

CARBON DIOXIDE (CO<sub>2</sub>) LASER CUT QUALITY OF  
ACRYLIC

AHMAD SHAZWI BIN KAMARUZAMAN

UNIVERSITI MALAYSIA PAHANG

CARBON DIOXIDE (CO<sub>2</sub>) LASER CUT QUALITY OF ACRYLIC

AHMAD SHAZWI BIN KAMARUZAMAN

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

Faculty of Mechanical Engineering  
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2008

### SUPERVISOR'S DECLARATION

“We hereby declare that we have checked this thesis and in our opinion this project is sufficient in terms of scope and quality for the purpose of the degree of Bachelor of Mechanical Engineering.”

Signature : .....  
Name of Supervisor : Nurul Shahida Binti Mohd Shalahim  
Position : Supervisor  
Date : .....

Signature : .....  
Name of Panel : Zamri Bin Mohamed  
Position : Panel  
Date : .....

### STUDENT'S DECLARATION

I hereby declare that this thesis entitled "Carbon dioxide (CO<sub>2</sub>) laser cut quality of Acrylic" is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature : .....

Name : AHMAD SHAZWI BIN KAMARUZAMAN

ID Number : MA05055

Date : .....

## **ACKNOWLEDGEMENTS**

Foremost, I would like to thank to ALLAH S.W.T for blessing me in finishing my thesis with success in achieving my objectives.

My grateful thanks to my supervisor Puan Nurul Shahida Shalahim and co-supervisor Mr Mahendran A/L Samykano for their guidance, encouragement, enthusiasm, inspiration and contribution towards my understanding and completing this thesis successfully.

I wish to thank to the vocational advisor at UMP Mechanical Laboratory, En. Hazami Che Hussain and for his guidance in operating laser cutting machine.

I wish to thank to my housemate, Mohd Nizam Mat Noor, Zairul Ezree, Hazmil Hapaz , Syafiq Nazarudin , Mohd Zaini Jamak for their understanding ,courage and caring they provided. I also want to thank those who involved directly or indirectly towards completing this thesis.

Lastly and most importantly, I wish to thank my parents, Kamaruzaman Mohd and Aida Issi. They have always supported and encouraged me to do my best in all matters of life.

## ABSTRACT

This thesis presents the study of Acrylic were cut on CO<sub>2</sub> laser cutting system and analyze the effects of power on cut quality. There are 2 cut quality involved during this thesis which are surface roughness and kerf width. Manual calculation analysis was used to investigate the effect of power on laser cut quality. The cutting process was implemented at apply power start from 15 – 28.5 W and 10 experiments were conduct during this thesis work. The feed rate will remain as constant variable parameter during this work study. Perthometer and image analyzer are conducted to examine the cut quality. From the analysis done, it was shown that the kerf width and surface roughness depends mainly on the laser power intensity. Power has great significance parameter in terms of improving productivity and good surface finish. As obtained through this thesis study, increasing the power intensity resulted in smaller value of surface roughness, Ra and higher value of kerf width.

## ABSTRAK

Tesis ini membentangkan tentang sampel Acrylic di potong menggunakan mesin pemotong laser karbon dioksida ( $\text{CO}_2$ ) dan mengkaji kesan parameter kuasa terhadap kualiti pemotongan. Sebanyak 2 kualiti pemotongan kualiti terlibat iaitu lebar kerf dan kekasaran permukaan. Kaedah manual pengiraan digunakan bagi mereka bentuk analisis data dan mengkaji kesan kuasa terhadap kualiti pemotongan. Proses pemotongan dijalankan dengan menggunakan kuasa daripada 15 – 28.5 W dan sebanyak 10 eksperimen dijalankan untuk menjayakan tesis ini. Perthometer dan imej analisa digunakan untuk menguji dan mengkaji setiap kualiti pemotongan hasil daripada pemotongan laser. Berdasarkan analisis, ia terbukti dan menunjukkan lebar kerf dan kekasaran permukaan amat bergantung kepada parameter kuasa yang digunakan semasa proses pemotongan. Kuasa merupakan parameter yang penting dalam meningkatkan produktiviti dan menghasilkan permukaan yang baik. Rumusan daripada analisis dan pemerhatian, peningkatan kuasa cenderung menjadikan kerf lebar lebih besar manakala nilai kekasaran permukaan,  $R_a$  menjadi semakin kecil.

## TABLE OF CONTENTS

	<b>Page</b>
<b>SUPERVISOR’S DECLARATION</b>	ii
<b>STUDENT’S DECLARATION</b>	iii
<b>ACKNOWLEDGEMENTS</b>	iv
<b>ABSTRACT</b>	v
<b>ABSTRAK</b>	vi
<b>TABLE OF CONTENTS</b>	vii
<b>LIST OF TABLES</b>	x
<b>LIST OF FIGURES</b>	xi
<b>LIST OF SYMBOLS</b>	xiii
<b>LIST OF ABBREVIATIONS</b>	xiv
<b>CHAPTER 1 INTRODUCTION</b>	
1.0 Introduction	1
1.1 Problem Statement	2
1.2 Objectives	3
1.3 Project Scopes	3
1.4 Thesis organization	4
<b>CHAPTER 2 LITERATURE REVIEW</b>	
2.0 Introduction	5
2.1 Laser	7
2.1.1 The maser	8
2.1.2 The laser	8
2.1.3 Laser chronology	10



2.2	Basic component and working principle	11
2.3	Laser Cutting	13
2.4	CO <sub>2</sub> laser	14
2.5	Acrylic	16
	2.5.1 Advantages and disadvantages of Acrylic	17
	2.5.2 Application of Acrylic	17
2.6	Cut quality	18
	2.6.1 Kerf width	18
	2.6.2 Surface roughness	19

### **CHAPTER 3      METHODOLOGY**

3.0	Introduction	20
3.1	Literature study	20
3.2	Experimental procedure	21
3.3	Experimental parameter	24
3.4	Drawing of sample	25
3.5	Cutting of material	26
3.6	Analyzing of cut quality	27
	3.6.1 Surface roughness	28
	3.6.2 Kerf width	29
3.7	Result analysis	30

### **CHAPTER 4      RESULTS AND DISCUSSION**

4.1	Introduction	31
4.2	Machinery experimental result	32
4.3	Results of surface roughness	38
4.4	Effects of power on surface roughness	40
4.5	Results of kerf width	43

4.6	Effects of power on kerf width	45
4.7	Comparison between theoretical	47
4.8	Error discussion	48

## **CHAPTER 5 CONCLUSION AND RECOMMENDATIONS**

5.1	Conclusions	49
5.2	Recommendations	50

<b>REFERENCES</b>	<b>52</b>
-------------------	-----------

<b>APPENDICES</b>	<b>53</b>
-------------------	-----------

**LIST OF TABLES**

<b>Table No.</b>		<b>Page</b>
2.1.3	Laser chronology	11
2.5	Properties of Acrylic	17
3.3	Data of the experiment	25
3.7	Result data	31
4.2	Parameter of cutting process	33
4.3	Result of surface roughness, $R_a$	40
4.5	Result of kerf width	45

## LIST OF FIGURES

<b>Figure No.</b>		<b>Page</b>
2.0	Flowchart of Chapter 2	6
2.2.1	Electromagnetic waves	11
2.2.2	Basic components of laser	11
2.2.3	Pumping energy	12
2.6.1	Kerf width region	18
2.6.2	Surface roughness structure	19
3.2.1	General flow chat	22
3.2.2	Experiment flow chat	23
3.4	(2-D view) of specimen	25
3.5	Laser Cutting Machine	26
3.6.1.1	Three different points to measure surface roughness	28
3.6.1.2	Perthometer	28
3.6.2.1	Slit region to measure kerf width	29
3.6.2.2	Image Analyzer	29
4.1	Specimen	33
4.1.1	Parameter Setup	34

4.1.2	Move sample to origin	35
4.1.3	Tool Database	35
4.1.4	Sequencing and Material setup	36
4.3	Surface roughness structure after cut using laser cutting machine	38
4.4	Graph Surface Roughness vs. Power	40
4.4.1	Surface roughness at 15 W	42
4.4.2	Surface roughness at 28.5 W	42
4.5	Kerf width structure after cutting using laser cutting machine	43
4.6	Graph kerf width vs. Power	45

**LIST OF SYMBOLS**

W	Watt
Mm	Millimeter
SR	Surface Roughness
R <sub>a</sub>	Coefficient for surface roughness
F	Fahrenheit
C	Celsius
R	Hardness
Hz	Hertz
μm	Micrometer
Cm	Centimeter
μm	Micrometer

**LIST OF ABBREVIATIONS**

EDM	Electro Discharge Machining
UV	Ultraviolet
IR	Infrared
CNC	Computer numerical control
PC	Personal computer
AISI	American Iron and Steel Institute
GPA	Giga Pascal
ANOVA	Analysis of variance
PSI	Pounds per square inch
CAD	Computer-aided design

## CHAPTER 1

### INTRODUCTION

#### 1.0 INTRODUCTION

Laser cutting is one of the most important applications of laser in manufacturing industry. Nowadays, Laser cutting become the dominant industrial in materials processing. It is mainly used for sheet metal cutting. It is believed that approximately 12 000 industrial laser cutting systems have been installed world-wide with a total market value over 5 billion USD [13].

