of cutting (surface roughness), comparison between theoretical study and experimental result and also error that occurred during the experiment.

4.3.1 Effect of different parameters used in each experiment on quality of cutting (surface roughness)

In this experiment, there are four different values of each parameter. For nozzle gap, it was to set as 1mm, 2.5mm, 4.5mm, and 6mm. Each distance of the nozzle will bring different result in surface roughness. For this experiment, nozzle gap which resulted best cutting quality is 2.5 mm. Its means that was the optimum value for nozzle gap in this experiment on cutting acrylic sheet with thickness of 3mm. If there are too high nozzle gap will cause the power was not enough to cut the material because the distance between the nozzle and the material is too far. While if too low nozzle gap will cause the material over-melted and it will result as bad surface roughness.

Air pressure is also important factor in cutting using laser machine. Its function as an assist gas which help during the cutting process. In this experiment, air pressure used is 0bar, 1bar, 2bars, and 3bars. Base on the result, 3 bars of air pressure caused the best surface roughness. This air pressure used to move molten material at the surface. If there was no air pressure, the melt material cannot move from its surface and it will be cause of rough surface. So, higher air pressure is better to produce finest surface roughness.

The other parameter, cutting angle (0^0, 2^0, 4^0, and 6^0) were the other factors that can affects the cutting quality. From the test 27 which produce the finest surface of cut, the cutting angle used is 0^0. That's mean the nozzle of the laser and the material is in perpendicular position. So the optimum cutting angle should be 0^0. There are the other factors that can affects cutting quality if used the other angle of cutting angle such as focusing characteristic. If put some angle on the nozzle during cutting process, it will give less focus of the laser light on the materials.

The next factor that can affect the cutting quality is laser power. It is the most important in cutting material using laser machine to know what laser power that will use. Laser power was one of the parameters that can gives effect to the result. It has strong relation with the other parameters. From this experiment, the optimum laser power is 26.5 Watt with cutting speed of 1200 pulse/sec and nozzle gap 2.5 mm. This power of laser is good for melting acrylic with thickness of 3mm without over-melting is or disables to cut the material.

The last parameter was cutting speed. It also has relation with laser power that can affect the quality of cutting. In this experiment, the cutting speed used was 900, 1000, 1100, and 1200 pulse/sec. The result that gets from test 27 used cutting speed of 1200 pulse/sec as cutting speed value. From this experiment, 1200 pulse/sec is the optimum cutting speed that gives the best cutting quality. The larger cutting speed, the slower the laser will move because cutting speed is in unit pulse/sec. if converted to mm/s, it will be 2.083 mm/s. but unlike 900 pulse/sec, it will be higher value if converted to mm/s. the value is 2.778 mm/s. that's mean the lower pulse/sec will be the faster cutting speed in mm/s. for cutting process, if the laser move faster, the cutting process maybe do not complete (the material do not break perfectly) because the surface will not completely melted and ejection of melted also not fully done during the cutting process since the laser move too fast. The acrylic specimen maybe still can be cut but it will produce rough surface.

4.3.2 Error discussion

There was some error that occurred while doing this experiment. But those errors were too small to consider so that we can just ignore the errors. One of the errors is error while measured the surface roughness. Since the tip of the test is too sensitive, the reading will be spoilt if the was any vibration. The other error that can occur is shape that has been designed in Art Cam was not exactly the same with real specimen that have been cut. The size of specimen that has been cut is larger than actual design in Art Cam about ± 0.3 mm. This is because the size of laser light is larger than expected size. But both of the errors can be ignore since it value was too small.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this chapter, a conclusion will be carried out from this project or experiment. This project has two objectives which have state earlier in Chapter 1. Those two objectives are to study of the Laser Beam Cutting (LBC) on Acrylic sheet and to find the best parameters that can produce the finest and most quality of cutting quality on Acrylic sheet by analysis using Microsoft Excel.

