

EXPERIMENTAL STUDY OF THE HEAT AFFECTED ZONE (HAZ)
AND SURFACE ROUGHNESS ON LASER BEAM CUTTING (LBC)
ON ACRYLIC SHEET

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
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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 Engineering.

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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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Dedicate to my beloved father, mother and my honour siblings

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ABSTRACT

Nowadays, laser beam is a practical and versatile tool for processing range of alloys, glasses, ceramics, composites, polymers and metal in manufacturing industries. Laser beam cutting (LBC) is achieved by the radiation emitted by a focused beam of coherent light with a assistance of a high pressure gas. Advantages of using laser beam cutting are, material with complex figures can be easily be cut by incorporating CNC motion equipment. High cutting speed, low distortion, very high edge quality and a minimal width of heat affected zone. It can sufficiently replace current existing techniques. LBC is different compared to the conventional machine tools that design for a particular purpose. There are number of parameters that plays important role in laser cutting processes. Each parameter will affect the processing operation. The significant parameter to be consider are laser power, cutting speed (delay time), nozzle gap, air pressure and cutting angle. This is because there is a significant relation between the parameters. Different in laser cut parameters will yield different type of results. In this project, sample of acrylic sheet with thickness of 3mm were cut using CO_2 laser cutting system with the variation of the five parameters. The effect of these five factors on surface roughness and width of heat affected zone have been studied. Data obtained was interpreted to develop graph to find the best combination of parameters on laser cut quality. Besides that relationship between laser power and delay time were also described. As a result for surface roughness research, the best combination of parameters was obtained. As for width of heat affected zone research, the best combination of parameters was obtained. Its means that all the parameters play a great role in produces high quality cut. To obtain better and precise results , environment effects such as air ventilation, air humidity, efficiency of laser beam machine and room temperature should be consider.

ABSTRAK

Kini, dalam industri pembuatan, pancaran laser ialah peralatan yang praktikal juga versatil untuk memproses aloi, kaca, seramik, komposit, polimer, dan logam. Pemotongan pancaran laser boleh dihasilkan dari pancaran radiasi melalui penumpuan pancaran cahaya yang terang dengan bantuan gas bertekanan tinggi. Banyak kelebihan menggunakan pemotongan pancaran laser, antaranya bahan yang mempunyai bentuk yang kompleks dapat dipotong dengan mudah menggunakan peralatan gabungan pergerakan CNC. Pemotongan pancaran laser juga mempunyai kelajuan pemotongan yang tinggi, perubahan bentuk yang rendah, kualiti pemotongan tepi yang tinggi dan kelebaran zon diserang haba yang minimum. Ia cukup memadai untuk menggantikan teknik pemotongan yang semasa. Pemotongan pancaran laser adalah berbeza dari peralatan mesin tradisional yang dirangka untuk suatu tujuan. Ada beberapa parameter yang berperanan penting didalam proses pemotongan laser. Setiap parameter akan member kesan dalam operasi proses. Parameter penting yang perlu diberi perhatian adalah kuasa laser, kelajuan pemotongan, jarak cerat, tekanan angin dan darjah pemotongan. Ini kerana adanya kaitan penting antara kelima-lima parameter. Perbezaan dalam parameter pemotongan laser akan menghasilkan hasil yang berlainan.. Dalam projek ini, bahan contoh ialah kepingan akrilik yang mempunyai tebal sebanyak 3 mm telah dipotong menggunakan sistem pemotongan laser karbon dioksida dengan bervariasi kelima-lima parameter penting. Kesan daripada 5 parameter keatas kekasaran permukaan dan kelebaran zon diserang haba telah dikaji. Data diperolehi kemudiannya diolah, dan graf dilakar untuk mendapatkan kombinasi parameter terbaik. Disamping itu pertalian antara kuasa laser dan kelajuan pemotongan telah dibincang. Sebagai hasilnya untuk kekasaran permukaan dan zon diserang haba, kombinasi parameter telah ditentukan. Ini bermaksud kesemua parameter memainkan peranan penting dalam menghasilkan kualiti pemotongan yang tinggi. Dalam mendapatkan hasil yang lebih baik dna tepat, kesan persekitaran perlu dititik beratkan.

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LIST OF SYMBOLS

- CO_2 : Carbon Dioxide
- R_a : Average surface roughness
- R_z : Average maximum height
- R_q : RMS roughness
- R_{max} : Maximum roughness depth

LIST OF ABBREVIATIONS

- LBC : Laser beam cutting
- CNC : Computer numerical control
- PCNC : Personal computer numerical control
- HAZ : Heat affected zone
- CLA : Centre Line Average
- DOE : Design of experiment
- RSM : Response surface methodology
- MSDS : Material safety data sheets

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The term "laser" is an acronym for Light Amplification Stimulation Emission of Radiation. 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.

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. [T. Norikazu, Y. Shigenori and H. Masao, (1996)] 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.

Advantages of using LBC are, materials with complex figures can easily be cut by incorporating CNC motion equipment, LBC has high cutting speed, Low distortion, very high edge quality and most important thing is LBC has a minimal heat affected zone (HAZ). [4]

Heat Affected Zone HAZ - Adjacent to the weld metal zone is the heat-affected zone that is composed of parent metal that did not melt but was heated to a high enough temperature for a sufficient period that grain growth occurred. Heat affected zone is that portion of the base metal whose mechanical properties and microstructure have been altered by the heat of welding.

The heat affected zone is subjected to a complex thermal cycle (sudden heating followed by rapid cooling) in which all temperatures from the melting range of the steel down to comparatively much lower temperatures are involved and HAZ therefore consists of a series of graded structures ringing the weld bead. HAZ usually contains a variety of microstructures. [I.A. Almeida, W. Rossi, M.S.F. Lima, J.R. Berretta, G.E.C. Nogueira and N.U. Wetter *et al.*, (2006)]

Surface roughness is the measure of the finer surface irregularities in the surface texture. These are the result of the manufacturing process employed to create the surface. Surface roughness Ra is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micro inches or micrometers. ISO standards use the term CLA (Centre Line Average). Both are interpreted identical. [G. Thawari, J.K. Sarin Sundar, G. Sundararajan and S.V. Joshi, (2005)]

1.2 PROJECT OBJECTIVE

1.2.1 To investigate the width of Heat affected zone of the material cut with LBC machine. To analyze the Surface roughness of the material cut with LBC machine.

1.2.2 To obtain a relationship between cutting quality and machining parameters.

1.3 PROJECT SCOPES

1.3.1 Laser parameters considered are pulse duration, laser power, the nozzle gap, cutting angle and the air pressure.

1.3.2 Experimental plan will be designed with Response Surface Method.

1.3.3 Shape of experiment material will be designed in Art Cam or in SOLIDWORK and cut using Laser Beam Cutting machine.

1.3.4 Analysis of the width of Heat affected zone (HAZ) by using optical microscope with analyzer.

1.3.5 Surface roughness analyze with Perthometer.

1.4 PROBLEM STATEMENT

Laser beam has been commonly used for machining for various materials. One of the problems with laser machining is unwanted heat-affected zone HAZ, which downgrades the quality of the cut surface of the material. Heat-affected zone HAZ occurs very often due to lack of information on the characteristic of the laser beam.

1.5 PROJECT PURPOSE

Purpose of this project is to analyze experimentally the acrylic cut by laser, to see the mechanical properties, heat affected zone and surface roughness changes as the parameters of the laser vary.

1.6 PROJECT AIM

Great hope that, by complete the project, it could help to analyze the changes of mechanical properties as the parameters of the laser varies. Hence helps manufacturers to produce a quality cutting surface.

1.7 PROJECT QUESTION

Experimental Study of the Heat Affected Zone (HAZ) and Surface Roughness on Laser Beam Cutting (LBC) on Acrylic Sheet.

1.8 THESIS ORGANIZATION

This thesis consists of 5 different chapters. Each chapter represents its own function. All chapters arranged chronologically.

Chapter 1 is the introduction of this research. It explains briefly on the research conduct. It also emphasizes the importance of this research. Problems and scopes are also being described.

In chapter 2, definition, history and the development of the research will be briefly described. The research components are Carbon Dioxide (CO_2) Laser Machine, Acrylics sheet, Laser cut quality, surface roughness and heat affected zone HAZ. The cutting parameters such as laser power, cutting speed, nozzle gap, inclined angle and air pressure will be explain briefly. Chapter 2 will also describe about the significance theories and formulas from the late studies.

Method and procedures that will be used in the experiment are discussed in chapter 3. Safety and precaution will be included.

Findings from the experiment will be displayed and discussed in chapter 4 via tables, figures, pictures and calculations.

Finally, in chapter 5 is the conclusion of the research. For future recommendation will also be included.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, every portion of the research will be explained. Particulars on Laser machine, material used, experiment parameters and theories are to be describes briefly. Figure 2.1 shows the general outline for chapter 2.

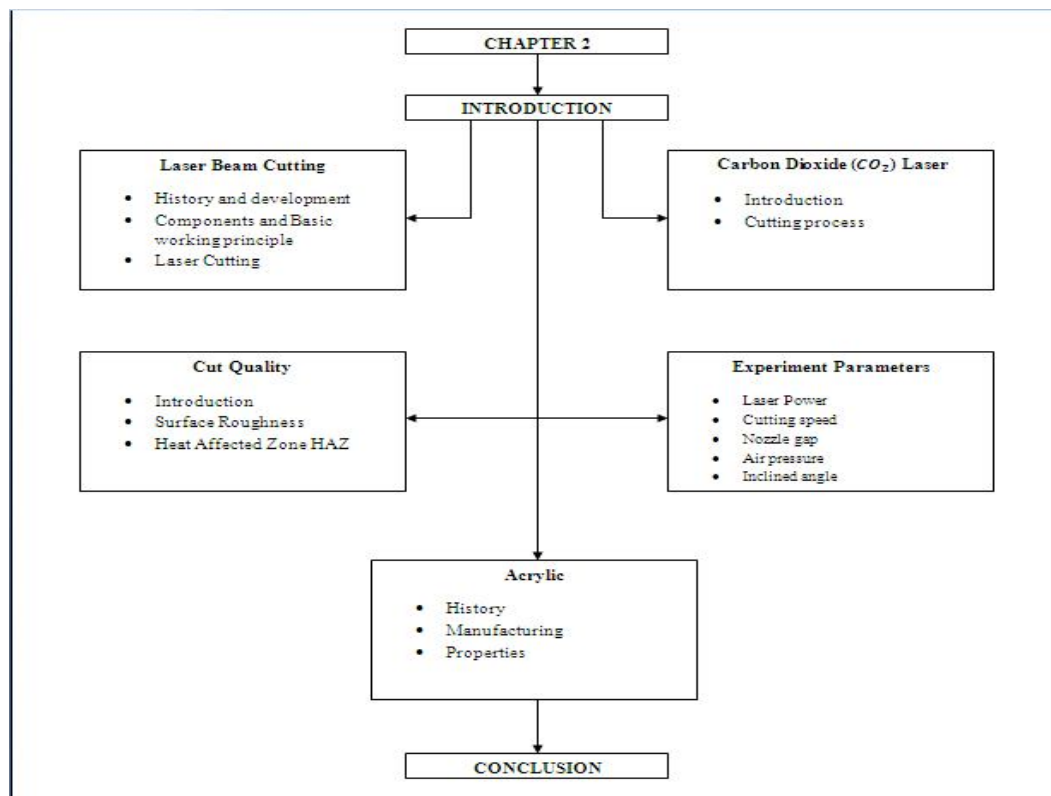


Figure 2.1: Chapter 2 General Outline

2.2 LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION

2.2.1 Definition and History

The word laser was originally spelled LASER and is an acronym for light amplification by stimulated emission of radiation. The word light in this phrase is used in the broader sense, referring to electromagnetic radiation of any frequency, not just that in the visible spectrum. Hence there are infrared lasers, ultraviolet lasers, X-ray lasers, etc.

The term "laser" is an acronym for Light Amplification Stimulation Emission of Radiation. 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.

In 1954, Charles Townes and Arthur Schawlow invented the maser (microwave amplification by stimulated emission of radiation), using ammonia gas and microwave radiation - the maser was invented before the (optical) laser. The technology is very close but does not use a visible light. On March 24, 1959, Charles Townes and Arthur Schawlow were granted a patent for the maser. The maser was used to amplify radio signals and as an ultrasensitive detector for space research.

In 1958, Charles Townes and Arthur Schawlow theorized and published papers about a visible laser, an invention that would use infrared and/or visible spectrum light; however, they did not proceed with any research at the time. Many different materials can be used as lasers. Some, like the ruby laser, emit short pulses of laser light. Others, like helium-neon gas lasers or liquid dye lasers emit a continuous beam of light.

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. [S.-H. Lim, C.-M. Lee and W.J. Chung, (2006)] 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.

Table 2.1: Laser Development from early finding stage until 20th century.