Laser cutting is more high quality than other conventional in term of flexible and much more cost effective. Lasers are capable of cutting steel, stainless steel, super alloys, copper, aluminum, and a variety of other metals and alloys. They can also cut non-metallic materials such as ceramic, quartz, plastic, thermoplastic, rubber, wood and a whole lot more. Laser cut quality cannot be easily predicted. This is due to the dynamic nature of the laser cutting process, and it is particularly obvious when cutting ferrous alloys using oxygen as an assisting gas [2].

The carbon dioxide (CO<sub>2</sub>) gas laser is one of the most versatile for materials processing applications .Whether laser cutting with CO<sub>2</sub> or other assist gas, the principles employed are basically the same. The beam from the laser is focused on to the surface of the material being cut by means of a lens .The focused laser beam heats the material surface and a very local melt capillary is quickly established throughout the



depth of the material. The carbon dioxide (CO<sub>2</sub>) lasers are frequently used in industrial applications for cutting metal and welding such as used in aircraft and automotive industries to trim, drill holes and weld sheet metal parts [12].

In laser cutting, cut surface quality is very important in order to get better product of cutting processing. Cut quality mainly depends on many kind of parameters. The basic parameters in laser cutting are cutting speed, kerf width, surface roughness, and size of heat affected zone, striation frequency, laser power, chemistry of gas, standoff height, assists gas pressure, workpiece thickness and surface quality. All parameters should be considered in order to get the maximum optimization quality of cut desired.

Carbon dioxide (CO<sub>2</sub>) laser cutting on thermoplastic such as Acrylic is one of evolving industrial application. Laser applications in polyethylene cutting have grown considerably in many industries since it is now possible to achieve a superior quality finished product along with greater process reliability [12]. The aim of this study is to investigate the cutting quality of Acrylic when different power and constant feed rate apply using CO<sub>2</sub> laser.

## **1.1 PROBLEM STATEMENT**

A Carbon Dioxide laser was used in this experiment to cut the Acrylic with maximum power of 28.5 Watt. This experiment is to study the effect of power on laser cutting quality parameters and determine the best or limit level of power in order to get better surface finish quality.

In this experiment, the most important parameters to be considered is the laser power level range. Besides that, the feed rate is also one of the main parameters. Different power level ranges will produce different type of results depends on the feed rate.

In laser cutting process, there are many kind of cut quality parameters. But in this study, there are only two laser cut quality parameters to be considered. There are surface roughness and kerf width.

## **1.2 OBJECTIVES**

The objectives of this study are:

- 1.2.1 To study about how laser cutter machine works.
- 1.2.2 To analyze the effects of different power values with a constant feed rate value in laser cut quality of Acrylic.

## **1.3 PROJECT SCOPES**

The project scopes of this study are:

- 1.3.1 Use sample of Acrylic to be cut on CO<sub>2</sub> laser cutting system.
- 1.3.2 Analyze effects of power on surface roughness and kerf width.
- 1.3.3 Conduct the experiment with 5 values of power ( 15,16.5, 18, 19.5, 21, 22.5, 24, 25.5, 27 and 28.5 W) and constant feed rate (0.789mm/sec).
- 1.3.4 Using manual calculation to analyze the data of experiment.

## 1.4 THESIS ORGANIZATION

This thesis is divided into five chapters and will be organized according to the following chapters.

Chapter 1 elaborates the main idea of the project whereas it introduces the title, objective, problem statement scope and thesis organization.

Chapter 2 explains the meanings and information regarding the project where it informs on details of the project. The idea, data and information are collected from various resources in order to understand the concept and useful information or knowledge for this project. In this chapter, it includes about introduction of laser, laser cutting Carbon Dioxide (CO<sub>2</sub>) Laser Machine, Acrylic, laser cut quality such as surface roughness and kerf width.

Chapter 3 enlighten on the method that are used in this project. The measurement, apparatus, method, machine which used for the experiment are informed and listed in this chapter. The steps and setting for experiment are exposed in this chapter before the experiment will be taken.

Chapter 4 presents the finding and result we get from the experiment. The effect of power on cut quality will show in table, figure and picture of work piece, any calculation and graft. The result and finding from experiment will compare with previous result from other journal and make the discussion from comparison and from experiment.

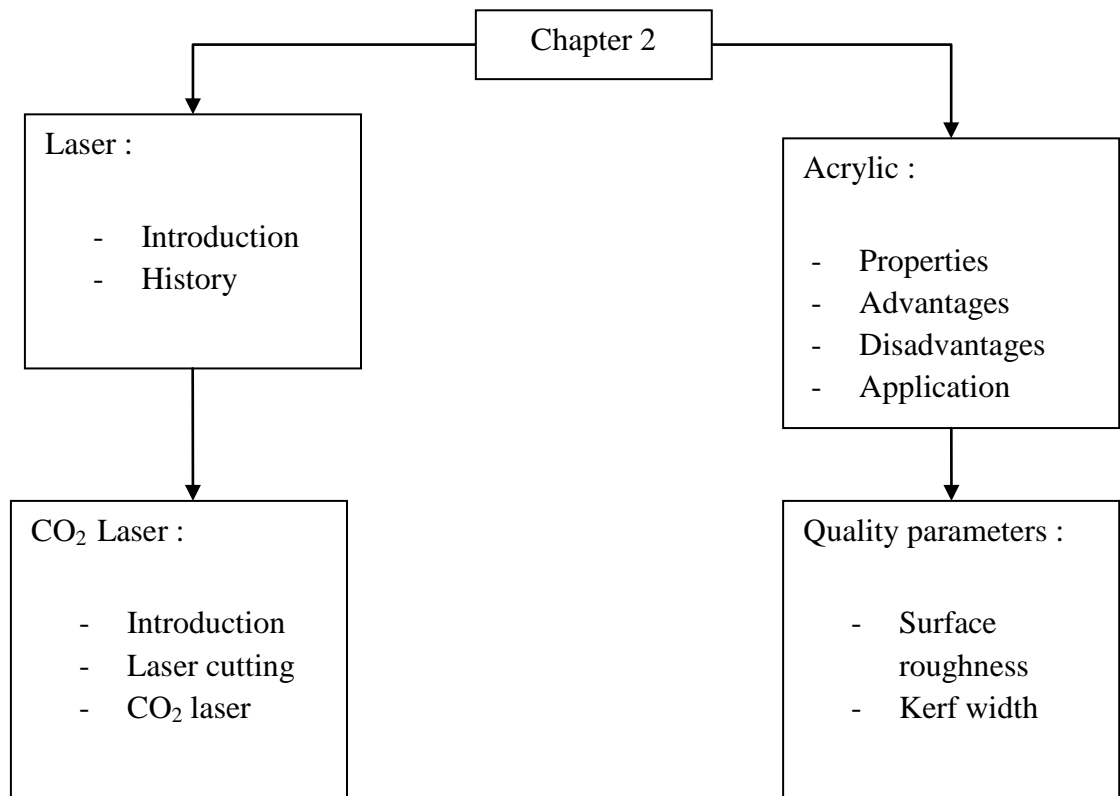
Chapter 5 elaborates the conclusion of the project and what have been learned. Recommendations are included to give opinion on further studies about this project. This chapter also concludes if the project is successful and experimentation result is same as expected result.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.0 INTRODUCTION

This chapter will discuss about the all information related of this study. This section explains the basic information about the laser cutting process, Acrylic and cut quality parameters. Through out this chapter we will see the all relevant information that significant as guideline to the next chapter. **Figure 2.0** shows the flow chat of this chapter.



**Figure 2.0 :** Flowchart of Chapter 2

## 2.1 LASER

Laser is the acronym of Light Amplification by Stimulated Emission of Radiation. Laser is light of special properties, light is electromagnetic (EM) wave in visible range. Lasers, broadly speaking, are devices that generate or amplify light, just as transistors generate and amplify electronic signals at audio, radio or microwave frequencies. The light must be understood broadly, since lasers have covered radiation at wavelengths ranging from infrared range to ultraviolet and even soft x-ray range [17].