5.2 CONCLUSION

In the earlier of this project, a literature study has been made before start doing the experiment. Theoretically, smoother surface is obtained by increasing cutting speed and frequency while decreasing the power and gas pressure (Kaebernick, 1999). From the literature, cutting speed has to be more if the cutting mode is continuous wave (Grevey and Desplats, 1994). For high cutting speed, it is suggested to use low pulsed frequencies and high peak power to obtain the good quality of cutting. But, increasing the cutting speed will increase the kerf width up to the critical value and then decrease. It was also found that if there are no assist gas used, less power density is required (Tahmouch, 1997).

According to the experiment, the best cutting quality can be produced using nozzle gap of 2.5mm, air pressure of 3 bars, cutting angle of 0 degree, laser power of 26.5 Watt and cutting speed of 1200 pulse/sec. The final result is acceptable if compare with theoretical result and literature study. The cutting mode of the laser machine that used in this project is continuous wave. The cutting speed that used is 1200 pulse/sec that is the highest value among the others value of cutting speed. With this cutting speed, it was produce the best quality of cutting. Since the value of cutting speed is the highest among the other values and the mode of laser is continuous wave, it is validate with previous research which done by Gravey and Desplats, 1994. The power used is low compared to the other power values in this experiment that is only 26.5 Watt. It was the 2nd lowest power that used in this project. While the cutting speed used is the highest. Based on Kaebernick (1999), smoother surface is obtained by increasing cutting speed and frequency while decreasing the power of the laser. The result for this project seems to be like the research that have done by those researcher so it make the result of this project is acceptable.

This project finally has achieved its objective since it was successfully cut the material under some parameters and the result has been analyzed after study of the machine has been made. And from the analysis, the best parameters that can produce the best cutting quality also have been determined. It was prove that different parameters will give different result in surface roughness and the best result (surface roughness) is just like the theoretically and it is acceptable.

From this experiment, finally it was determined that the best parameters that should use to cut Arcrylic with thickness of 3mm using PCNC Laser Cutting Machine in order to produce the finest and the most good quality of cutting, the parameters was shown below:

- Nozzle Gap = 2.5 mm
- Air pressure = 3 bars
- Cutting Angle = 00
- Laser Power = 26.5 Watt
- Cutting Speed = 1200 pulse/sec

5.3 RECOMMENDATION

From the discussion overview it was a few recommended using efficient methods for future study to gain precise and accurate result. The recommendations are as follows:

i. Consider maximum 3 variable parameters that will affect the cutting quality. If there are too many parameters, fixed the rest and just make 3 of them variables so that it can be analyze efficiently.

ii. Use laser cutting machine that can produce laser with higher power so that it can cut thicker or harder materials.

iii. Cutting angle should not consider as experiment's parameters because the nozzle cannot be move into angle. Or change the nozzle that can be adjusted its angle.

iv. Use another method to analyze the data such as regression analysis or ANOVA to get the optimum parameters in order to get good quality of cut.

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APPENDIX A

Gantt chart of FYP 1

ACTIVITY/ WEEK	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Confirmation of thesis title	■	■												
Searching the related information	■	■	■	■	■	■	■							
Reading and collecting the information obtained earlier		■	■	■	■	■	■	■	■	■	■	■		
Experiment and analysis data											■	■	■	■
Preparing apparatus, materials and method of experiment							■	■	■	■	■	■		
Preparing chapter 1 and 2		■	■	■	■									
Preparing chapter 3					■	■	■	■	■	■				
Beginning chapter 4										■	■	■	■	■
Submit chapter to supervisor											■	■	■	
Presentation preparation												■	■	
Submit technical paper and slide presentation													■	
FYP 1 presentation														■