Year	Impetus	Findings
1917	<i>Albert Einstein</i>	Established Idea
1954	<i>Charles A. Townes</i>	First maser based on ammonia molecules
1958	<i>L. Schawlow and Charles H. Townes</i>	Propositions and calculations for the realization of masers for light and infrared
	<i>T. H. Maiman</i>	First Laser
	<i>Ali Javan</i>	First Gas Laser
1964	<i>Kumar Patel</i>	Gas (CO₂) Laser invented
1968	<i>W. T. Walter</i>	Discover the first copper vapour laser
1973	<i>M. Nakamura and A. Yariv</i>	First distributed Feedback Laser
1977	<i>D. A. G. Deacon</i>	First free electron laser has been invented
1979	<i>H. Soda</i>	First Surface emitting laser diodes
1983	<i>L. F. Mollenauer and R. Stolen</i>	First silicon Laser
1994	<i>K. Ann</i>	First single atom Laser

Source: <http://www.wikipedia.com> accessed on 14 March 2009

2.2.2 Fundamentals of Laser Beam Cutting

The fundamentals of laser beam cutting have been described in great detail in several texts. Laser beam cutting belongs to the group of thermal cutting processes. The laser beam is focused on the work piece (Fig. 2.2), heats it up locally and, according to the cutting procedure, and induces a phase transformation of the material. [S.C. Tam, L.E.N. Lim and K.Y. Quek, (1992)] The material is blown out of the developing cut kerf by the normally coaxial gas jet that is added to support the process. [C. Karatas, O. Keles, I. Uslan and Y. Usta, (2006)]

The laser beam heats the material to an ignition temperature for the initiation of an exothermal reaction with a reactive cutting gas, as rule oxygen. This reaction influences the viscosity of the melt and the absorption conditions, and additional process energy is provided. The gas jet removes the reaction products from the cut kerf.

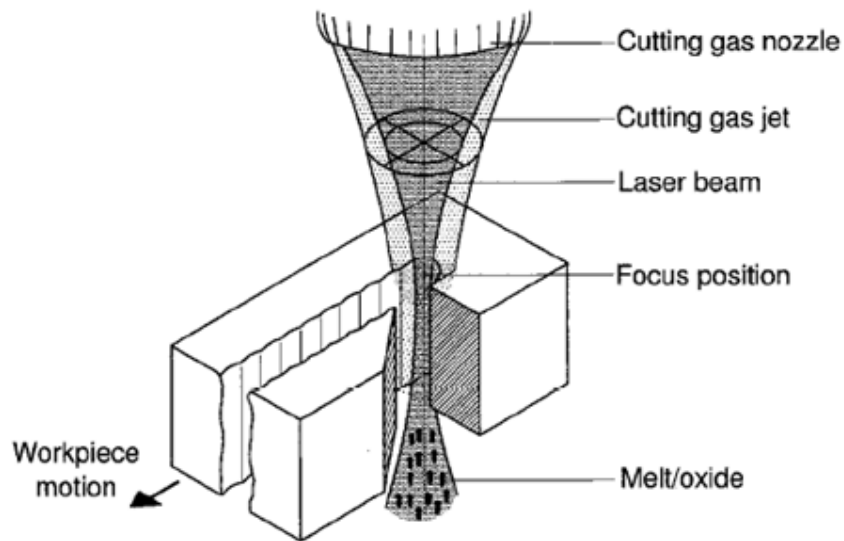


Figure 2.2: Principle of laser beam cutting

Source: W.M. Steen (1991)

Laser beam cutting allows much higher cutting speeds because the material has only to be melted. The inert cutting gas facilitates the production of shiny metallic cut

surfaces. With a reactive cutting gas, additional energy from the exothermal reaction between material and gas speeds up the process noticeably. [C.-H. Li, M.-J. Tsai and C.-D. Yang, (2007)]

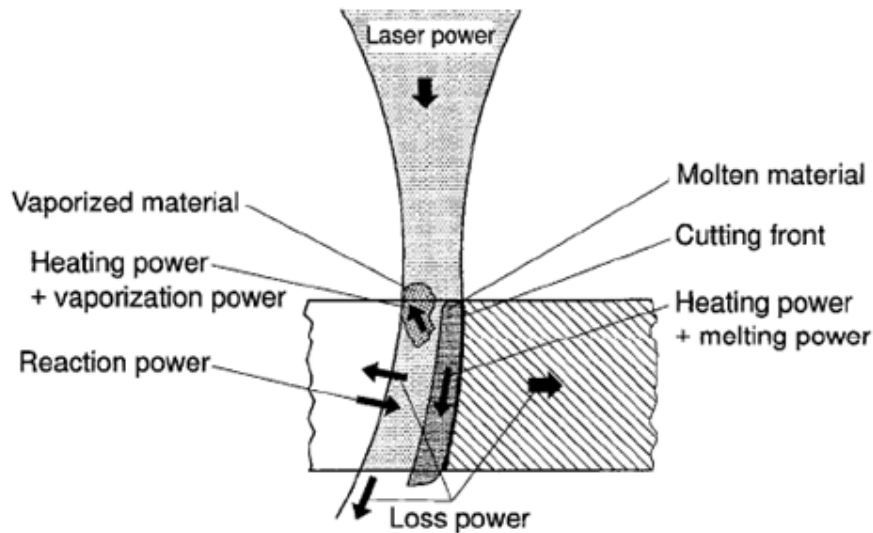


Figure 2.3: Power flows at cutting front during laser beam cutting

Source: J. Meijer (2004)

2.2.3 Laser Cutting Process

In the laser cutting process, a kerf is created to relative motion between the laser beam and the workpiece surface. This process allows intricate two dimensional shapes to be cut on workpiece. The physical mechanisms for material removal and energy losses are similar to those for drilling, where the incoming laser beam is balanced by the conduction heat, energy from melting or vaporization of material, and heat losses to the environment. [J. Mathew, G.L. Goswami, N. Ramakrishnan and N.K. Naik, (1999)]

The width produced by the laser beam is narrower than those achieved with mechanical cutting. This results in less wasted material. When cutting fibrous materials

such as composites, the laser beam vaporizes the volume of material to be removed, thereby eliminating the residue and debris that remains after mechanical cutting.

Laser beam cutting has become an important process and is used with computer controlled equipment to cut a variety of shapes consistently and in various thicknesses. Lasers provide a competitive edge when used in sheet metal cutting. In this procedure blanks are cut from large rolled sheets and further processed into desired shapes. [L. Shanjin and W. Yang, (2006)]

Laser beams may be used in combination with gas stream, such as oxygen nitrogen, or argon for cutting thin sheets materials. Gas streams also have the importance function of blowing away molten and vaporized material from the workpiece surface.

2.3 CO_2 LASER BEAM

2.3.1 Introduction

There are two types of industrial CO_2 lasers. CO_2 laser excited by direct current (DC) and CO_2 lasers excited by radio frequency (RF). Industrial lasers up to 2.2 kW use DC excitation. Lasers above 2.2 kW generally use RF excitation. It is less expensive to manufacture a DC excited laser, and DC excited lasers consume less power than a RF excited laser. However, RF excitation is recommended for more powerful lasers. The main difference between the two is the electrode location. These electrodes excite the CO_2 gas mixture inside the glass cavity. The anode and cathode are located inside the glass cavity in a DC excited laser, whereas, a RF excited laser excites the gas with electrodes mounted externally to the glass cavity. [A. Lamikiz, L.N.L. Lacalle, J.A. Sanchez, D. Pozo, J.M. Etayo and J.M. Lopez, (2005), S.L. Chen, (1999)]

A DC excited laser gas mixture becomes more unstable at the higher end of 2.2kW. High current being pumped into the glass cavity causes the laser gas to disassociate quickly, which leads to the degradation of the output beam. The poor beam quality results in poor cutting performance of the laser-cutting machine. As the RF

excited laser will not pump high current into the gas mixture directly, it allows the beam quality to be better even at high powers of up to 10kW. Better beam quality is the main reason for RF excited lasers to be better performers in industries which cut thicker material. [N. Rajaram, J.S. Ahmad and S.H. Cheraghi, (2003)]

2.3.2 Cutting Process

The beam from the laser is focused on the surface of the material being cut by using a lens as a reflector. The focused laser beam heats the material surface and a local melt capillary is quickly established throughout the depth of the material. The diameter of this capillary is usually just slightly greater than the diameter of the focused laser beam. Majority of CO_2 laser cutting is performed using an assist gas. The significant function of gas assisted laser cutting is that the molten material is ejected from the base of the capillary by a jet of gas coaxial with the laser beam. For some material this gas can further assist the process by chemical reaction as well as physical work. The cut is generated by both moving the focused laser beam across the surface of the stationary material or by keeping the laser beam stationary and move the workpiece. Combination of these two options is also possible. In this way simple and complex linear cut or two dimensional parts can be produced.

2.4 ACRYLIC SHEET

2.4.1 Annals

Acrylic was first studied in 1901 by Dr. Otto Rohm. He continued his studies on this material and eventually in 1927, Rohm together with Hass conducted limited production of poly (methyl acrylate) under the trade names Acryloid and Plexigum. About 1930, R. Hill and W. Bauer independently prepared a rigid and transparent which is polymethyl methacrylate or known as acrylic. By 1936, American, British, and German companies were producing acrylic. During World War II, acrylic glass was used for periscope ports on submarines and for windshields, canopies and gun turrets on airplanes.

Acrylonitrile, the substance from which acrylic fibers are produced, was first made in 1893 in Germany and was used as another chemical in research for the DuPont Company. In 1944, acrylic was developed by DuPont Company and was first commercially produced to human daily life in 1950. Until today, acrylic is known as one of the most popular materials used.

2.4.2 Acrylic Forming

Acrylic plastic polymers are performed by the reaction of a monomer, such as methyl methacrylate, with a catalyst. A typical catalyst would be organic peroxide. The catalyst starts the reaction and enters into it to keep it going, but does not become part of the resulting polymer. Acrylic plastic sheets are formed by a process known as bulk polymerization. In this process, the monomer and catalyst are poured into a mold where the reaction takes place. Two method of bulk polymerization may be used: batch cell or continuous. Batch cell is the most common because it is simple and is easily adapted for making acrylic sheets in thickness from 0.06 to 60 inches and width from 3 feet up to several hundred feet.

2.4.3 Properties

Acrylic is so useful in many ways because of its properties that are versatile and suitable in manufacturing any products based on plastic. It's transparent in physical look and the properties that more better than the properties of glass. These are the main factor that increases the demand on acrylic in market. Table 2.3 shows the properties of an acrylic.

Table 2.2: Properties of Acrylic

Properties	Value, Units and Grade
Tensile Strength, Ultimate	6820 – 11500 psi
Tensile Strength, Yield	7980 – 12300 psi
Tensile Creep Modulus, 1 hour	261000 – 392000 psi
Density	0.0415 – 0.043 lb/in ³
Thermal Conductivity	1.32 – 1.67 BTU-in/hr-ft ² -°F
Processing Temperature	469 – 482 °F
Melting Point	266 °F
Refractive Index	1.49 – 1.498

Corrosion Resistance	Good
Chemical Resistance	Good
Dimensional Stability	Good
Process Ability	Good
Cure	Fast

Source: <http://www.metalweb.co.uk/default.aspx?id=12> accessed on 29 February 2009

2.5 CUT QUALITY

2.5.1 Introduction

Cut quality is defined as rate of finish of the workpiece or final product. Cut quality depends on physical characteristic, composition and structure. In laser beam cutting, there are many cut quality can be determined such as kerf, burrs, pitting, groove lag, surface roughness, heat affected zone HAZ, perpendicularity and surface condition. This project only emphasize on two cut quality:

1. Surface Roughness
2. Heat Affected Zone HAZ

2.5.2 Surface roughness

Surface roughness is the measure if the finer surface irregularities in the surface texture. These are the result of the manufacturing process employed to create the surface. Surface roughness Ra is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micro inches or micrometers. ISO standards use the term CLA (Centre Line Average). Both are interpreted identical.