Einstein can be considered as the father of the laser. 90 years ago he postulated photons and stimulated emission and won the Nobel Prize for related research on the photoelectric effect. In 1916, Albert Einstein. In his paper *Strahlungs-Emission and absorption nach der Quantentheorie*, laid the foundation for the invention of the laser and its predecessor, the maser, in a ground-breaking rederivation of Max Planck's law of radiation based on the concepts of probability coefficients (later to be termed 'Einstein coefficients') for the absorption, spontaneous and stimulated emission.

In 1928, Rudolph W. Landenburg confirmed the existence of stimulated emission and negative absorption. In 1939, Valentin A. Fabrikant (USSR) predicted the use of stimulated emission to amplify short waves. In 1947, Willis E. Lamb and R. C. Retherford found apparent stimulated emission in hydrogen spectra and made the first demonstration of stimulated emission. In 1950, Alfred Kastler (Nobel Prize for Physics 1966) proposed the method of optical pumping, which was experimentally confirmed by Brossel, Kastler and Winter two years later.

### **2.1.1 The maser**

In 1953, Charles H. Townes and graduate students James P. Gordon and Herbert J. Zeiger produced the first maser, a device operating on similar principles to the laser, but producing microwave rather than optical radiation. Townes's maser was incapable of continuous output. Nikolay Basov and Aleksandr Prokhorov of the Soviet Union worked independently on the quantum oscillator and solved the problem of continuous output systems by using more than two energy levels. These systems could release stimulated emission without falling to the ground state, thus maintaining a population inversion.

Townes, Basov, and Prokhorov shared the Nobel Prize in Physics in 1964 "For fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle.

### **2.1.2 The laser**

In 1957 Charles Hard Townes and Arthur Leonard Schawlow, then at Bell Labs, began a serious study of the infrared maser. As ideas were developed, infrared frequencies were abandoned with focus on visible light instead. The concept was originally known as an "optical maser". Bell Labs filed a patent application for their proposed optical maser a year later. At the same time Gordon Gould, a graduate student at Columbia University, was working on a doctoral thesis on the energy levels of excited thallium. Gould and Townes met and had conversations on the general subject of radiation emission. Afterwards Gould made notes about his ideas for a laser in November 1957, including suggesting using an open resonator, which became an important ingredient of future lasers.

In 1958, Prokhorov independently proposed using an open resonator, the first published appearance of this idea. Schawlow and Townes also settled on an open resonator design, apparently unaware of both the published work of Prokhorov and the unpublished work of Gould.

The first working laser was made by Theodore H. Maiman in 1960 at Hughes Research Laboratories in Malibu, California, beating several research teams including those of Townes at Columbia University, Arthur L. Schawlow at Bell Labs, and Gould at a company called TRG (Technical Research Group). Maiman used a solid-state flashlamp-pumped synthetic ruby crystal to produce red laser light at 694 nanometres wavelength. Maiman's laser, however, was only capable of pulsed operation due to its three energy level pumping scheme.

Later in 1960 the Iranian physicist Ali Javan, working with William Bennet and Donald Herriot, made the first gas laser using helium and neon. The concept of the semiconductor laser diode was proposed by Basov and Javan. The first laser diode was demonstrated by Robert N. Hall in 1962. Hall's device was made of gallium arsenide and emitted at 850 nm in the near-infrared region of the spectrum. The first semiconductor laser with visible emission was demonstrated later the same year by Nick Holonyak, Jr. As with the first gas lasers, these early semiconductor lasers could be used only in pulsed operation, and indeed only when cooled to liquid nitrogen temperatures[19].



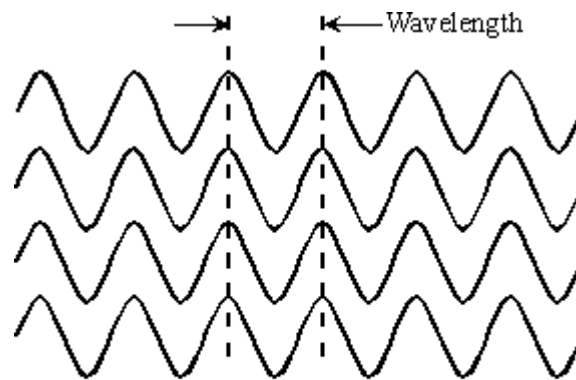
### 2.1.3 Laser chronology

**Table 2.1.3:** Laser chronology

<b>Year</b>	<b>Founders</b>	<b>Findings</b>
1917	Albert Einstein	Foundation for the invention of the laser
1954	Charles .A. Townes	First maser based on ammonia molecules.
1957	Charles Hard Townes Arthur Leonard Schawlow	Serious study of the infrared laser
1960	T. H. Maiman William R. Bennet Ali Javan	First gas laser with continuous stimulated emission. Made first gas laser using helium and neon
1964	Kumar Patel	Gas (CO <sub>2</sub> ) laser was invented.
1968	W. T. Walter	Discovery of first copper vapour laser.
1973	M. Nakamura and A. Yariv	First Distributed Feedback Laser (DFB) semiconductor laser.
1977	D. A. G. Deacon	First “free electron” laser has been invented
1979	H. Soda	First surface-emitting laser diodes.
1983	L. F. Mollenauer, R. Stolen	First siliton laser.
1994	K. Ann	Produce first single proton laser.

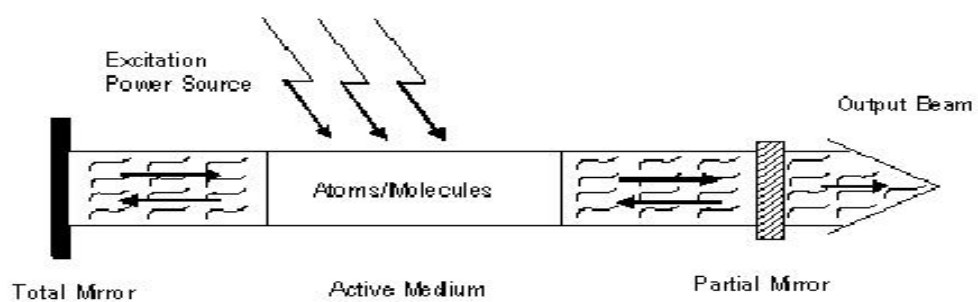
## 2.2 BASIC COMPONENT AND WORKING PRINCIPLE

Lasers work as a result of resonant effects. The output of a laser is a coherent electromagnetic field. In a coherent beam of electromagnetic energy, all the waves have the same frequency and phase.



Coherent electromagnetic waves have identical frequency, and are aligned in phase.

**Figure 2.2.1 :** Electromagnetic waves

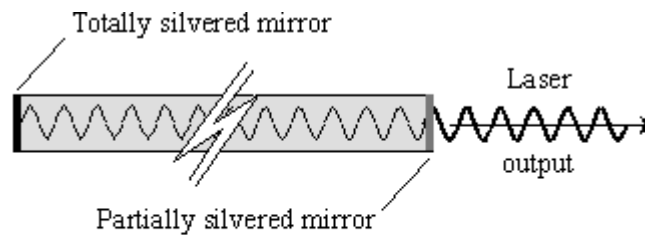


**Figure 2.2.2 :** Basic components of laser

In a basic laser, a chamber called a cavity is designed to internally reflect infrared (IR), visible-light, or ultraviolet (UV) waves so they reinforce each other. The cavity can contain gases, liquids, or solids. The choice of cavity material determines the wavelength of the output. At each end of the cavity, there is a mirror.

One mirror is totally reflective, allowing none of the energy to pass through; the other mirror is partially reflective, allowing approximately 5 percent of the energy to pass through. Energy is introduced into the cavity from an external source; this is called pumping.

As a result of pumping, an electromagnetic field appears inside the laser cavity at the natural (resonant) frequency of the atoms of the material that fills the cavity. The waves reflect back and forth between the mirrors. The length of the cavity is such that the reflected and re-reflected wavefronts reinforce each other in phase at the natural frequency of the cavity substance. Electromagnetic waves at this resonant frequency emerge from the end of the cavity having the partially-reflective mirror. The output may appear as a continuous beam, or as a series of brief, intense pulses [13].



A simple laser works via resonant effects in a cavity with mirrors at either end.

**Figure 2.2.3:** Pumping energy

## 2.3 LASER CUTTING

Laser cutting is one of the fastest growing processes in industrial manufacturing equipment. Laser cutting machines are being used by metal fabricators in place of older technology equipment like turret punches. Laser cutting machines offer significant advantages in productivity, precision, part quality, material utilization and flexibility. Laser Cutting Systems are the solution to the manufacturing challenges of today and the future. The laser cutting system is a proven industrial machine tool that can operate day in and day out in an industrial fabricating shop. Laser cutting machines consist of several main components including resonator, beam delivery; machine frame, CNC or PC control, and drive system.