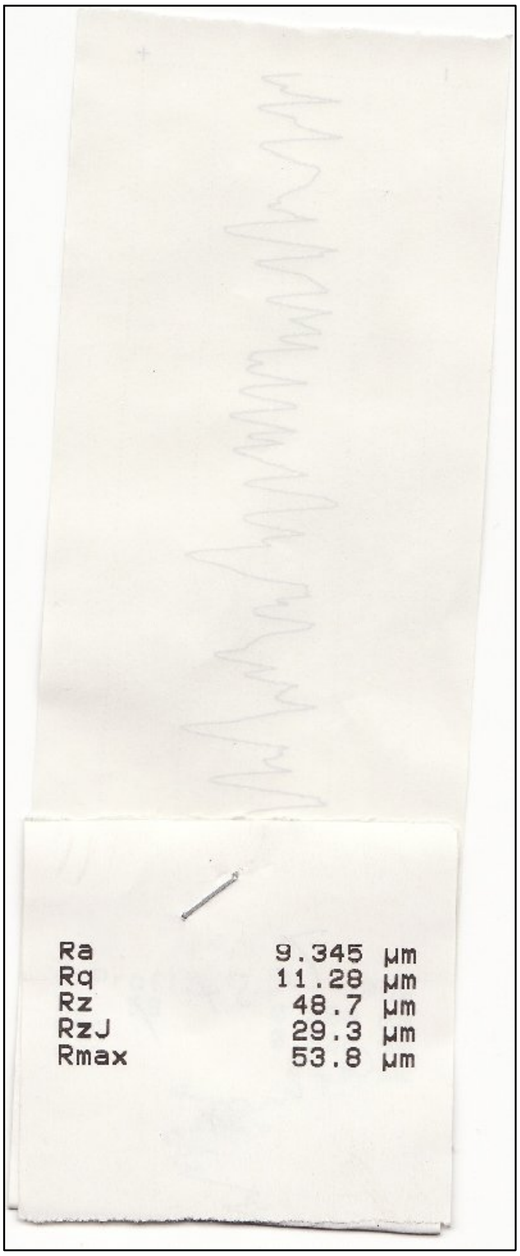
APPENDIX A

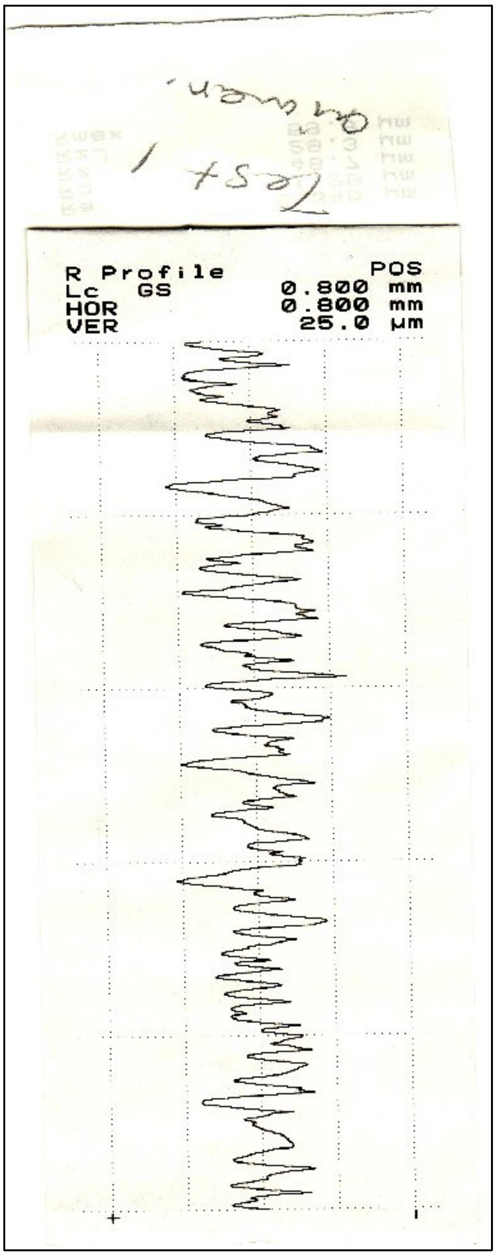
Gantt chart for FYP 2

Project Activities	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16
Experiment Setup	■	■														
Laser Cutting Experiment		■	■	■	■	■										
Surface Roughness analysis							■	■	■	■	■					
Results analysis											■	■				
Prepare all Chapters					■	■	■	■	■	■	■	■	■			
Report Writing										■	■	■	■	■		
Presentation Preparation															■	
FYP 2 Presentation																■