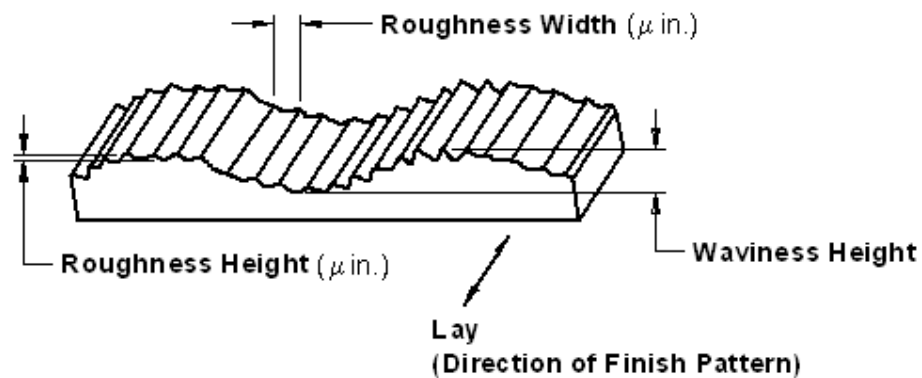


Figure 2.4: Surface Roughness

Source: J.D. Majumdar and I. Manna (2003)

2.5.3 Heat Affected Zone HAZ

Heat Affected Zone HAZ - Adjacent to the weld metal zone is the heat-affected zone that is composed of parent metal that did not melt but was heated to a high enough temperature for a sufficient period that grain growth occurred. Heat affected zone is that portion of the base metal whose mechanical properties and microstructure have been altered by the heat of welding. HAZ is determined according to its width. The HAZ width increase as the energy input per unit length and cut thickness increase. [J. Antony, (2001)]

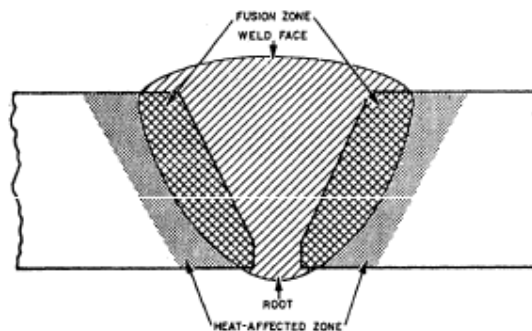


Figure 2.5: Width of heat affected zone (HAZ)

Source: L. Shanjin and W. Yang (2006)

2.6 EXPERIMENT PARAMETERS

2.6.1 Introduction

Parameter here is referred as the elements that can be set up or adjust. As for this research, Laser beam cutting, there are five parameters to be controlled. They are Laser Power, Cutting speed, nozzle gap, Air pressure and inclined angle. These parameters contribute to the quality of the workpiece or the final product.

2.6.2 Laser Power

Laser power is the amount of energy that the laser produced to cut a workpiece. With enough and efficient power will reduce the defects of the workpiece. For this research it needs 4 different laser power that are, for 25.5 watt, 26.5 watt, 27.5 watt, and 28.5 watt. As the maximum laser power is 30 watt.

2.6.3 Cutting Speed

Cutting speed is the delay time for the laser beam to cut a material. It also called feed rate. The more fast the delay time means the more slower the cutting speed will result in engraving state while for ample cutting speed it will result in a fine cut.

2.6.4 Nozzle Gap

Nozzle gap means the distance between the focal of the laser machine with the workpiece. This parameter also one of the essential parameter to watched. With correct distance it will contribute to a finer quality of cut.

2.6.5 Air Pressure

Air pressure or more accurately jet gas is the assist gas that deployed just in front of the focal nozzle of a laser beam. It works to assist the laser to cut the material.

2.6.6 Cutting Angle

This happened when the workpiece does not vertically 90° to the laser beam. This parameter also affects the cut quality.

2.7 CONCLUSION

Laser is classified as one of the promising new technology. This is because until today the development of laser is still on track. In maximizing the cut quality many parameters should be control for achieving high quality of cut. In the next chapter 3, the machine, apparatuses, procedures and method used will be briefly discussed as well as the safety and precaution steps.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Chapter 3, methodology will described the experimental study of the Heat Affected Zone (HAZ) and Surface Roughness by Laser Beam Cutting (LBC) on Acrylic Sheet. Methodology plays an important role to make sure the project flows smoothly and systematically with optimum expected result gain. This chapter will be discussing on the process flow due to flow chart. In chapter 3, there are several steps that are essential to be follow to ensure that the objective of the project successfully achieved, starts from the very beginning of literature review until submit the full report. Briefly are steps of the project in terms of flow chart schematics diagram.

Figure 3.1 and Figure 3.2 shows the flow chart of the overall FYP and also the flow chart of the laser experiment.

3.2 FLOW CHARTS

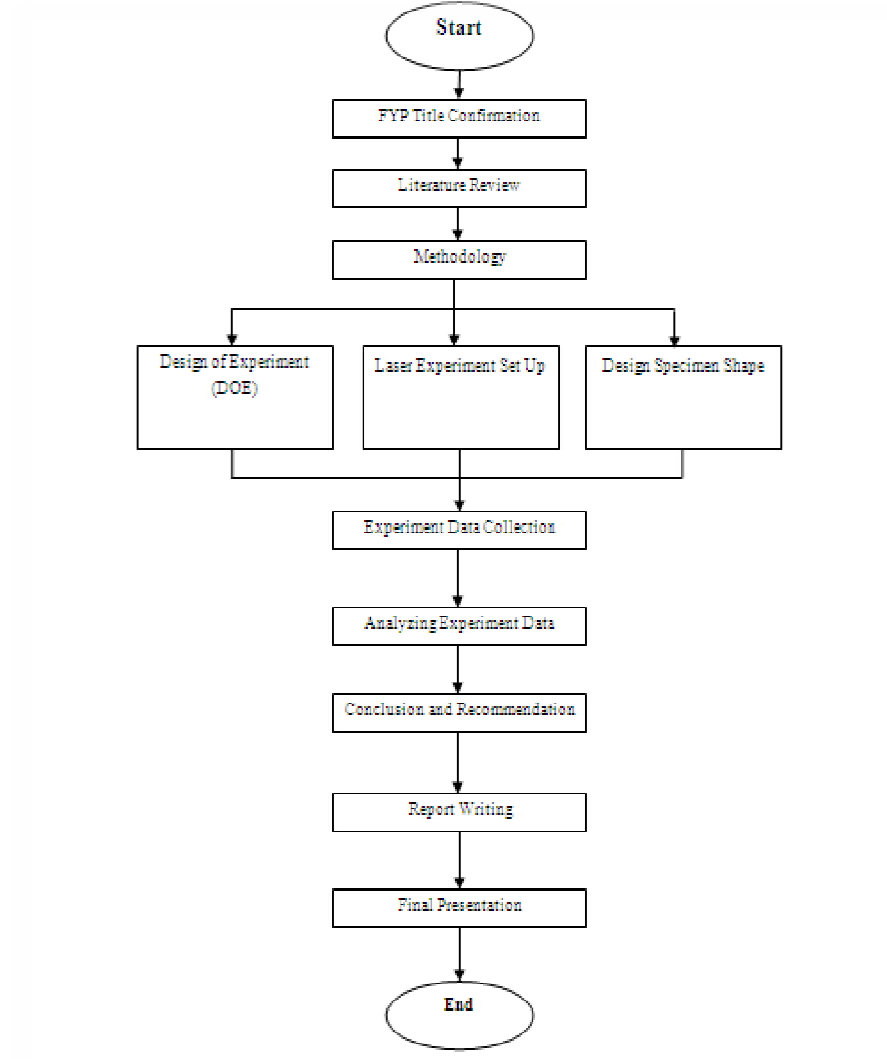


Figure 3.1: Flow Chart for Overall FYP

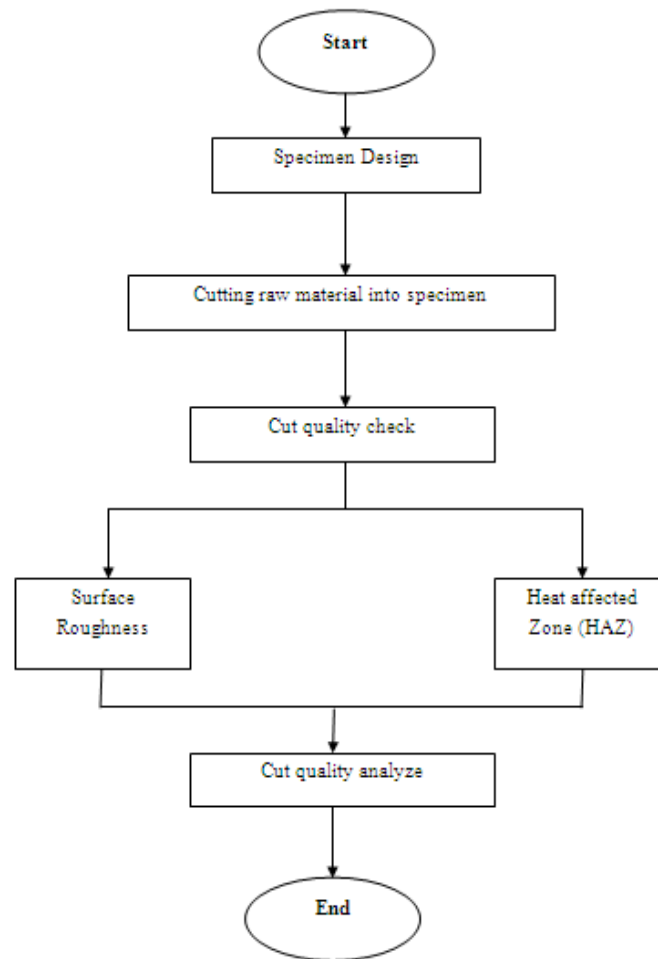


Figure 3.2: Flow chart of laser experiment

3.3 DESIGN OF EXPERIMENT

Design of experiment is essential when dealing with experiment set up. Generally DOE helps the experimenter to achieve their goals in a systematic step. There are some procedures when taking DOE into consideration. If the experimenter follows the steps correctly, at the end of the experiment, experimenter can make a conclusion based on the experiment runs and most importantly the experiment is validate.

In this experiment, DOE was used as a guideline to arrange the flow. Decision to used the Response surface method RSM to design the parameters given. For each material, there are precisely 40 experiments to run and the total experiment for two materials is 80 experiments. When finished the experiment, the results obtain that is HAZ and surface roughness will be analyze.

In DOE it is very important to measure the interaction between the parameters in order to seek for the optimum parameter for this experiment. Moreover the DOE avoid the experimenter to run unnecessary experiments. This is good because it will eliminate the errors while running the experiment. Types of error that is possible for this project are random error and repeatability.

3.4 LASER MACHINE SPECIFICATION

In UMP FKM lab the laser machine is known as PCNC Laser Cutting Machine. 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. Table 3.1 below shows the general specification for the laser machine.

Table 3.1: PCNC Laser Machine Specification

Specification	Data
Name	ILIOS CO_2 Laser Machine System
Picture	

Figure 3.3: ILIOS CO₂ Laser Machine System

Laser Source	
Wavelength	10.57 – 10.63 μ m
Power Output	30 Watt (Maximum)
Mode Quality	TEM ₀₀ , 95 % Purity
Beam Quality	M ₂ < 1.1
Power Stability	
From Cold Start	\pm 5%
After 2 minutes	\pm 3%
Marking Head	
Aperture	15mm
Interface	XYZ – 100 16 – bit digital
Objective lens	F = 100mm
Maximum field size	70mm \times 70mm
Marking speed	3500mm per sec
Writing speed	>600 possible
Good quality	400 char per sec
Excellent quality	350 char per sec

3.5 PARAMETER DESIGN

Before begin any type of experiment, one should draft and design all the parameters required in the experiment. This is to ensure, the experiment run according to the objective and scopes of the project. Eliminate unnecessary and unreliable parameters that are not required in the experiment. Take or consider the optimum parameters design only. For my experiment, one must consider five essential parameters that are, Nozzle gap, air pressure, cutting angle, laser power and cutting speed. Table below shows all the parameters for the experiment:

Table 3.2: Experiment Parameters

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

The RSM method is to be applied to design the parameters. It would give the utmost optimum parameter design. The RSM generally have shrink or more specifically summarizes all the parameters into a required and desirable parameter design. For my case, the RSM have minimized my experiment test from 243 experiments only to 40 tests of experiments. Table below shows all the parameters design after applying RSM:

Table 3.3: Experiment test design using Response Surface Method

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	A	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 DESIGNING SPECIMEN

In designing the specimen, first sketch the specimen using SOLIDWORK software. Then the sketch specimen will be imported into design software called ART CAM. After imported into ART CAM the software will convert the specimen to a G code coding. This is for the laser machine to read the code and automatically cut the material according to the desire design.

3.6.1 SOLIDWORK Design

Using SOLIDWORK, the specimen design have been sketched into a dimension of 30mm×30mm with the thickness of the specimen will be 3mm. Below are the sketching view of the specimen.