Laser cutting is a thermal process that can be applied to high quality precision cutting. The laser cutting process is similar to taking a magnifying glass outside on a clear day and focusing the sun's energy to burn paper or a leaf. Laser cutting energy from a resonator is focused on a material in order to melt, burn or vaporize it. Some laser resonators produce a beam that can focus to a smaller hotter spot allowing faster, high quality laser cutting with lower operating costs.

Laser cutting equipment usually introduces an assist gas along with the beam to aid cutting. Oxygen adds heat to the laser cutting process and causes the metal to burn leaving a blackened edge. Laser cutting with nitrogen cools the cut and leaves a high quality edge. Both gases remove the molten material from the laser cutting process by blowing it through the cut or kerf [11, 13].

## 2.4 CO<sub>2</sub> LASER

Laser cutting equipment typically uses a Carbon Dioxide or CO<sub>2</sub> resonator. CO<sub>2</sub> Laser cutting machines are productive, reliable, and easy to maintain. CO<sub>2</sub> laser resonators are similar to a fluorescent light bulb. A fluorescent light bulb has gas on the inside that is excited with electricity. The laser has a mixture of gasses, including carbon dioxide, which are excited either with electricity or radio waves. The light bulb gives off light in every direction. Visible light waves are electromagnetic waves, meaning that they have an electric wave in one plane and a magnetic wave in another.

In the laser the light waves are lined up so that they are all oscillating in the same plane and vibrating together. This polarization of laser waves is a term that scientists call coherence. Coherence is one of the differences between light and laser light that make it suitable for laser cutting. A CO<sub>2</sub> Laser cutting machine operates in the infrared or heat range of the energy spectrum and not the visible range. CO<sub>2</sub> Laser cutting machines' wavelength is the same kind of energy you feel from a fireplace or heat lamp.

Industrial laser cutting machines take the laser light from the resonator and bounce it off of several mirrors in what is known as the beam delivery system. The beam is reflected into a laser cutting head where there is a lens. This lens works like a magnifying glass to focus the laser beam to a very small spot. The laser cutting machine either moves the cutting head or the metal or both to cut parts. High performance precision laser cutting systems all move the laser cutting head and keep the metal stationary. Most of these laser cutting machines are dual pallet systems that support the metal on movable pallets.

Once the laser finishes cutting the metal on one pallet, the pallets switch positions and the laser starts cutting on the second pallet. The only time that the laser is not cutting is the brief pallet switch time. Dual pallet laser cutting machines can approach 100% program run time. Industrial laser cutting equipment can cut a

variety of materials including steel, stainless steel, aluminum, titanium, wood, plastic, thermoplastic, acrylic, bronze, rubber and leather [12, 18].

## 2.5 ACRYLIC

Acrylic is a thermoplastic commodity heavily used in laser cutting processing product. Over 60 million tons of the materials are produced worldwide every year. Acrylic is defined by a density of greater or equal to 1.16 g/cc. Acrylic can be successfully cut with a laser. Testing the laser on the material to be cut is recommended because the power of the laser must be matched with the thickness of the material for a crisp clean cut. Complex patterns of Acrylic can be cut from a drawing CAD file with remarkable accuracy [1,14,16].

**Table 2.5** Properties of Acrylic

<b>Properties</b>	<b>Value</b>
Specific gravity	1.18
Specific density	1.16 g/cc
Melting point	212 °F 90 °C
Tensile strength	7000 psi
Tensile modulus	1.20 GPa
Compression strength	11500 psi
Maximum temperature	194 °F 90 °C
Minimum temperature	-76°F -60°C
Hardness	R120
Fabrication machining	Excellent
UV resistance	Good
Chemical resistance (acids)	Good
Chemical resistance (solvents)	Poor

### **2.5.1 Advantages and disadvantages of Acrylic**

Acrylic is offers excellent in clarity and UV resistance. Good abrasion resistance, hardness and stiffness. Low water absorption, low smoke emission good and track and arc resistance but poor in solvent resistance and fatigue resistance [14].

### **2.5.2 Application of Acrylic**

Acrylic is used to make various of product, such as lenses, light covers, glazing (particularly in aircraft), light pipes, meter covers, bathroom fittings, outdoor signs, skylights, baths, toys [14].

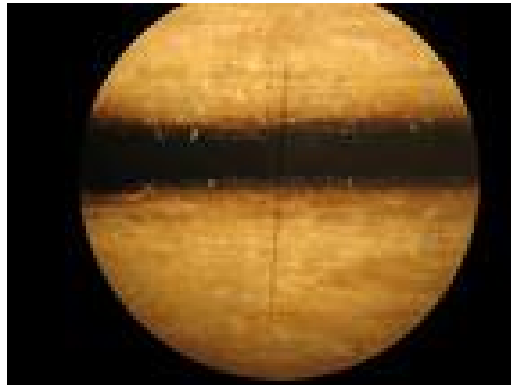


## 2.6 CUT QUALITY

Cut quality is defined as quality of the cut. The precision or dimensional accuracy of a cut quality is important to produce better product and ensure correct part tolerances and fit-up, thus eliminating rework or secondary processing operations further down the production line. Furthermore, the suitability of machining parameters is important in order to get good cut quality of product. In this experiment, there are only two cut quality can be consider which are kerf width and surface roughness [10].

### 2.6.1 Kerf Width

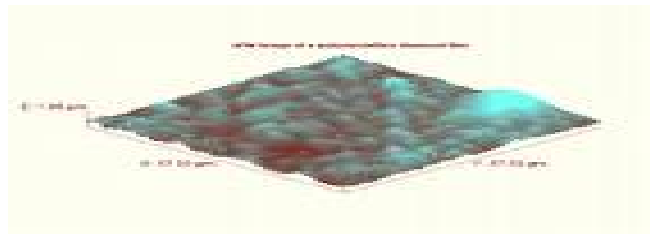
Kerf width defined as width of cut at it is widest point in millimetres. Kerf width gives an indication of the minimum internal radius or feature that can be cut. Basically, laser cuts possess very narrow kerf width (0.5- 1.0 mm) [10, 11].



**Figure 2.6.1:** Kerf width region

## 2.6.2 Surface roughness

Each type of cutting tool leaves its own individual pattern which therefore can be identified. This pattern is known as surface finish or surface roughness. Surface roughness consists of surface irregularities which result from the various machining process. There are many different roughness parameters in use, but  $R_a$  is by far the most common [8, 11].



**Figure 2.6.2:** Surface roughness structure

## **CHAPTER 3**

### **METHODOLOGY**

#### **3.0 INTRODUCTION**

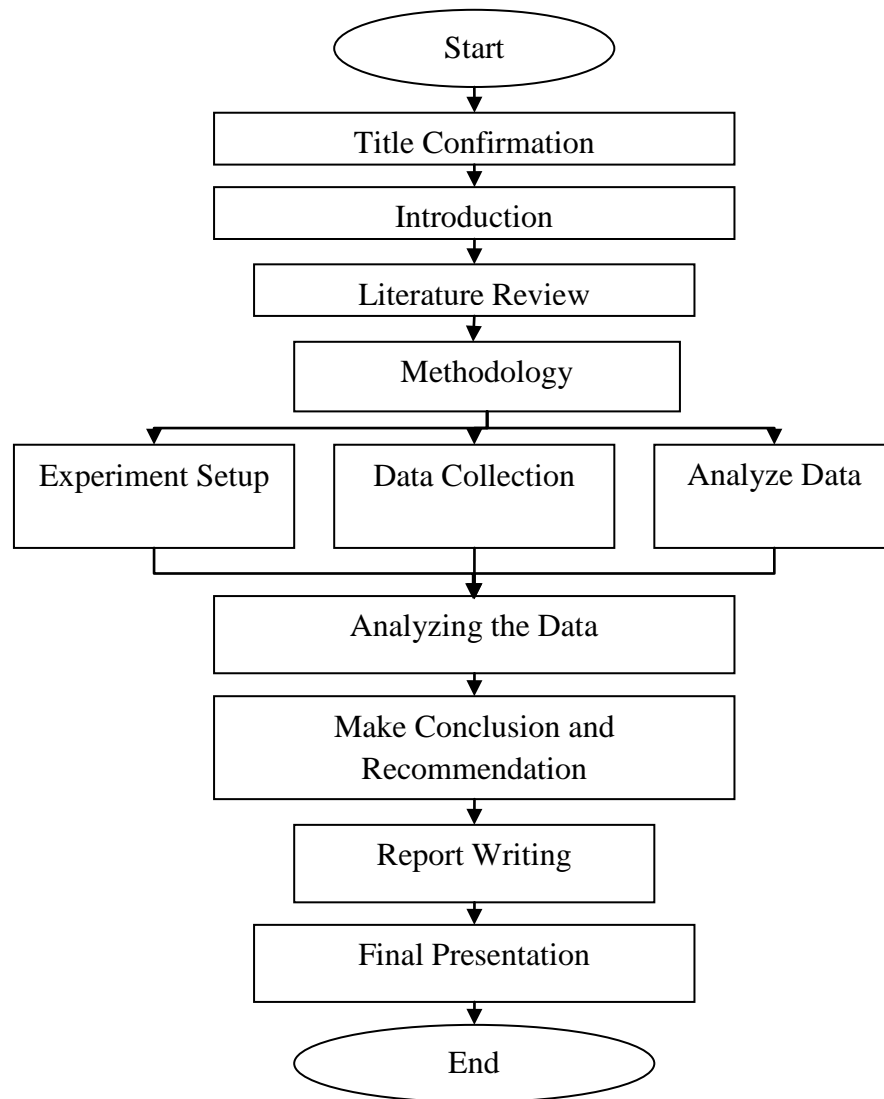
In developing a research, methodologies are one of the most important elements to be considered in order to make that the development of the study running smooth and get expected result. Methodology is a common method to be followed from the beginning of the studies until the analysis result followed by report in the end of the project. This chapter will explain on the concept and method being used for this project. Furthermore this chapter provides the guideline for generating successful experimental result.