APPENDIX B

Sample of printed roughness result

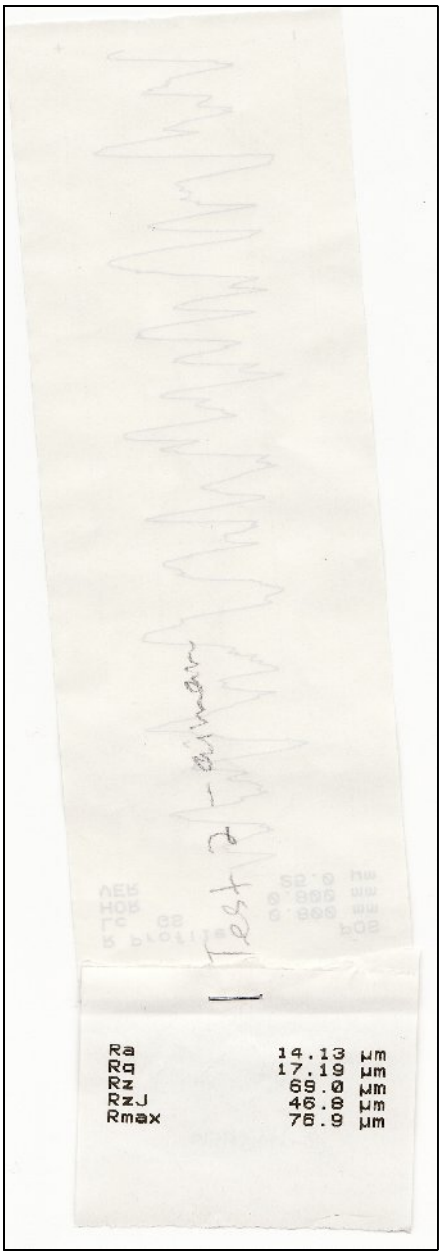


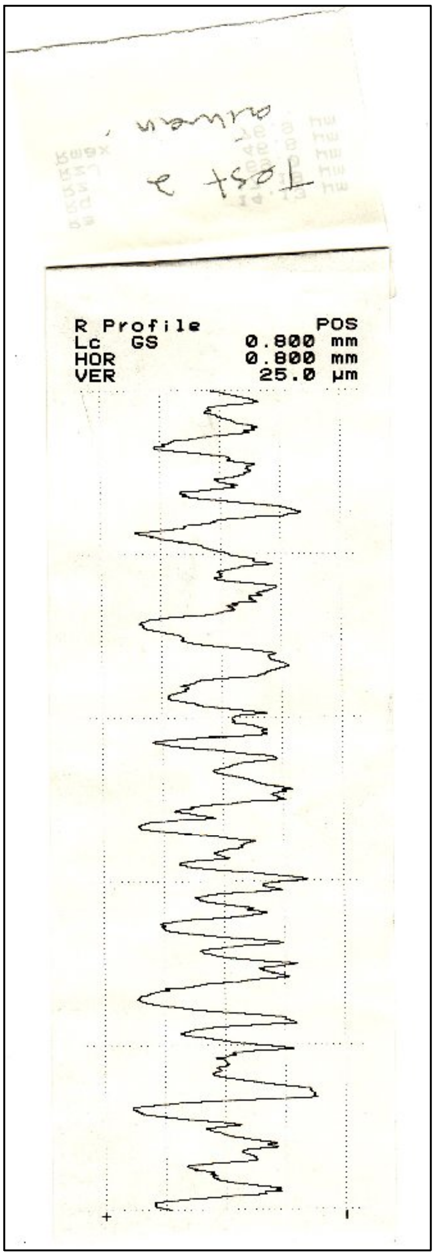


Test number 1

APPENDIX B