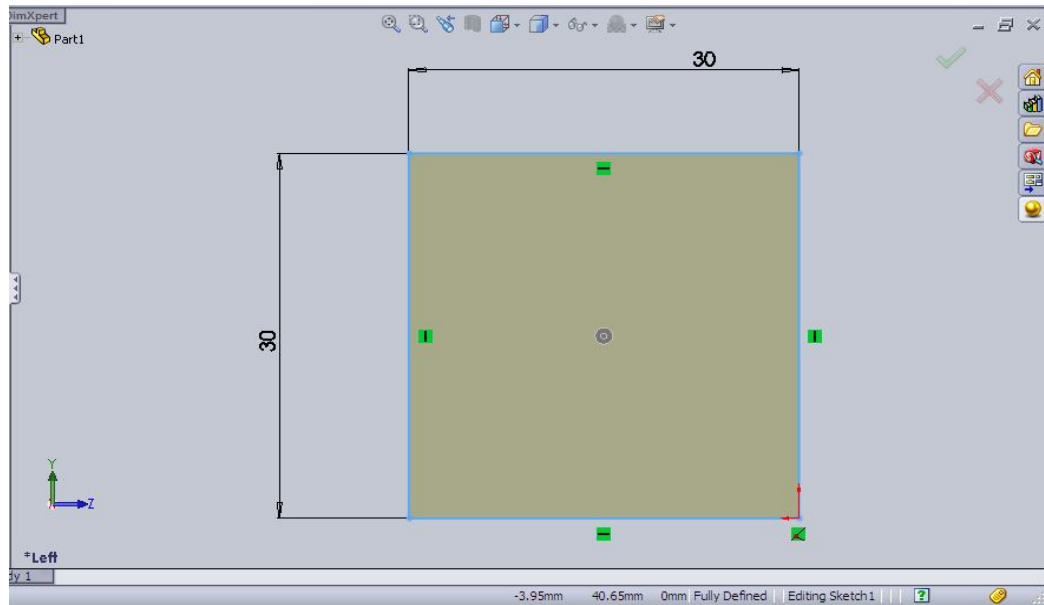


Figure 3.4: Left view of the specimen (Acrylic)

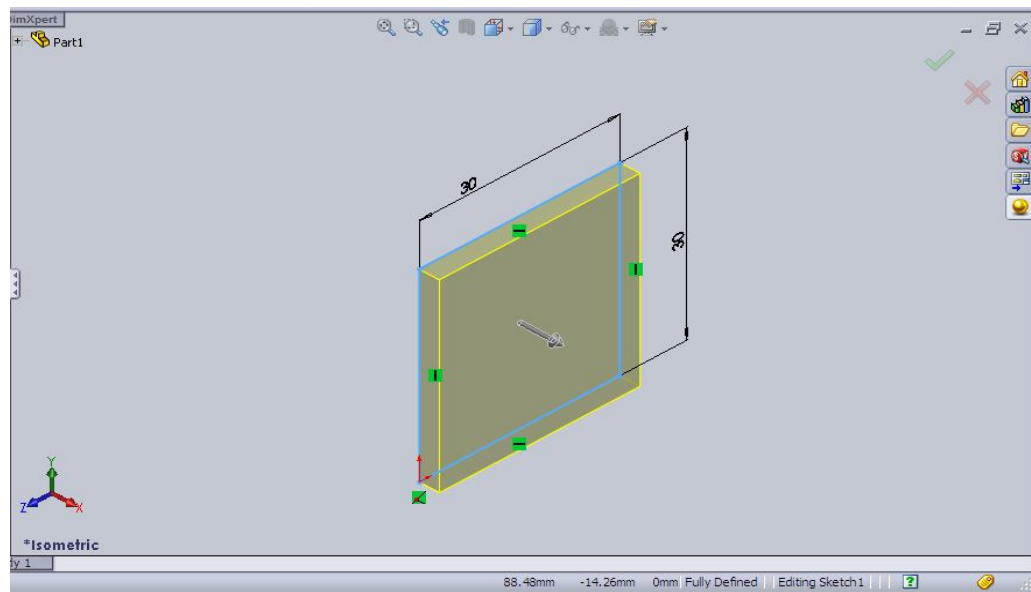


Figure 3.5: Isometric view of the specimen (Acrylic)

3.6.2 ART CAM

After finish with the sketch in SOLIDWORK the design specimen will be imported into ART CAM. Then the G code coding for the specimen will be produced. Save as filename .txt



Figure 3.6: ART CAM specimen design

```

RAPID X0.000 Y0.000 Z5.556 TOOL# 0
RAPID X0.905 Y1.257 Z5.556
LINE Z0.000 FEED 240.0
LINE X30.905 FEED 780.0
LINE Y31.257
LINE X0.905
LINE Y1.257
RAPID Z5.556
RAPID X0.000 Y0.000

```

Figure 3.7: G coding for specimen

3.7 CUTTING RAW MATERIAL INTO SPECIMEN

3.7.1 Laser Machine Alignment

First of all, before proceed to the cut stage; the laser machine must go in a process that is alignment. These alignment process including the laser head itself, nozzle and the stand table, that is use to put the raw material. It is an essential stage because to ensure that the cutting process take place is in a precise move.

For the laser head, procedure of alignment is by using software ‘PANATERM’. This is to ensure that the laser head will directly follows the command entered, so that the cutting process flows smoothly. Likewise for laser nozzle, checking the flow inside the nozzle will result in good laser beam intensity. Take off the nozzle from the laser head, then used jet air to clean and throw away unwanted things inside the nozzle.

Lastly for the stand table, where the material will be place, we need to align the table by using the water ruler. This is very important so that the material will be cut do not result in uneven cut.

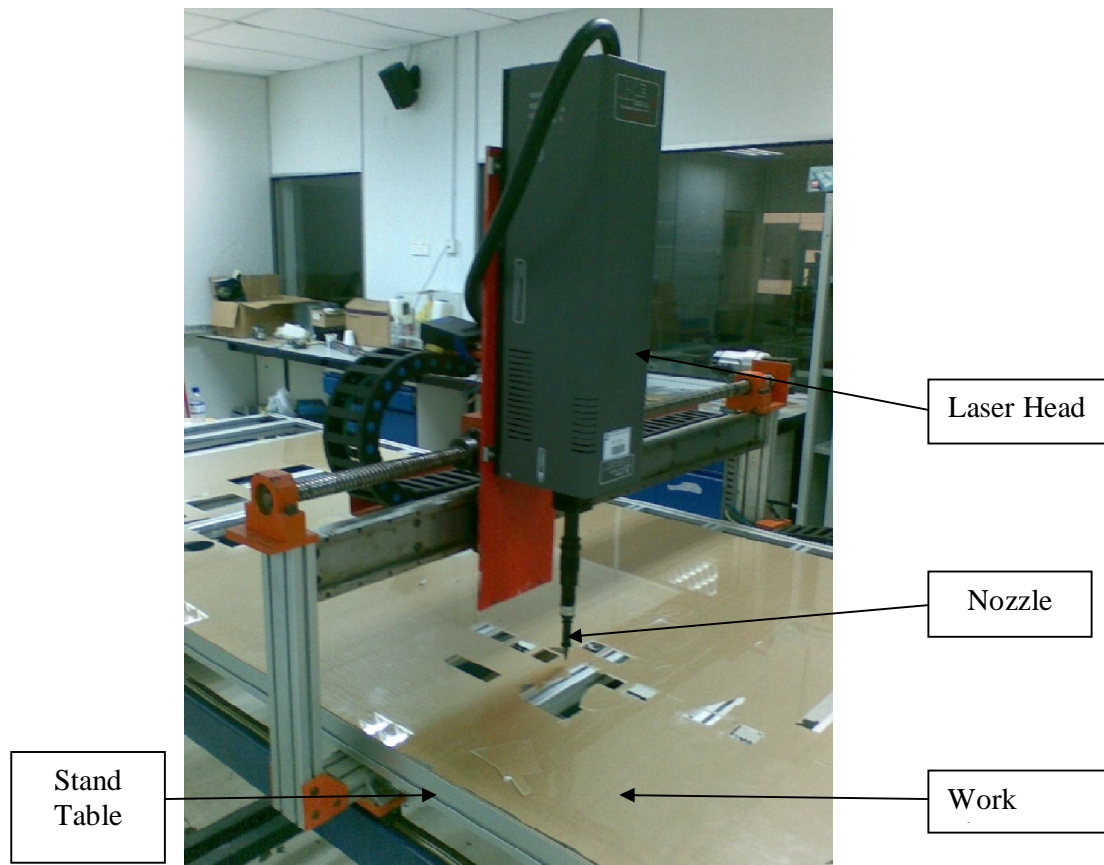


Figure 3.8: Laser Machine

3.7.2 Cutting Process

After alignment process have completed, next only the cut process can be execute. Before that the laser cutting machine has to be program first so it will cut the raw material into the desired design shape. Based on every test, the parameter varies different from another test. That is why it is important to check and recheck every time move to the next experiment test.

To change the cutting speed, go to folder name 'PCNC guna', and then click on file name 'PCLINE.H'. It will appear in C++ VISUAL software. Change the cutting

speed to the desired value and compile. Then only save the coding. By doing all the steps mentioned, the laser machine will cut with a cutting speed that been save before.

Figure 3.9 below shows the C++ coding and where is the value that needs to change for cutting speed.

```
#ifndef PCLINE__H
#define PCLINE__H

__inline double IXFUN(double u, double cx1,double cx2){return cx1+(cx2-cx1)*u;}
__inline double IYFUN(double u, double cy1,double cy2){return cy1+(cy2-cy1)*u;}
__inline double IZFUN(double u, double cz1,double cz2){return cz1+(cz2-cz1)*u;}
__inline double IXFUN_1ST(double u, double cx1,double cx2){return cx2-cx1;}
__inline double IYFUN_1ST(double u, double cy1,double cy2){return cy2-cy1;}
__inline double IZFUN_1ST(double u, double cz1,double cz2){return cz2-cz1;}

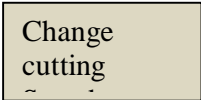
void pcline(int on,double cx2,double cy2,double cz2);

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 = IXFUN_1ST(u,cx1,cx2);
        yp = IYFUN_1ST(u,cy1,cy2);
        zp = IZFUN_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 (11110):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 = IXFUN(u,cx1,cx2);
    y = IYFUN(u,cy1,cy2);
    z = IZFUN(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(700); //200 utk engrave, 700 utk potong
    PortOut(prnport,valout_dir+on);
    Delay(700); //200 utk engrave, 700 utk potong
    TP++;

```



```
    }  
return;  
}  
#endif
```

Figure 3.9: Coding C++ PCLINE.H

After set the cutting speed, set the laser power by adjusting at the control panel for laser beam power. Nozzle gap should also alter according to parameter desired. It same apply to angle and Air pressure.

When all the parameter has been set up, go to the same folder, 'PCNC guna' and then click file name PCNC.H. Then compile and run the coding. It will appear C++ window, after that type the coding specimen with the filename .txt. It will ask a confirmation to precede the cut by requiring a YES or NO. If YES then the laser machine will run according to the specimen coding that entered earlier. If NO then the command window will quit itself and the laser will not run. Below are Figure 3.9, the flow chart for the cutting process and coding C++ for run the PCNC Laser Machine.