#### **3.1 LITERATURE STUDY**

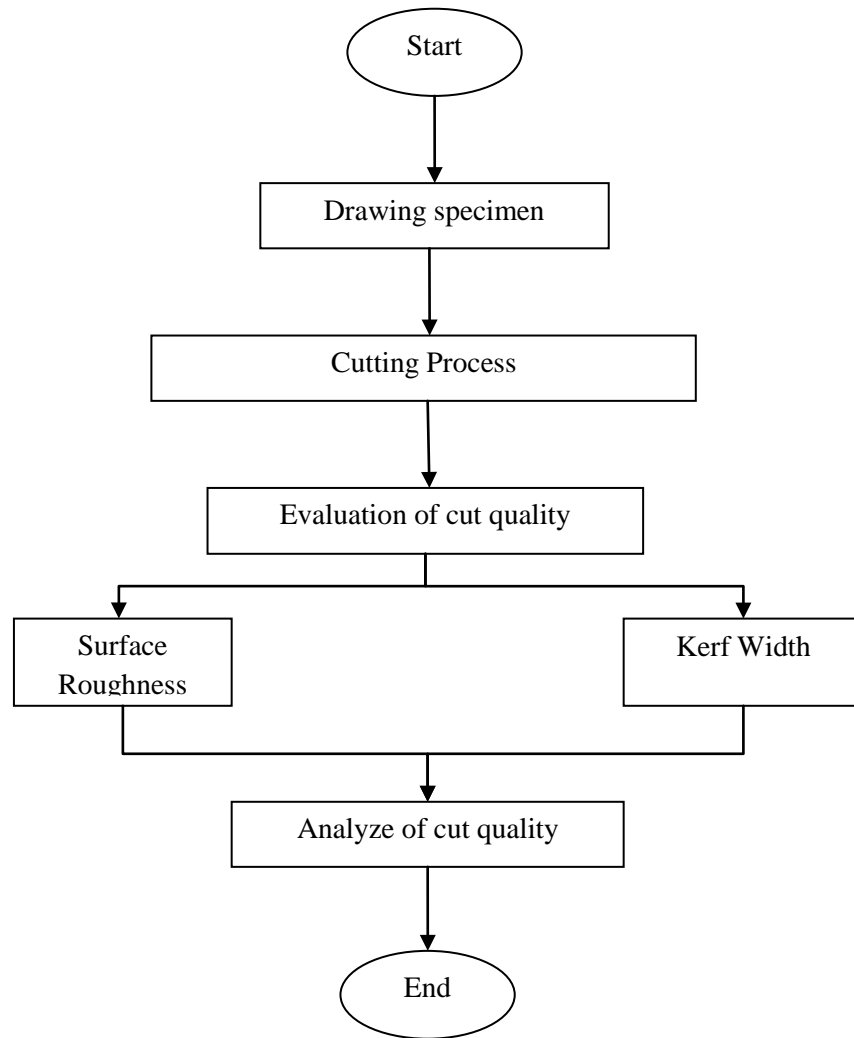
These studies begin as research developed through the objective and scope of the project. All information were gathered from books, previous journal and discussion. The objective of the project is to analyze the effect of different power constant feed rate . A method is planned regarding the necessary parameter to be evaluated.

## 3.2 EXPERIMENTAL PROCEDURE

In this section, the experimental procedure will explain all the steps or machining that are used in this research until the final result have been completed. **Figure 3.2.1** and **Figure 3.2.2** shows the general flow chart and experimental flow chart of the methodology involved in this experiment.



**Figure 3.2.1:** General flow chat



**Figure 3.2.2:** Experiment flow chat

### 3.3 EXPERIMENTAL PARAMETER

At this stage, all the information for literature review is collected and analyze. All the needed parameters were prepared since the experiment will be started. Here the chosen material study and machines for the experiment to be done:

- i. CO<sub>2</sub> laser cut
- ii. Acrylic
- iii. Image analyzer
- iv. Perthometer

CO<sub>2</sub> laser cut with different power and constant feed rate respectively, was used to conduct the cutting experiments in this project. Because of the large number of independent parameters that control the laser cutting process, some preliminary experiments were conducted in order to analyze the effect of different power on cut quality laser cut. Details of these experiments are found in **Table 3.3**.

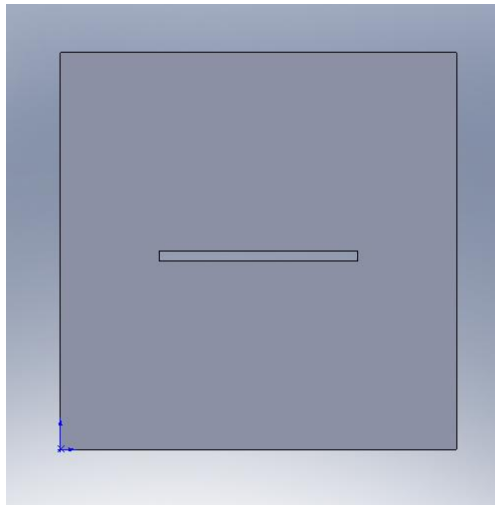
**Table 3.3:** Data of the experiment

<b>Parameter</b>	<b>Value</b>
Material and thickness(mm)	Acrylic, 3
Delay (pulse/sec)	1000
Power (W)	15,16.5, 18, 19.5,21, 22.5, 24, 25.5,27, 28.5
Frequency (Hz)	50/60
Wavelength (micrometer)	10.57- 10.63
Feed rate (mm/sec)	0.789

### 3.4 DRAWING OF SAMPLE

The chosen material study of this experiment is Acrylic. The dimension of the specimen is about 40mm x 40mm and 3mm of thickness. The specimen of material is generated using CAD software. The cut will accomplish according to desire dimension on CAD software.

Figure below shows the sample's feature. This part will save as in (.dwg) format. **Figure 3.4** shows the part's drawing in product of laser cut.



**Figure 3.4:** (2-D view) of specimen



### 3.5 CUTTING OF MATERIAL

Laser cutting machine is used as a cutter machine in this experiment. A CO<sub>2</sub> laser machine in FKM lab delivered maximum output power of 30W was used in this experiment. It can be control using PC, where running window and software that can be network with laser cut machine. The sample of specimen product from previous stage will open using Mean Execute (Art Cam) software. All parameter of the experiment will be setup before implement the experiment.

The feed rate value to be set on this experiment is about 0.789 mm/s it will remain as constant parameter. The cutting process will be started with the power of 15 until 28.5 watt. Then, 10 experiments were conduct using different power and constant feed rate to get data analysis.

Before start cutting the material, we need to wear safety equipments such as eyewear, and mask. This is the precaution for the laser machine. The laser cutting machine also have the hazard like others machine. The laser machine produces radiation and it can give effects to system body of human. **Figure 3.5** shows the laser cutting machine in the University Malaysia Pahang lab.