Sample of printed roughness result

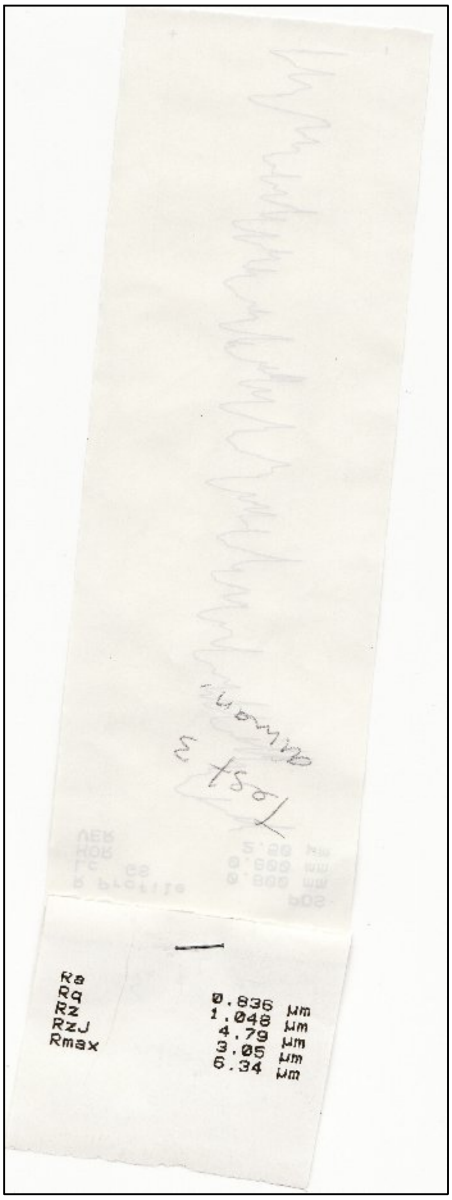


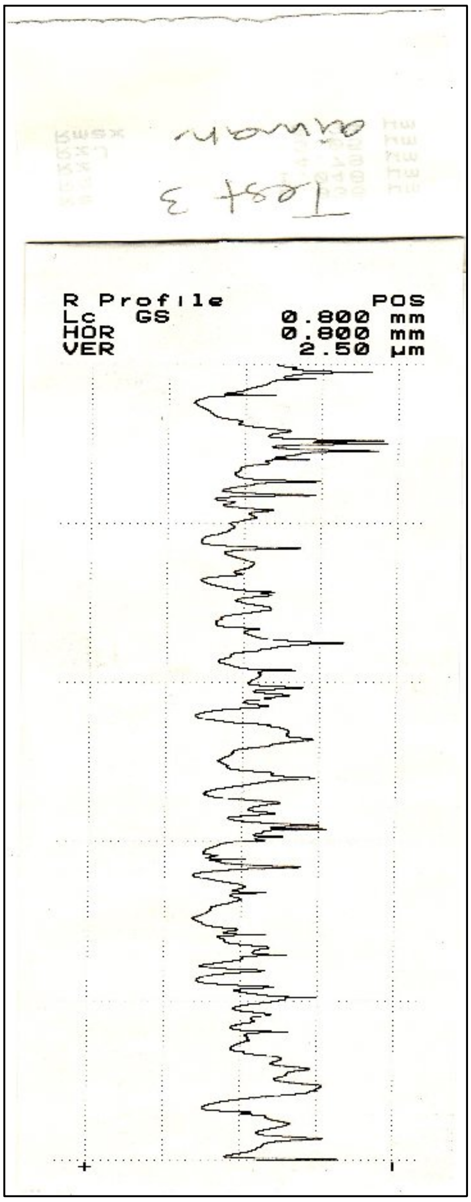


Test number 2

APPENDIX B

Sample of printed roughness result