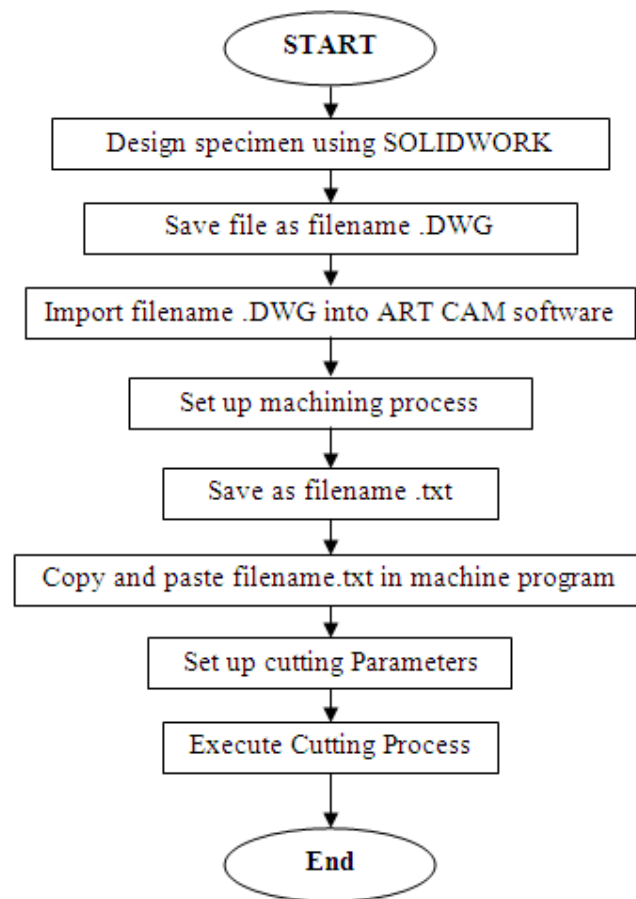


Figure 3.10: Flow chart of cutting process

```

#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%d\t%f\t%f\t%f\t%f\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 3.11: Coding C++ PCNC.H

3.8 CHECKING CUT QUALITY

The next step after completed cutting process is the cut quality checking. In this process, the specimen will go through the analyzing step to determine the cut quality for each experiment test. The process of the checking quality will be explained below.

3.8.1 Checking the width Heat affected zone (HAZ)

To determine the HAZ, it will require the Image Analyzer to do the job. The specimen will be drag into image analyzer where the part which involves HAZ (cut surface) will be examined. The microstructure under goes effect of HAZ will be captured. The less of HAZ will increase the cut quality.



Figure 3.12: Optical Microscope with analyzer ProgRes C3

3.8.2 Checking the surface roughness

Mahrsurf XR 20 Perthometer S2 will be used to determine the surface roughness. The specimen will be held still and the pointer sensor will be move on the surface of the cut. Three reading will be considering along the part so that to obtain the average of the reading.



Figure 3.13: Mahrsurf XR 20 Perthometer S2

3.9 SAFETY AND PRECAUTION

Safety and precaution steps are very important matters to keep in mind when handling the laser machine. Every process involve during the experiment has its own safety and precaution steps to be follow. Below are the safety and precaution steps for every process in this experiment.

3.9.1 Safety and precaution steps for cutting Raw material.

List of safety and precaution steps to be obey during conducting experiment:

- I. One must wear eye protection when conducting the laser machine or in the same area as an exposed laser beam. CO_2 Laser radiation can be reflected from metallic object even though the surface is darkened. Direct or diffuse laser radiation can inflict severe corneal injuries leading to eye damage or blind.

- II. Acrylic sheet going under laser state can generate air contaminant that is toxic to human. One must use suitable mask in order to curb this problem. Material Safety Data Sheets (MSDS) for acrylic must be thoroughly evaluated and adequacy of provisions for fume extraction, filtering and venting should be consider.

- III. Do not place any miscellaneous item along the cutting path.

3.9.2 Safety and Precaution steps for analyzing the specimen

List of safety and precaution steps to be obey during the analyzing process:

- I. Make sure the lighting condition is in well condition so that the clearer image can be captured.

- II. Take image from the middle of the cut surface because the data obtain at the middle is more stable compare to both ends.

- III. Measurement must be taken carefully so that the parallax error can be reduced.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In chapter 4 will discuss more on the results and discussion of this project. The results are obtained from the Perthometer machine to measure surface roughness and the Image Analyzer to measure heat affected zone HAZ. From forty samples specimens, that is acrylic, four values have been tabled for each specimen, and the average of surface roughness will be calculated. As for heat affected zone HAZ, the image of the affect surface will be captured. The results are then analyzed to see the effect of the acrylic surface when changing the parameters of the laser machine.

4.2 EXPERIMENT RESULTS

Based on Chapter 3 Methodology, the laser parameters were setup using Response Surface Method (RSM). With five parameters, the numbers of experiment to be completed is 243 experiments. RSM have narrowed these 243 experiments into only 40 effective experiment tests. Means that only these 40 experiments test give the significant result in terms of surface roughness and heat affected zone (HAZ). The cutting parameters were set up before cutting process begins. Table 4.1 shows the parameters used for cutting condition. Figure 4.1 shows the PCNC laser cutting machine in UMP FKM. Figure 4.2 shows the head of the PCNC laser cutting machine that generate laser beam.

Table 4.1: Laser cutting Parameters

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



Figure 4.1: ILIOS CO_2 30 W Laser Machine System

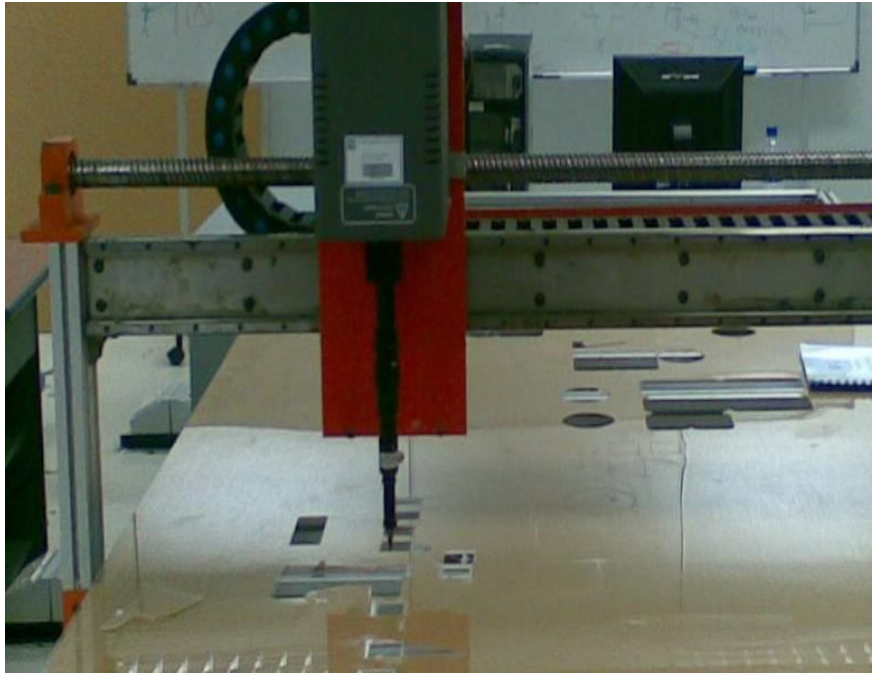


Figure 4.2: Laser Head

Next the cutting process will be starting to cut the acrylic into specimen with design of square shape. The data for surface roughness will be analyzed from 3 sides of the specimen and the average of the surface roughness will be calculated. This to ensure the results is precise as the surface contact with laser beam is in square shape. As for heat affected zone (HAZ), two surfaces will be analyzed from the specimen and based on 20 experiments. Figure 4.1 below shows the sample specimen of acrylic.



Figure 4.3: Sample specimen

4.2.1 Surface roughness, Ra results

From the experiments conducted, the specimens were taken for analyzing the surface roughness, Ra. Using Mahrsurf XR 20 Perthometer S2, all 40 specimens go through the procedure. Data of surface roughness obtain from the perthometer will be collected and recorded. Table 4.2 below shows the surface roughness for 40 significant experiments test. It is from 3 surfaces of the specimen and the average of the Ra calculated.

Table 4.2: Average Surface Roughness, Ra

No. of test	Parameters	Surface Roughness, Ra (μm)			
		Reading 1	Reading 2	Reading 3	Average
1	Nozzle Gap = 6 mm				
	Air Pressure = 3 bar				
	Cutting Angle = 6°	0.657	0.642	0.653	0.6507
	Laser Power = 28.5 W				

	Cutting Speed =	1200 pulse/s				
	Nozzle Gap =	4.5 mm				
	Air Pressure =	2 bar				
2	Cutting Angle =	0°	0.627	0.638	0.629	0.6313
	Laser Power =	28.5 W				
	Cutting Speed =	1200 pulse/s				
	Nozzle Gap =	6 mm				
	Air Pressure =	0 bar				
3	Cutting Angle =	2°	0.554	0.545	0.536	0.5450
	Laser Power =	27.5 W				
	Cutting Speed =	1200 pulse/s				
	Nozzle Gap =	1 mm				
	Air Pressure =	1 bar				
4	Cutting Angle =	6°	0.660	0.672	0.681	0.6710
	Laser Power =	26.5 W				
	Cutting Speed =	1200 pulse/s				
	Nozzle Gap =	2.5 mm				
	Air Pressure =	3 bar				
5	Cutting Angle =	4°	0.592	0.609	0.611	0.6040
	Laser Power =	25.5 W				
	Cutting Speed =	1200 pulse/s				
	Nozzle Gap =	6 mm				
	Air Pressure =	3 bar				
6	Cutting Angle =	0°	0.950	0.912	0.899	0.9203
	Laser Power =	26.5 W				
	Cutting Speed =	1000 pulse/s				
	Nozzle Gap =	1 mm				
	Air Pressure =	3 bar				
7	Cutting Angle =	2°	3.596	3.327	3.381	3.4347
	Laser Power =	28.5 W				
	Cutting Speed =	900 pulse/s				
	Nozzle Gap =	4.5 mm				
	Air Pressure =	3 bar				
8	Cutting Angle =	6°	0.931	0.887	1.002	0.9400
	Laser Power =	27.5 W				
	Cutting Speed =	1100 pulse/s				
	Nozzle Gap =	2.5 mm				
	Air Pressure =	0 bar				
9	Cutting Angle =	6°	0.718	0.693	0.756	0.7223
	Laser Power =	28.5 W				
	Cutting Speed =	1000 pulse/s				
	Nozzle Gap =	6 mm				
	Air Pressure =	2 bar				
10	Cutting Angle =	6°	1.144	1.279	1.093	1.1720
	Laser Power =	25.5 W				
	Cutting Speed =	900 pulse/s				
	Nozzle Gap =	6 mm				
	Air Pressure =	2 bar				
11	Cutting Angle =	4°	0.832	0.849	0.894	0.8583

	Laser Power =	28.5 W				
	Cutting Speed =	1100 pulse/s				