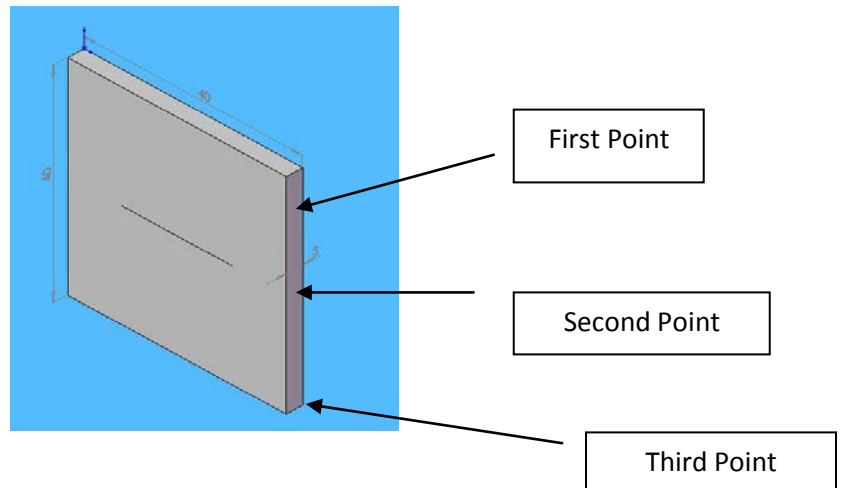
**Figure 3.5:** Laser Cutting Machine

### **3.6 ANALYZING OF CUT QUALITY**

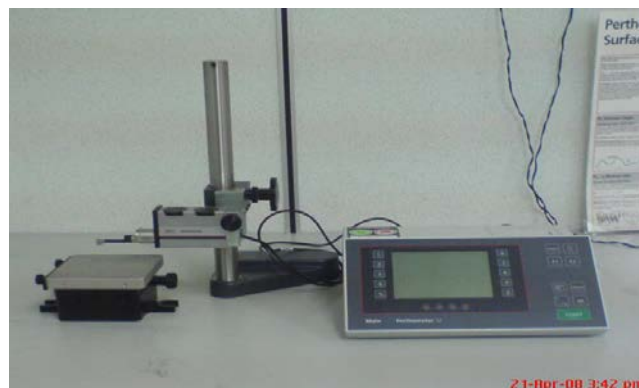
After laser cutting process done, the next stage must be evaluation of cut quality. The laser cut quality was monitored by measuring surface roughness and kerf width. The process of checking the cut quality is explained in next stage.

### 3.6.1 Surface Roughness

The surface roughness was measured using a perthometer as shown in **Figure 3.6.1.2**. Surface roughness on the cut edge is measure in terms of the average roughness,  $R_a$ . The reading was obtained by averaging surface roughness measurements along the length of cut, as start laser cutting process, on the middle and at the end of the cut process. Means 3 reading of surface roughness taken at different point and average them to give more accuracy and exact data of experiment as shown in **Figure 3.6.1.1**



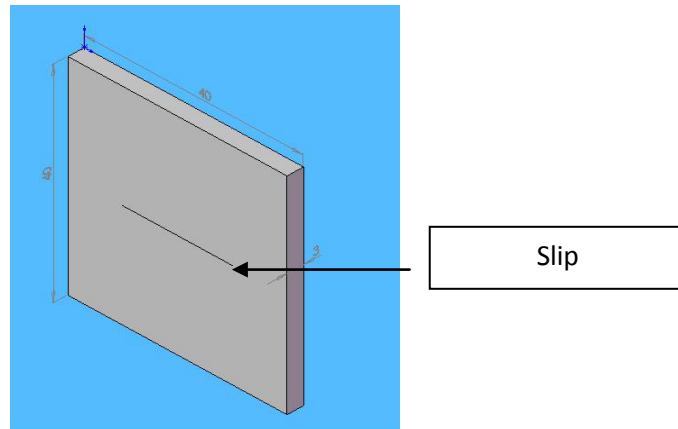
**Figure 3.6.1.1:** Three different points to measure surface roughness



**Figure 3.6.1.2:** Perthometer

### 3.6.2 Kerf Width

Kerf width was measured using an image analyzer as shown in **Figure 3.6.2.2**. The reading was obtained by averaging 3 kerf width measurement along the length of slip. **Figure 3.6.2.1** shows the slip region to measure the kerf width. Kerf width was measure on the top surface of the specimen.



**Figure 3.6.2.1:** Slit region to measure kerf width



**Figure 3.6.2.2:** Image Analyzer

### 3.7 RESULT ANALYSIS

The data of the result gained will be investigated afterwards. The results are then analyzed and graph cut quality versus power is plot. From the graph plotted, we will see how different power influenced the cut of quality. The results are interpreted based on the data and tables. **Table 3.7** shows the table of result data.

**Table 3.7:** Result data

Power (W)	Reading of cut quality			Average
	1	2	3	
28.5				
27.0				
25.5				
24.0				
22.5				
21.0				
19.5				
18.0				
16.5				
15.0				

## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

#### **4.1 INTRODUCTION**

This chapter will discuss about the result and discussions that have been made based from methodology in chapter 3. In this following section, the result of the analysis will be shown.

The results of the experimentation are analyzed by using manual calculation method. The results are interpreted based on the data, tables, and graph. The analysis consists of 2 main elements which are:

- a) Surface Roughness
- b) Kerf Width

The two elements will show the significance of power and how power influenced to this cut quality in laser cutting process.

In this chapter, there are some errors that occurred while conduct the experiment also been discussed in the end of this chapter.

## 4.2 MACHINERY EXPERIMENTAL RESULT

Due the methodology and literature review, the laser cut parameter has been planned and setup to be followed laser cutting process. **Table 4.2** shows the parameter of cutting process.

**Table 4.2:** Parameter of cutting process

Parameter	Value
Material and thickness	Acrylic (Polymethyl Methacrylate, PMMA)(3mm)
Feed rate (cutting speed)	0.789 (mm/sec)
Power	15, 16.5, 18, 19.5, 21, 22.5, 24,25.5, 27, 28.5 W
Frequency	50/60 Hz
Operating temperature	-10 - +71 degree/c
Wavelength	10.57 – 10.63 $\mu$ m
Nozzle standoff height	9.5cm

This experimental study started from cut the raw material study, this cutting process conducted by laser cutting machine. After undergo the cutting process, comes out with measurement analysis that conducted by Perthometer and Image Analyzer. Each specimen will taken three reading of cut quality and averaging it. The reading of surface roughness will takes place at side of the specimen. The reading of kerf width will be measured at slit of the specimen.

**Figure 4.1** shows the image of acyclic specimen after being cutting using Laser Cutting Machine.

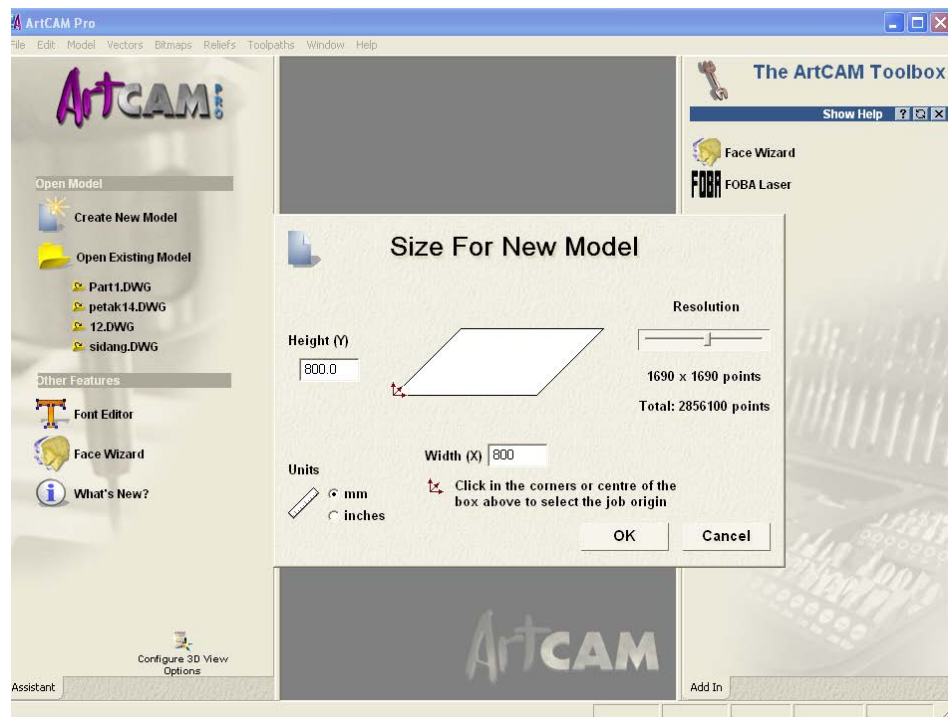


**Figure 4.1:** Specimen

The dimension of this experiment is 40 mm  $\times$  40 mm and 3 mm of thickness. The specimen of material firstly drawing using CAD software. Based from observation, it should be noted that the actual specimen is not exactly same according to desire dimension drawing on CAD software. It is due by the width of cut generates during the laser cutting process that will affect the actual dimension needs.