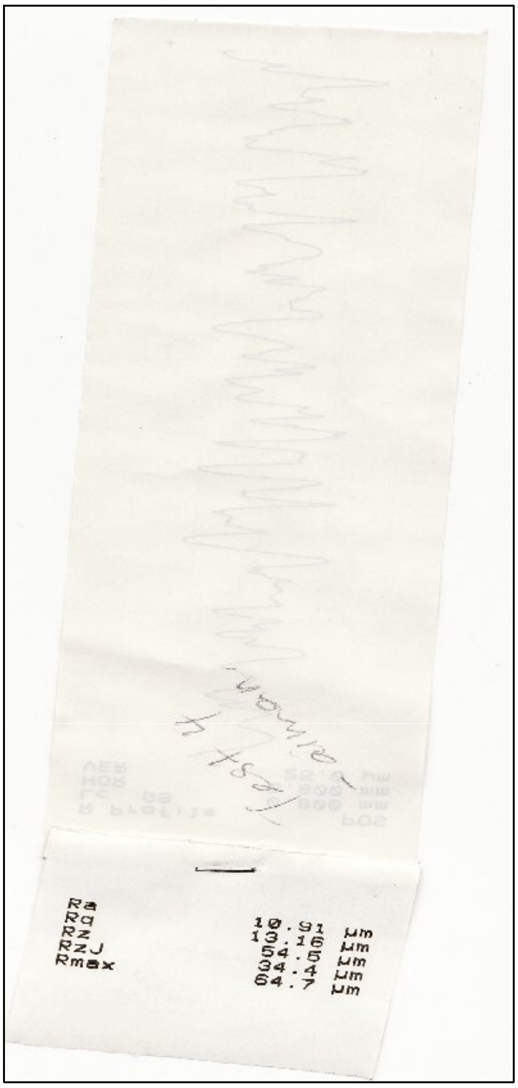


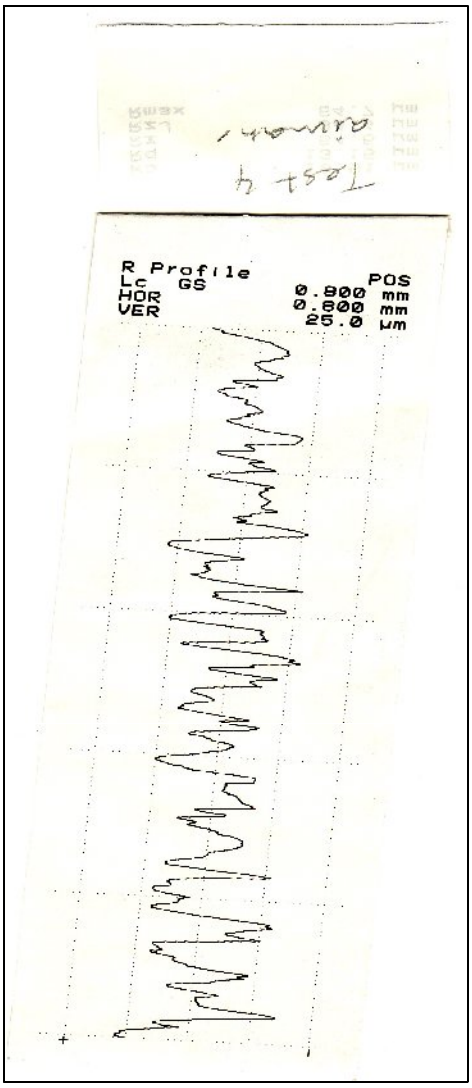


Test number 3

APPENDIX B

Sample of printed roughness result

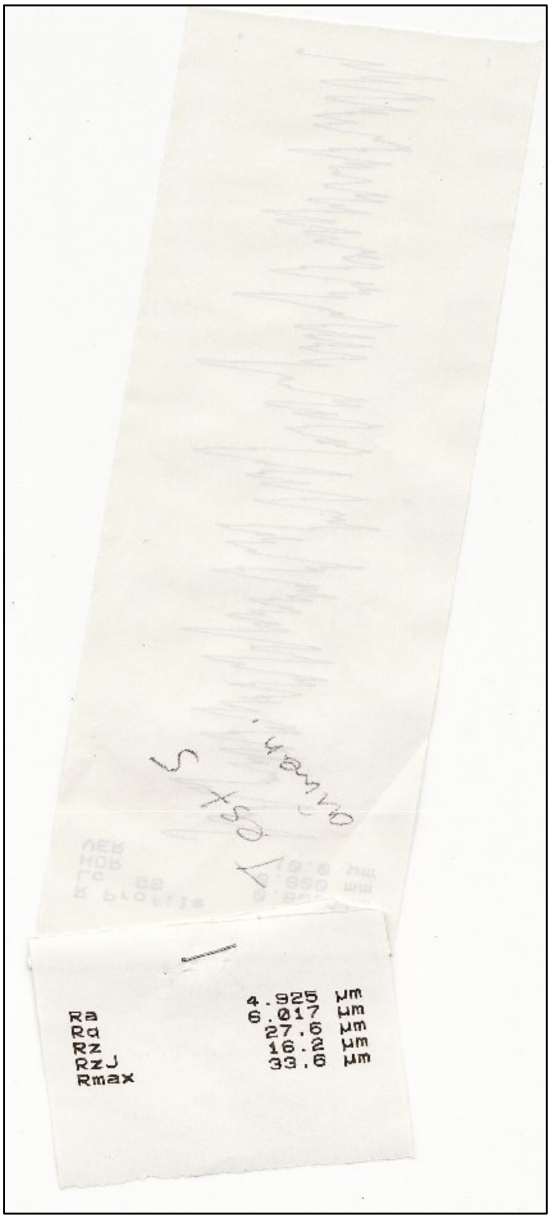