12	Nozzle Gap =	2.5 mm				
	Air Pressure =	1 bar				
	Cutting Angle =	0°	1.118	1.231	1.192	1.1803
	Laser Power =	27.5 W				
	Cutting Speed =	900 pulse/s				
13	Nozzle Gap =	4.5 mm				
	Air Pressure =	0 bar				
	Cutting Angle =	4°	1.113	1.194	1.187	1.1647
	Laser Power =	26.5 W				
	Cutting Speed =	900 pulse/s				
14	Nozzle Gap =	1 mm				
	Air Pressure =	2 bar				
	Cutting Angle =	4°	0.811	0.795	0.835	0.8137
	Laser Power =	27.5 W				
	Cutting Speed =	1000 pulse/s				
15	Nozzle Gap =	4.5 mm				
	Air Pressure =	1 bar				
	Cutting Angle =	2°	0.954	0.918	0.898	0.9233
	Laser Power =	25.5 W				
	Cutting Speed =	1000 pulse/s				
16	Nozzle Gap =	2.5 mm				
	Air Pressure =	2 bar				
	Cutting Angle =	2°	1.191	1.217	1.173	1.1937
	Laser Power =	26.5 W				
	Cutting Speed =	1000 pulse/s				
17	Nozzle Gap =	1 mm				
	Air Pressure =	0 bar				
	Cutting Angle =	0°	0.656	0.573	0.631	0.6200
	Laser Power =	25.5 W				
	Cutting Speed =	1100 pulse/s				
18	Nozzle Gap =	2.5 mm				
	Air Pressure =	2 bar				
	Cutting Angle =	2°	0.664	0.682	0.707	0.6843
	Laser Power =	26.5 W				
	Cutting Speed =	1100 pulse/s				
19	Nozzle Gap =	4.5 mm				
	Air Pressure =	3 bar				
	Cutting Angle =	2°	2.024	1.991	2.089	2.0347
	Laser Power =	27.5 W				
	Cutting Speed =	900 pulse/s				
20	Nozzle Gap =	1 mm				
	Air Pressure =	1 bar				
	Cutting Angle =	2°	0.822	0.898	0.918	0.8793
	Laser Power =	25.5 W				
	Cutting Speed =	1200 pulse/s				
21	Nozzle Gap =	1 mm				
	Air Pressure =	3 bar	0.478	0.460	0.513	0.4837

	Cutting Angle =	4°				
	Laser Power =	26.5 W				
	Cutting Speed =	1100 pulse/s				
22	Nozzle Gap =	6 mm				
	Air Pressure =	1 bar				
	Cutting Angle =	4°	0.540	0.573	0.587	0.5667
	Laser Power =	27.5 W				
	Cutting Speed =	1000 pulse/s				
23	Nozzle Gap =	1 mm				
	Air Pressure =	2 bar				
	Cutting Angle =	6°	0.712	0.690	0.794	0.7320
	Laser Power =	27.5 W				
	Cutting Speed =	1100 pulse/s				
24	Nozzle Gap =	4.5 mm				
	Air Pressure =	2 bar				
	Cutting Angle =	4°	0.474	0.496	0.522	0.4973
	Laser Power =	25.5 W				
	Cutting Speed =	1200 pulse/s				
25	Nozzle Gap =	4.5 mm				
	Air Pressure =	1 bar				
	Cutting Angle =	6°	0.559	0.532	0.547	0.5460
	Laser Power =	26.5 W				
	Cutting Speed =	900 pulse/s				
26	Nozzle Gap =	4.5 mm				
	Air Pressure =	0 bar				
	Cutting Angle =	2°	0.491	0.509	0.483	0.4943
	Laser Power =	28.5 W				
	Cutting Speed =	1100 pulse/s				
27	Nozzle Gap =	2.5 mm				
	Air Pressure =	0 bar				
	Cutting Angle =	0°	0.583	0.523	0.544	0.5500
	Laser Power =	27.5 W				
	Cutting Speed =	1200 pulse/s				
28	Nozzle Gap =	1 mm				
	Air Pressure =	2 bar				
	Cutting Angle =	0°	0.811	0.794	0.820	0.8083
	Laser Power =	28.5 W				
	Cutting Speed =	900 pulse/s				
29	Nozzle Gap =	1 mm				
	Air Pressure =	0 bar				
	Cutting Angle =	6°	0.668	0.650	0.693	0.6770
	Laser Power =	25.5 W				
	Cutting Speed =	1000 pulse/s				
30	Nozzle Gap =	6 mm				
	Air Pressure =	3 bar				
	Cutting Angle =	0°	0.656	0.647	0.639	0.6473
	Laser Power =	25.5 W				
	Cutting Speed =	1100 pulse/s				
31	Nozzle Gap =	2.5 mm	0.744	0.704	0.738	0.7287

	Air Pressure =	0 bar				
	Cutting Angle =	4°				
	Laser Power =	25.5 W				
	Cutting Speed =	900 pulse/s				
32	Nozzle Gap =	6 mm				
	Air Pressure =	1 bar				
	Cutting Angle =	2°	0.720	0.699	0.711	0.7100
	Laser Power =	26.5 W				
	Cutting Speed =	900 pulse/s				
33	Nozzle Gap =	2.5 mm				
	Air Pressure =	1 bar				
	Cutting Angle =	6°	0.566	0.573	0.555	0.5647
	Laser Power =	28.5 W				
	Cutting Speed =	1100 pulse/s				
34	Nozzle Gap =	4.5 mm				
	Air Pressure =	3 bar				
	Cutting Angle =	0°	0.540	0.553	0.527	0.5400
	Laser Power =	26.5 W				
	Cutting Speed =	1000 pulse/s				
35	Nozzle Gap =	2.5 mm				
	Air Pressure =	3 bar				
	Cutting Angle =	4°	0.653	0.644	0.673	0.6567
	Laser Power =	28.5 W				
	Cutting Speed =	1000 pulse/s				
36	Nozzle Gap =	1 mm				
	Air Pressure =	0 bar				
	Cutting Angle =	4°	0.538	0.561	0.582	0.5603
	Laser Power =	26.5 W				
	Cutting Speed =	1200 pulse/s				
37	Nozzle Gap =	6 mm				
	Air Pressure =	2 bar				
	Cutting Angle =	4°	0.773	0.780	0.724	0.7590
	Laser Power =	28.5 W				
	Cutting Speed =	900 pulse/s				
38	Nozzle Gap =	2.5 mm				
	Air Pressure =	3 bar				
	Cutting Angle =	6°	0.660	0.647	0.701	0.6693
	Laser Power =	25.5 W				
	Cutting Speed =	900 pulse/s				
39	Nozzle Gap =	2.5 mm				
	Air Pressure =	1 bar				
	Cutting Angle =	0°	0.679	0.638	0.695	0.6707
	Laser Power =	26.5 W				
	Cutting Speed =	1100 pulse/s				

	Nozzle Gap =	6 mm			
	Air Pressure =	2 bar			
40	Cutting Angle =	6°	0.821	0.799	0.846
	Laser Power =	26.5 W			0.8220
	Cutting Speed =	1200 pulse/s			

From the data above, the graph will be plotted in order to analyze the surface roughness, Ra. For 40 experiments test, graph surface roughness, Ra vs. no. of experiments plotted. Figure 4.4 shows the graph of surface roughness, Ra vs. no. of experiments. It also shows the lowest Ra value; hence it is the best surface roughness.

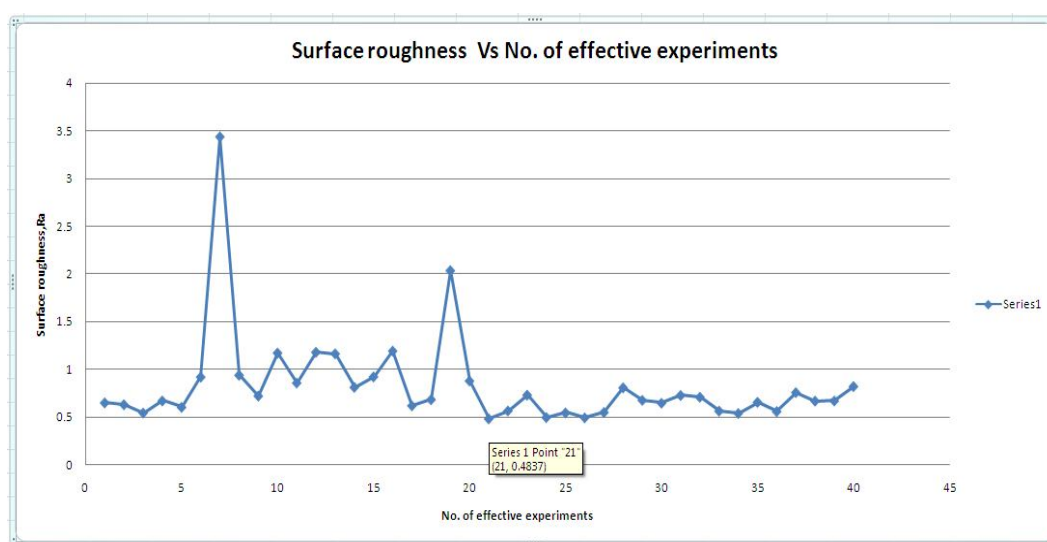


Figure 4.4: Graph of Surface roughness, Ra Vs No. of effective experiments

From the graph above, it shows that the lowest surface roughness, Ra value is at point 21 that is experiment no. 21 recorded the best surface roughness, Ra = 0.4837 μm . For this case, experiment test no. 21 consist parameters of:

Nozzle Gap =	1 mm
Air Pressure =	3 bar
Cutting Angle =	4°
Laser Power =	26.5 W
Cutting Speed =	1100 pulse/s

Figure 4.5: Specific parameter of experiment test no.21

As refer to Figure 4.5 above, observed that the parameters that produce the lowest surface roughness value, Ra are with nozzle gap of 1mm, air pressure of 3 bar, cutting angle of 4°, laser power of 26.5 W and lastly the cutting speed of 1100 pulse/s.

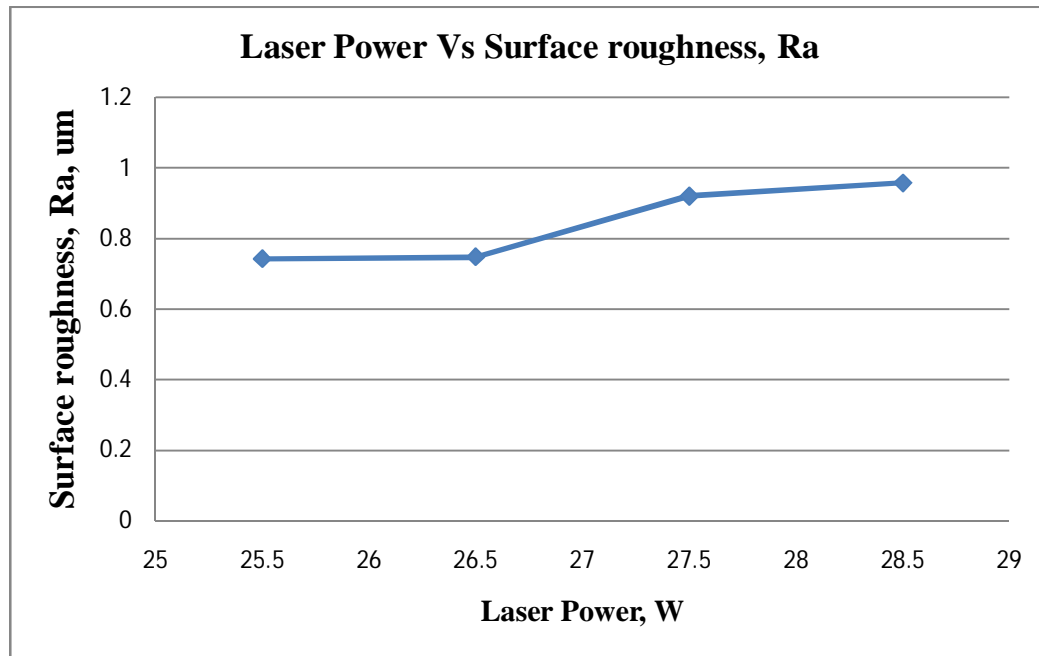


Figure 4.6: Graph of Laser Power Vs Surface Roughness, Ra

From the graph above, we can observe that the surface roughness, Ra is increasing proportionally as the amount of laser power is increase. As the level of laser power ascending, it also affects the value of surface roughness, Ra to rise.

This can be explaining by referring to the power of the laser itself. More power applied to the acrylic sheet means the area contact with heat will be sufficiently distributed hence it will results in a low value of surface roughness.

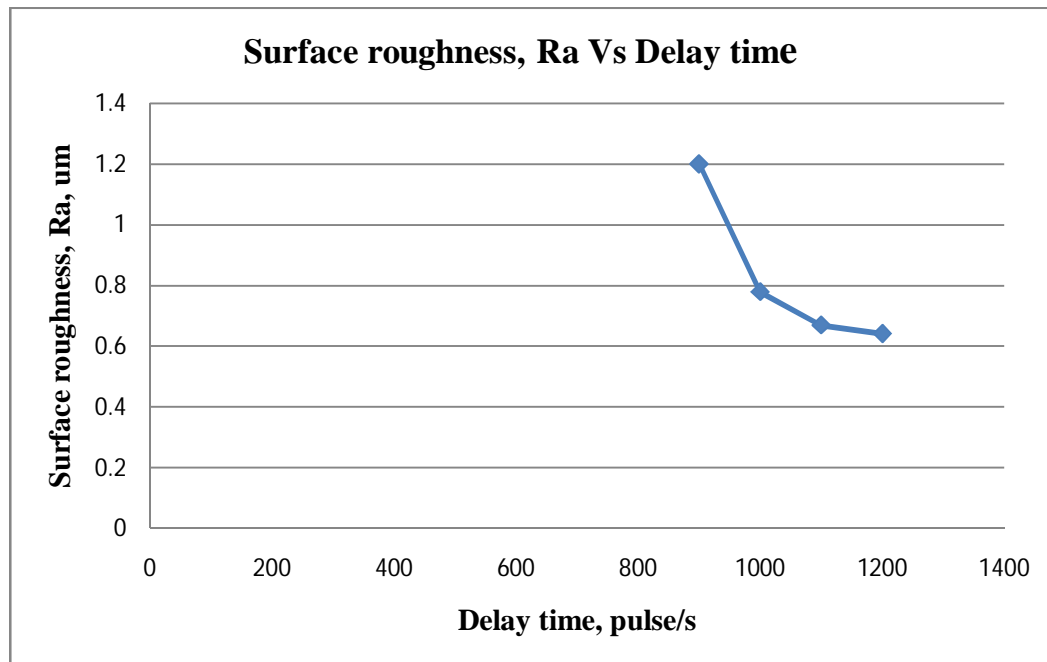


Figure 4.7: Graph of Surface roughness, Ra Vs Delay time

From the graph above, can be view that the surface roughness, Ra is indirectly proportional to the delay time. As delay time increase or in other words the cutting decrease, it produces higher value of surface roughness, Ra or low surface finish.

This is occurred because of the delay time of cutting, as delay time increases the cutting speed do decrease, when this happen the surface contact will have the heat more to melt the surface finely.

4.2.2 Width Heat affected zone (HAZ) Analysis

Table 4.3: Average width of heat affected zone (HAZ)

No. of test	Parameters	Width of heat affected zone, HAZ (mm)		
		Reading 1	Reading 2	Average
11	Nozzle Gap = 6 mm Air Pressure = 2 bar	0.6775	0.6771	0.6773

	Cutting Angle =	4°			
	Laser Power =	28.5 W			
	Cutting Speed =	1100 pulse/s			
12	Nozzle Gap =	2.5 mm			
	Air Pressure =	1 bar			
	Cutting Angle =	0°	0.5928	0.5922	0.5925
	Laser Power =	27.5 W			
	Cutting Speed =	900 pulse/s			
13	Nozzle Gap =	4.5 mm			