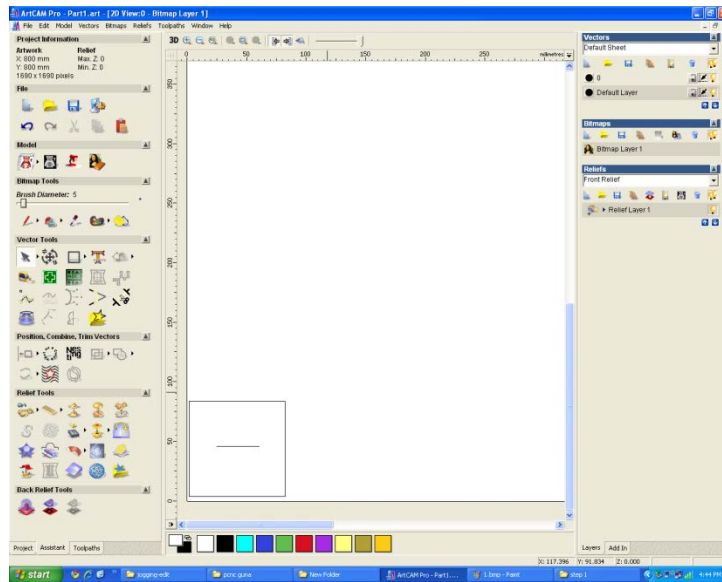
After drawing the specimen at CAD software, the file saves as (. DWG) file will open using Mean Execute (Art Cam) software. The Art Cam software provides a unique CAD modeling and CNC CAM laser cutting machine. This software comes together with running window and CO<sub>2</sub> laser cut that can be network to utilize laser cutting system.





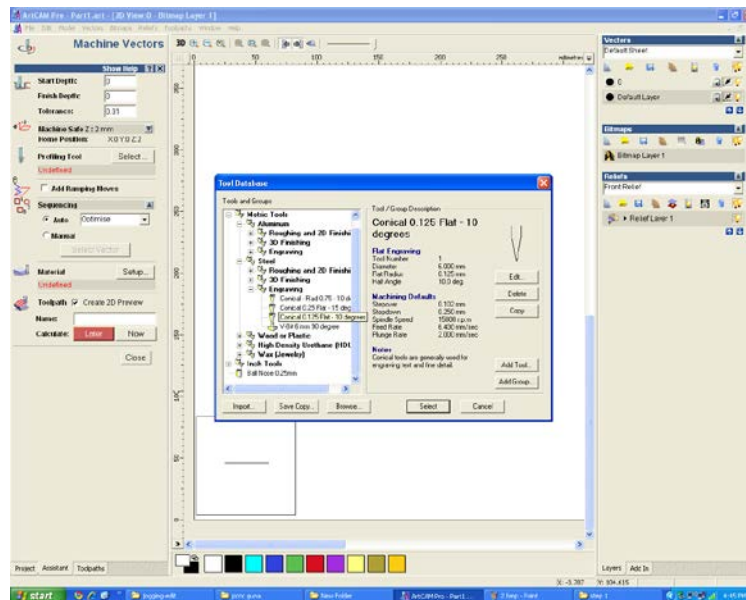
**Figure 4.1.1:** Parameter Setup

As shown in **Figure 4.1.1**, the Art Cam software is open to determine the size of height and width of the specimen. Both of height and width of the model is adjusted to 800 mm. Noticed that the experimental material study dimension is about 400 mm, the parameter setup should be higher than desire dimension to make it easy to simulate.



**Figure 4.1.2:** Move the sample to origin

Based on **Figure 4.1.2**, it depicts the sample must be move to origin (0, 0) to generates accurate cutting.



**Figure 4.1.3:** Tool Database

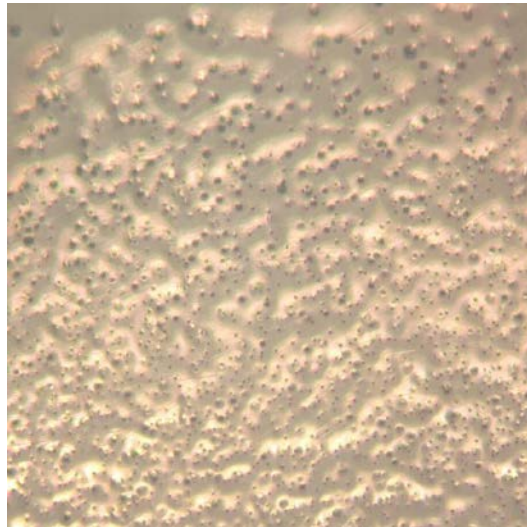


Lastly, the applied of power will be set and adjusted in term of percentage. After that, running the pcnc.cpp program and type the name file and the laser cut system will be generate cut to the specimen.

### 4.3 RESULTS OF SURFACE ROUGHNESS

**Figure 4.3** shows the one of the image structure of surface roughness after being cutting using laser cut. The surface roughness,  $R_a$  of each sample is measure using perthometer S2. The total results of experimentation are analyzed using manual calculation

**Table 4.3** presents the data of each sample result. From the table, shows the values of surface roughness (mm) that have been calculated due by using vary of power intensity applied at laser cut process.

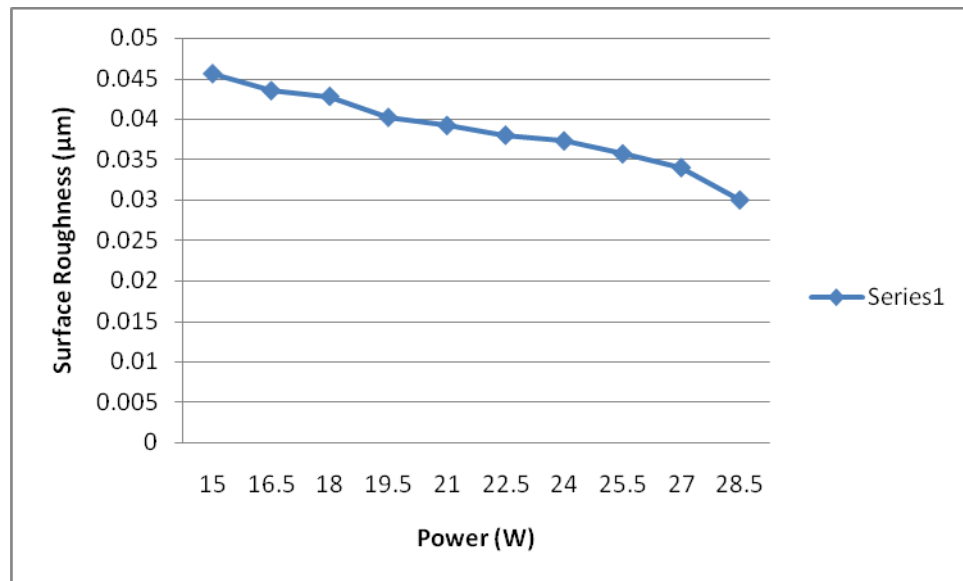


**Figure 4.3:** Surface roughness structure after cut using laser cutting machine

**Table 4.3:** Result of surface roughness,  $R_a$ 

<b>Power (W)</b>	<b>Reading of Surface Roughness(mm)</b>			<b>Average(mm)</b>
	<b>1</b>	<b>2</b>	<b>3</b>	
28.5	0.0230	0.0240	0.0430	0.0300
27.0	0.0520	0.0250	0.0250	0.0340
25.5	0.0390	0.0420	0.0260	0.0357
24.0	0.0360	0.0410	0.0350	0.0373
22.5	0.0270	0.0570	0.0300	0.0380
21.0	0.0352	0.0454	0.0446	0.0392
19.5	0.0528	0.0305	0.0373	0.0402
18.0	0.0384	0.0454	0.4460	0.0428
16.5	0.0473	0.0289	0.0543	0.0435
15.0	0.0384	0.0467	0.0517	0.0456

#### 4.4 EFFECTS OF POWER ON SURFACE ROUGHNESS



**Figure 4.4:** Graph Surface Roughness vs. Power

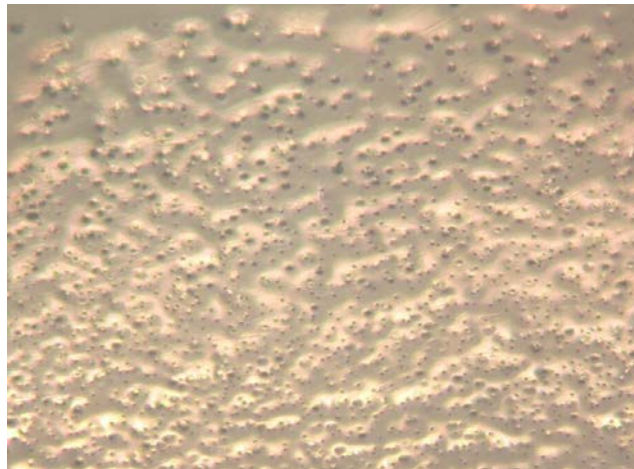
From the Figure 4.4, showed the graphs gained from 10 sample of specimens that been conducted using Perthometer machine. X-axis is represented as power parameter while the y-axis represented as Surface roughness, Ra. From the graph plotted, the significant and interaction between power and surface roughness can be observe obviously. In addition, the relationship between surface roughness and power is inversely proportional.