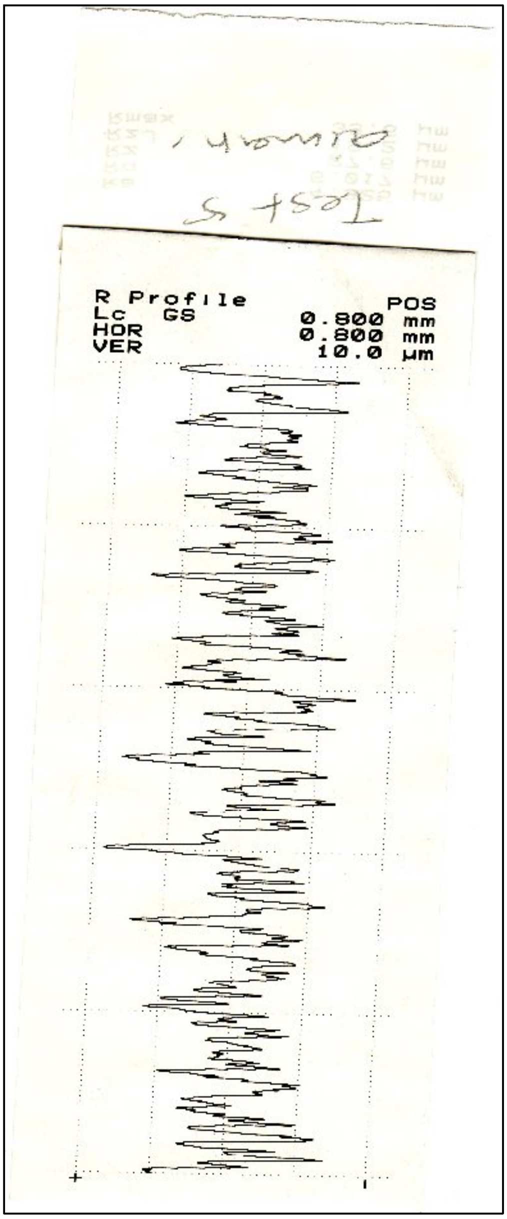


Test number 4

APPENDIX B

Sample of printed roughness result





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