	Air Pressure =	0 bar			
	Cutting Angle =	4°	0.5953	0.5975	0.5964
	Laser Power =	26.5 W			
	Cutting Speed =	900 pulse/s			
14	Nozzle Gap =	1 mm			
	Air Pressure =	2 bar			
	Cutting Angle =	4°	0.6351	0.6360	0.6356
	Laser Power =	27.5 W			
	Cutting Speed =	1000 pulse/s			
15	Nozzle Gap =	4.5 mm			
	Air Pressure =	1 bar			
	Cutting Angle =	2°	0.6293	0.6289	0.6291
	Laser Power =	25.5 W			
	Cutting Speed =	1000 pulse/s			
16	Nozzle Gap =	2.5 mm			
	Air Pressure =	2 bar			
	Cutting Angle =	2°	0.6327	0.6334	0.6331
	Laser Power =	26.5 W			
	Cutting Speed =	1000 pulse/s			
17	Nozzle Gap =	1 mm			
	Air Pressure =	0 bar			
	Cutting Angle =	0°	0.6689	0.6676	0.6683
	Laser Power =	25.5 W			
	Cutting Speed =	1100 pulse/s			
18	Nozzle Gap =	2.5 mm			
	Air Pressure =	2 bar			
	Cutting Angle =	2°	0.6702	0.6717	0.6710
	Laser Power =	26.5 W			
	Cutting Speed =	1100 pulse/s			
19	Nozzle Gap =	4.5 mm			
	Air Pressure =	3 bar			
	Cutting Angle =	2°	0.5911	0.5903	0.5907
	Laser Power =	27.5 W			
	Cutting Speed =	900 pulse/s			
20	Nozzle Gap =	1 mm			
	Air Pressure =	1 bar			
	Cutting Angle =	2°	0.7024	0.7032	0.7028
	Laser Power =	25.5 W			
	Cutting Speed =	1200 pulse/s			

21	Nozzle Gap =	1 mm	0.6106	0.6099	0.6103
	Air Pressure =	3 bar			
	Cutting Angle =	4°			
	Laser Power =	26.5 W			
	Cutting Speed =	1100 pulse/s			
22	Nozzle Gap =	6 mm	0.6348	0.6355	0.6352
	Air Pressure =	1 bar			
	Cutting Angle =	4°			
	Laser Power =	27.5 W			
	Cutting Speed =	1000 pulse/s			
23	Nozzle Gap =	1 mm	0.6751	0.6758	0.6755
	Air Pressure =	2 bar			
	Cutting Angle =	6°			
	Laser Power =	27.5 W			
	Cutting Speed =	1100 pulse/s			
24	Nozzle Gap =	4.5 mm	0.6992	0.6983	0.6986
	Air Pressure =	2 bar			
	Cutting Angle =	4°			
	Laser Power =	25.5 W			
	Cutting Speed =	1200 pulse/s			
25	Nozzle Gap =	4.5 mm	0.5907	0.5898	0.5903
	Air Pressure =	1 bar			
	Cutting Angle =	6°			
	Laser Power =	26.5 W			
	Cutting Speed =	900 pulse/s			
26	Nozzle Gap =	4.5 mm	0.6821	0.6819	0.6820
	Air Pressure =	0 bar			
	Cutting Angle =	2°			
	Laser Power =	28.5 W			
	Cutting Speed =	1100 pulse/s			
27	Nozzle Gap =	2.5 mm	0.7134	0.7127	0.7131
	Air Pressure =	0 bar			
	Cutting Angle =	0°			
	Laser Power =	27.5 W			
	Cutting Speed =	1200 pulse/s			
28	Nozzle Gap =	1 mm	0.5966	0.5983	0.5975
	Air Pressure =	2 bar			
	Cutting Angle =	0°			
	Laser Power =	28.5 W			
	Cutting Speed =	900 pulse/s			
29	Nozzle Gap =	1 mm	0.6284	0.6293	0.6289
	Air Pressure =	0 bar			
	Cutting Angle =	6°			
	Laser Power =	25.5 W			
	Cutting Speed =	1000 pulse/s			

	Nozzle Gap =	6 mm			
	Air Pressure =	3 bar			
30	Cutting Angle =	0	0.6693	0.6701	0.6697
	Laser Power =	25.5 W			
	Cutting Speed =	1100 pulse/s			

From the data above, the graph will be plotted in order to analyze the width of heat affected zone (HAZ). For 20 experiments test, graph width of heat affected zone (HAZ) vs. no. of experiments plotted. Figure 4.5 shows the graph of average width of heat affected zone (HAZ) vs. no. of experiments. It also shows the lowest width of heat affected zone (HAZ) value; hence it is the best width of heat affected zone (HAZ).

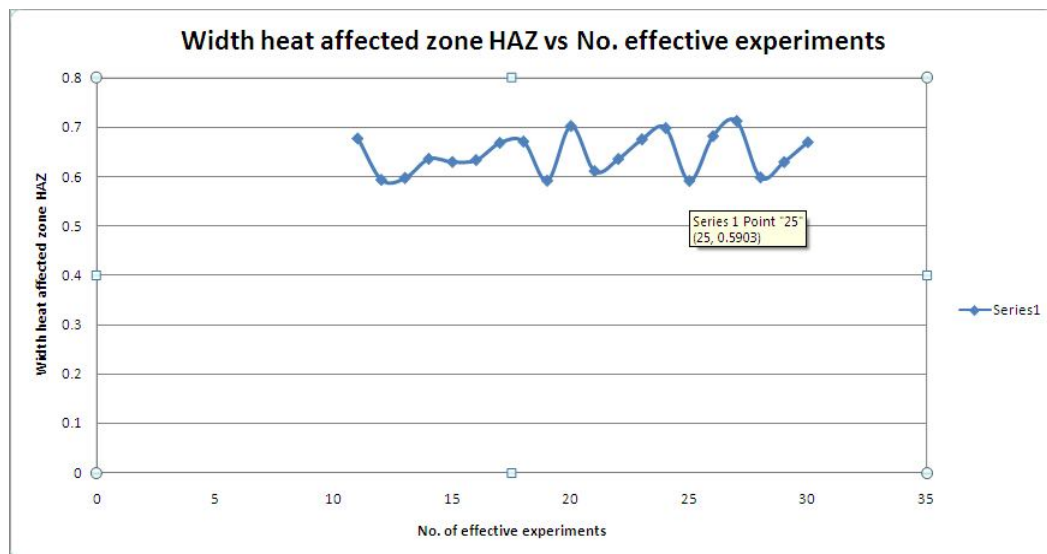


Figure 4.8: Graph of average width of heat affected zone (HAZ) vs. no. of experiments

From the graph above, it shows that the lowest average width of heat affected zone (HAZ) value is at point 25 that is experiment no. 25 recorded the best average width of heat affected zone (HAZ) = 0.5903. For this case, experiment test no. 25 consist parameters of:

Nozzle Gap =	4.5 mm
Air Pressure =	1 bar
Cutting Angle =	6
Laser Power =	26.5 W

Cutting Speed =	900 pulse/s
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Figure 4.9: Specific parameters of experiment test no. 25

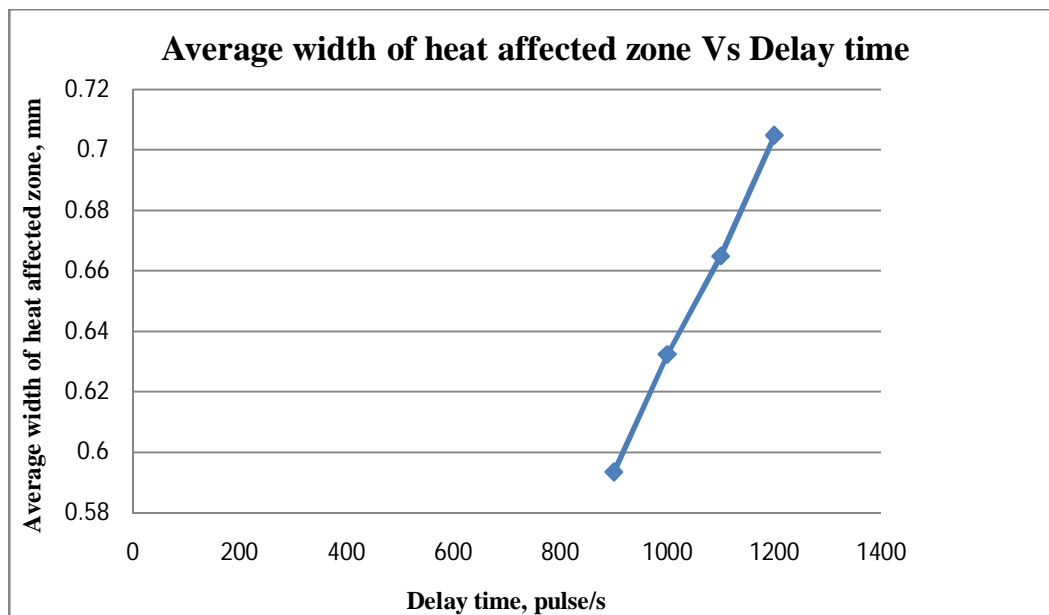


Figure 4.10: Graph of Average width of heat affected zone Vs Delay time

From the graph above, observed that the average width of heat affected zone is directly proportional to the delay time. As the delay time increase similarly, the average width of heat affected zone (HAZ) also increase. The higher the delay time or in other words is the cutting speed lower; it will result in high value of width of heat affected zone (HAZ). This means the surface quality have been downgrade. This occurred because the slower the cutting speed or the time contact of the laser beam to the surface is longer, it cut through the material with distributing the heat of the laser beam evenly thus a finely surface finish obtained. Besides that the structure of the material does not get over burned that contribute to a higher width of heat affected zone (HAZ).

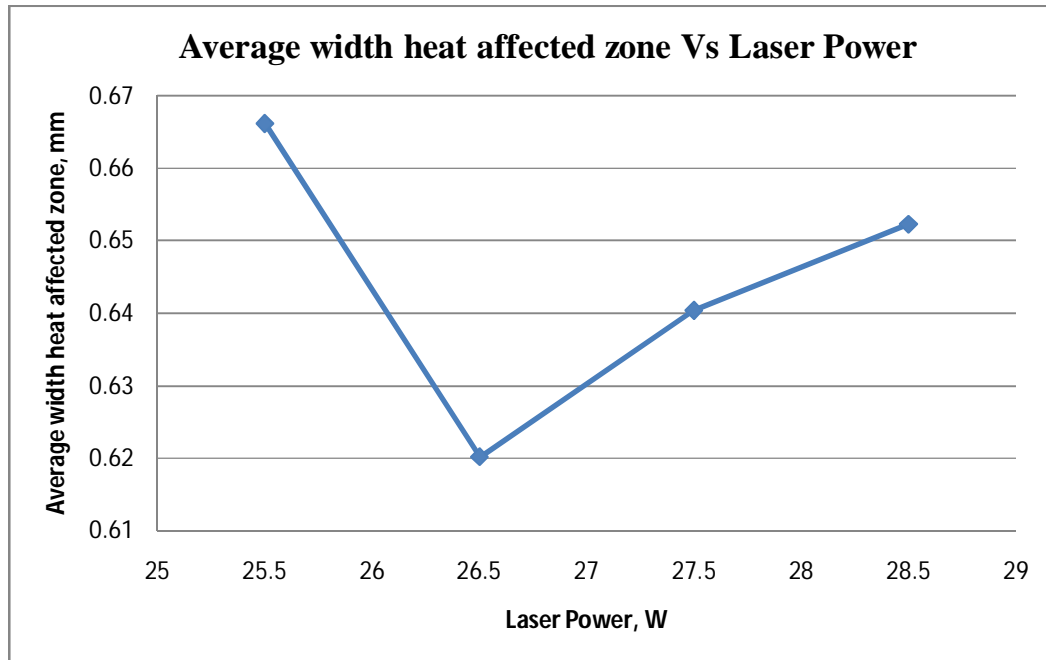


Figure 4.11: Graph of Average width heat affected zone Vs Laser Power

From the graph above, the average width heat affected zone (HAZ) is proportional to the amount of laser power from laser power of 26.5 W to 28.5 W. But from laser power of 25.5 W it is indirectly proportional to the amount of laser power until laser power of 26.5 W. Generally as the laser power increase the average width of heat affected zone (HAZ) do also increase. This happen because the laser power is to provide enough heat to melt the surface of the material, but this applied only with ample laser power not with exceeded laser power.

4.3 RESULTS AND DISCUSSION

4.3.1 Discussion on the surface roughness due to parameters

Nozzle gap with distance 1mm from acrylic sheet to the laser beam front nozzle produce lowest surface roughness because the nozzle direct the laser beam through the acrylic sheet and thus provide enough power to cut the acrylic with lower surface roughness. Another parameter contribute to this lowest surface roughness is air pressure of 3 bar. Literally with the assist of air pressure, it can help to eject the molten material that occurs during the cutting. 3 bar of pressure can produce a gas jet that blows rapidly to eject all the unwanted molten material. This contributes to a finer surface finish.

Cutting angle also is one of the factors that play an important role in making a surface finer. It works by giving pathway to the molten material by being easily ejected from the cutting surface. For this particular experiment test, with angle of 4° gives the best result in reducing the surface roughness and heat affected zone.

Beside all the previous parameter, Laser power was also included. With ample laser power, the laser beam yielded can cut the acrylic sheet smoothly and at the same time will decrease the heat affected zone (HAZ) directly lessen the surface roughness, Ra that is so essential to meet a good surface finish.

The last parameter, cutting speed at higher delay causes the Ra to be smaller by theory. But for this special case it needs cutting speed of 1100 pulse/s to broaden the molten area of the acrylic during cutting process. The heat transfer from laser beam to specimen surface higher than the acrylic specimen can melted more material and the complete cutting is obtained. [A. Lamikiz, L.N.L. Lacalle, J.A. Sanchez, D. Pozo, J.M. Etayo and J.M. Lopez, (2005)] At higher cutting speed, the acrylic specimen absorbs lower heat from laser beam cause the surface incomplete melted and ejection of melted also not fully done during cutting process.

4.3.2 Discussion on heat affected zone HAZ

From Figure 4.5, the structure from top to bottom of specimen does not have the same structure in terms of heat affected zone HAZ. At the top of the specimen, the

microstructure shows that the HAZ is not occur so much as the heat distribute evenly when cutting process take place. The mechanical properties do change as the microstructure change due to laser beam heat. The width of this heat affected zone occurred after the cutting process took place. This affected surface is composed of parent metal that did not melt but was heated to a high enough temperature for a sufficient period that grain growth occurred and this width is essential to determine the cut quality. The less the width of heat affected zone, the higher quality the workpiece will be.

As for the bottom of the specimen, HAZ occur more than the top but still in small amount. The reason HAZ at bottom more than the top is the molten material that produced during cutting gathers at the bottom. Again it is still in a small amount of value due to the assist jet gas that ejected the molten metal before they cooled down. In this research, observed that with a good combination of parameters, it can upgrade the quality of the workpiece by lessen the width of heat affected zone (HAZ). As in Figure 4.9, the parameters that give the lowest width of heat affected zone are nozzle gap of 4.5mm, air pressure of 1 bar, cutting angle of 6° , laser power of 26.5 W and cutting speed of 900 pulse/s. [S.-H. Lim, C.-M. Lee and W.J. Chung, (2006)]

These parameters contribute to a smallest value of width of heat affected zone. With suitable distance of nozzle to the workpiece it will affect the surface of the heat affected zone. Same applies to the air pressure, efficient gas jet could help to eject the unwanted molten metal to give lower width of heat affected zone. Cutting angle and laser power is also the same. Lastly for cutting speed it needs higher cutting speed to achieve good surface finish.

4.3.3 Different between actual designs and SOLIDWORK design

Commonly, in cutting process will have some problems that will occurred after undergoes cutting process. The cutting process do not gives exact dimensions as been

designed initially. The specimen designed using SOLID WORK slightly does not same in terms of dimension. The dimension of specimen produced is less than the actual design. These different in shape is caused by the laser beam is not at its sharpness and defocusing to specimen surface.

It maybe because of the laser nozzle don't install firmly with the laser head thus, resulting in defect in dimension. The real problem is when to assemble the parts that cut by using laser machine; it can be assemble firmly and properly. Parts can results in created gap between parts.

4.3.4 Discussion on error

Errors do occurred during cutting process and cut quality checking process. The laser cutting machine used in this project is not fully good enough to cut the material because this laser was actually design to engraving a material. But this laser machine somehow can cut material with low melting point as acrylic sheet. It also applied to certain thickness of acrylic sheet. This is cause of the sharpness of the laser or the limited laser power.

Quality checking process, there has some error during the process of analysis the surface roughness and the heat affected zone. The PERTHOMETER analyzer reader first has to be aligning using the reference material. If we have align by refer to the surface of the ready material, it will not consistently same throughout the analyze process. Image Analyzer can contribute some error when comes to take the surface of specimen. Sometimes the specimen surface does not smoothly taking care off.

Other than that, the environmental factors such as lack of skills handling the laser machine, temperature surrounding and humidity.

4.4 Conclusion

Generally, this chapter have briefly discuss on results of the experiment conducted. The results that obtained were genuinely taken based on the experiment conducted. This chapter also discussed the error that effect the reading of the analyze data. Procedures should be abided completely in order to reduce the error. Lastly, the overall summary of this project will be concluded in next chapter 5 .

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This FYP project has achieved two objectives, which is the analysis of the heat affected zone HAZ and the surface roughness on acrylic sheet by using PCNC laser machine.

5.2 CONCLUSION

Considering the parameters used in this project, it will produced rather low surface roughness, Ra and reduced width heat affected zone on the material undergoes laser machine. With certain amount of laser power, cutting speed, nozzle gap, cutting angle and air pressure it will give best results. Based on the outcome from the results and discussion, it can be concluded that this project is successfully achieving the objectives with acceptable results.

Based on the parameter that produce the lowest value of surface roughness, Ra as well as the heat affected zone HAZ, Laser power of 26.5 W, nozzle gap of 1mm, cutting angle of 4°, cutting speed of 1100 pulse / s and air pressure of 3 bar are the acceptable parameters. As for width of heat affected zone, nozzle gap of 4.5mm, air pressure of 1 bar, cutting angle of 6°, laser power of 26.5 W and cutting speed of 900 pulse/s.

5.3 RECOMMENDATION

Some recommendation are to be suggest for future research based on the results and finding of this FYP project. The recommendations are as follows:

- i. Use another method of analyzes the data collected such as ANOVA, regression method and Taguchi method to have the optimum level of parameters.
- ii. If can use a PCNC laser machine that offers more laser power output, so that it can used to cut material with more extreme mechanical properties.
- iii. Instead of using image analyzer, use Scanning Electron Microscope (SEM) to see more accurate microstructure.
- iv. Do more analysis on laser properties such as tapper to further more the research on characteristic of laser machine.

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APPENDIX

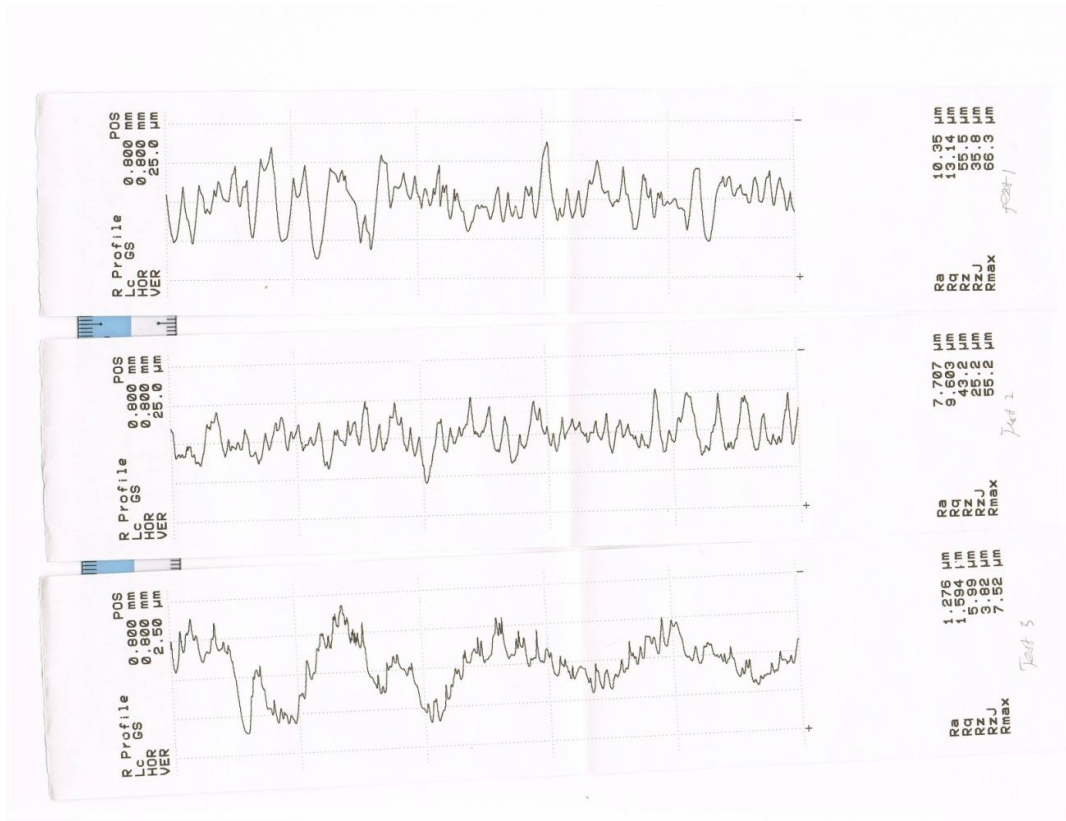


Figure 1: Sample of result for surface roughness

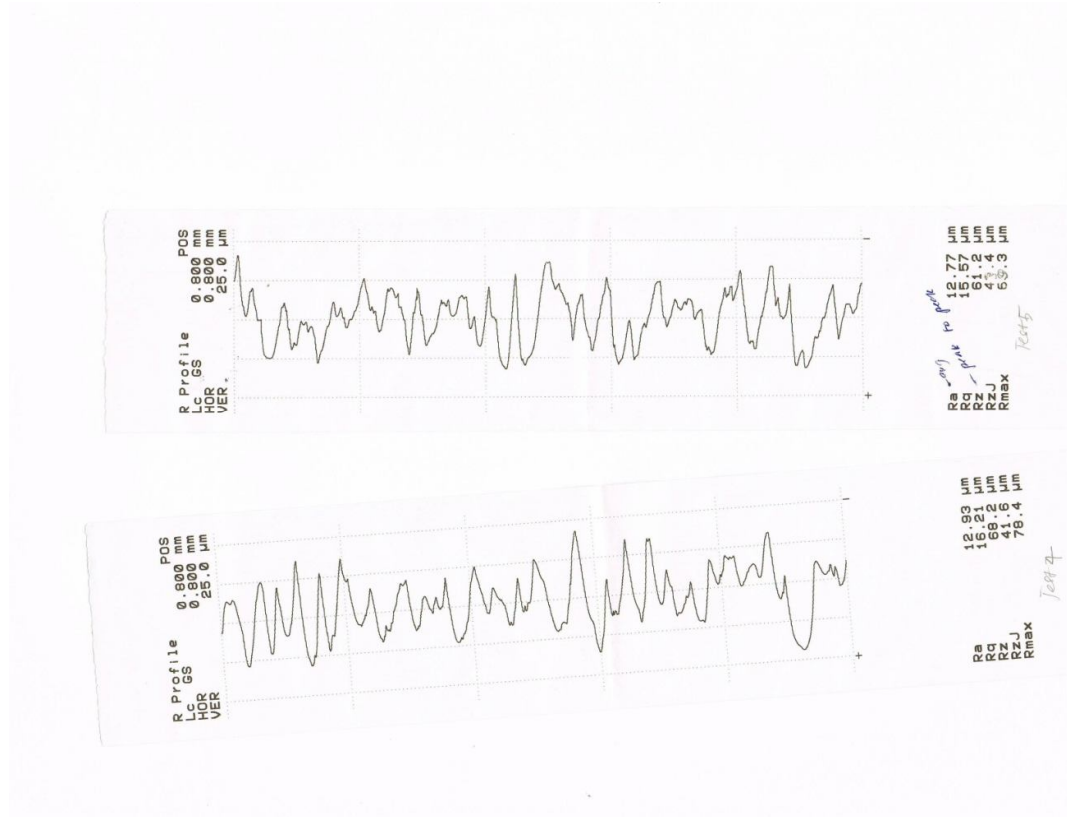


Figure 2: Sample of result for surface roughness

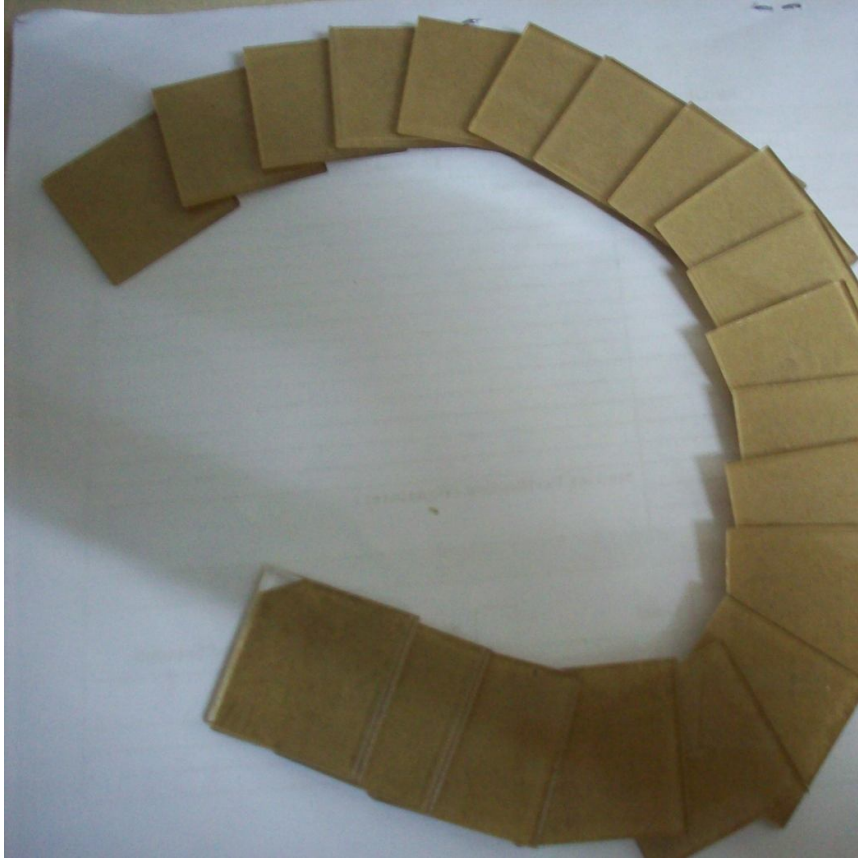


Figure 3: Sample of specimens

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
Literature Review	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Project Briefing		■												
Laser Machine Study						■	■	■	■	■				
Material Request							■	■						
Preliminary Experiment												■	■	
Submit Chapters											■	■	■	
Submit Technical Report and Slide Presentation												■	■	
Presentation Preparation													■	
FYP 1 Presentation														■

Figure 4: Gantt chart FYP 1

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		■	■	■	■	■										
HAZ analysis							■	■	■	■						
Surface Roughness analysis							■	■	■	■						
Results analysis										■	■					
Prepare all Chapters					■	■	■	■	■	■	■	■				
Report Writing										■	■	■	■	■		
Presentation Preparation															■	
FYP 2 Presentation																■

Figure 5: Gantt chart FYP 2