From the graph above, the result for surface roughness at 28.5 W (maximum power) is 0.030 µm. While the result for surface roughness at 15 W (minimum power) is 0.04456 µm. It is indicated that using the high intensity of laser power will decreasing the value of surface roughness, Ra. The smaller value of power contributes smaller surface roughness mean good surface quality of acyclic.

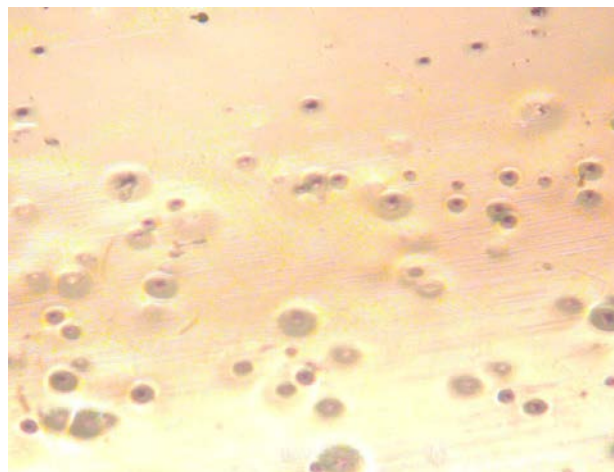
Based from analysis obtained, it is can be justified that using low power level is not suitable due by producing the higher value of surface roughness, Ra. At lower power

the power applied is not enough sufficient to accomplish the cutting process with offer good surface roughness and smooth surface. Hence, the incomplete cutting process will be obtained and ejection of melted also not fully done during the cutting process thus produce high surface roughness. The cutting process may not be completed due to insufficient laser power for complete cutting.





**Figure 4.4.1:** Surface roughness at 15 W



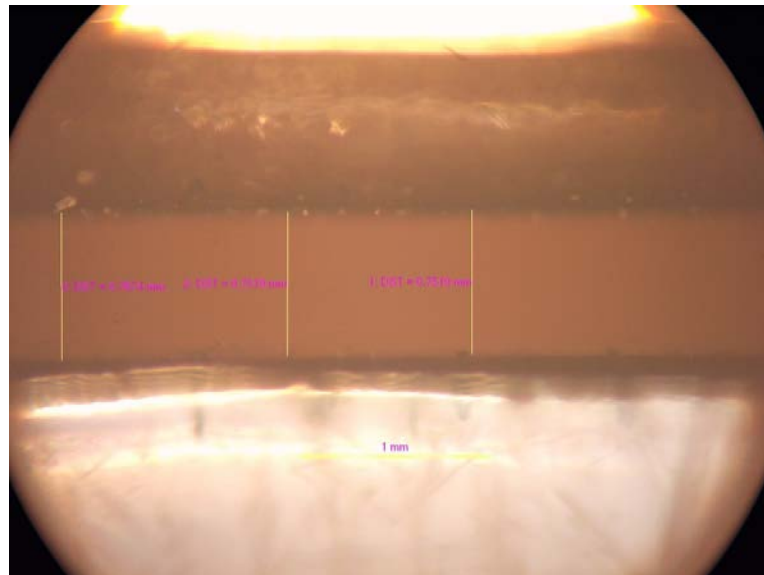
**Figure 4.4.2:** Surface roughness at 28.5 W

**Figure 4.4.1** shows the image structure of laser cut surfaces at 15 W while **Figure 4.4.2** shows the similar view of laser cut surface using 28.5 W of power. This figure was observed by Image Analyzer. Definitely the surface roughness for 28.5 W is more pretty smooth comparing with surface roughness gained using 15 W of power. On the other hand, figures above proved that the increasing of laser power tends to decrease the value of surface roughness.

## 4.5 RESULTS OF KERF WIDTH

Figure 4.5 shows the one of the image structure of surface roughness after being cutting using laser cut. The kerf width value of each sample is measure using Image Analyzer machine. The total results of experimentation are analyzed using manual calculation.

Table 4.5 presents the data of each sample result. From the table, shows the values of kerf width (mm) that have been calculated due by using vary of power intensity applied at laser cut process.

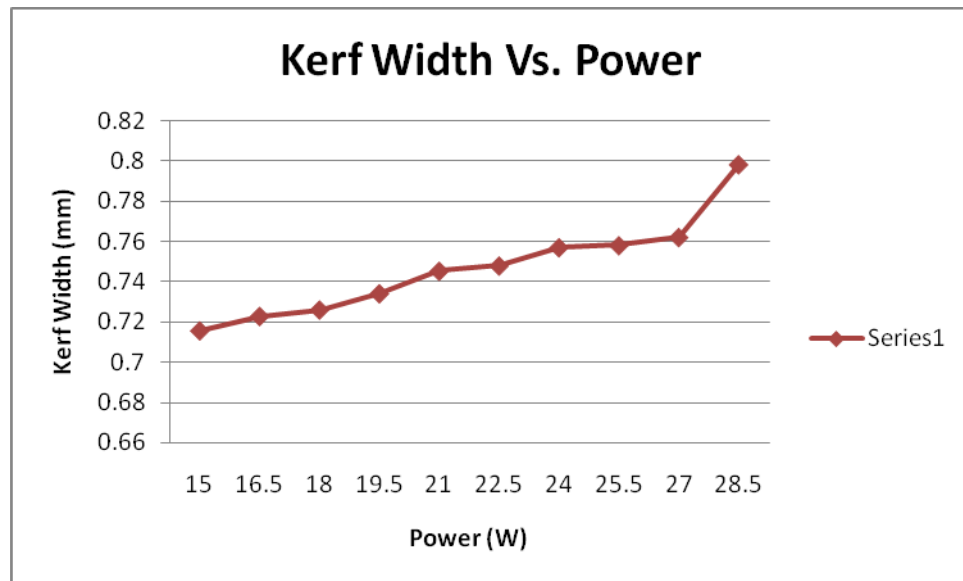


**Figure 4.5:** Kerf width structure after cutting using laser cutting machine

**Table 4.5:** Result of kerf width

<b>Power (W)</b>	<b>Kerf Width (<math>\mu\text{m}</math>)</b>			<b>Average(<math>\mu\text{m}</math>)</b>
	<b>1</b>	<b>2</b>	<b>3</b>	
28.5	0.8139	0.8023	0.7791	0.7984
27.0	0.7558	0.7596	0.7713	0.7622
25.5	0.7674	0.7549	0.7519	0.7581
24.0	0.7480	0.7558	0.7674	0.7571
22.5	0.7558	0.7480	0.7403	0.7480
21.0	0.7519	0.7441	0.7403	0.7454
19.5	0.7170	0.7364	0.7493	0.7342
18.0	0.7325	0.7209	0.7248	0.7261
16.5	0.7248	0.7209	0.7230	0.7229
15.0	0.7209	0.7131	0.7132	0.7157

#### 4.6 EFFECTS OF POWER ON KERF WIDTH



**Figure 4.6:** Graph kerf width vs. Power

From the **Figure 4.6**, shows the graph gained from 10 sample of specimens that been conducted using Image Analyzer machine. X-axis is represented as power parameter while the y-axis represented as kerf width. From the figure above, the obtained line were not smooth, apparently, the drastically value of kerf width gained between using 27 W and 28.5 W of power.

Based from graph plotted, the result can be observed obviously. In addition, the relationship between kerf width and power is proportional.

From the graph above, the result for kerf width at 28.5 W (maximum power) is 0.7984 mm. While the result for kerf width at 15 W (minimum power) is 0.7157 mm. It is indicated that using the high intensity of laser power will increasing the value of kerf width. The smaller value of power contributes smaller kerf width mean good width desire.

Based from analysis done, its can be observed that power applied during laser cutting process produce accumulation of heat input at cutting spot. The purpose of this localized heat input is to generate the cut during cutting process. The more power applied will tends to produce high accumulation of heat input [7]. Under this circumstance the localized heat input will led to increasing the size of width because of high intensity of heat at the cutting spot while conduct the cutting process .

#### **4.7 COMPARISON BETWEEN THEORETICAL AND EXPERIMENTAL**

As obtained through the experimental result, increasing the power intensity resulted in smaller value of surface roughness higher value of kerf width. When comparing the theoretical and experimentally obtained kerf width and surface roughness, both results are in good agreement [3, 4,].

Based from theoretically, increasing power intensity will caused more amount material removed from the kerf during cutting process. Consequently, the cut quality of kerf width enhances with increasing power intensity. Increasing power intensity will affect good surface during laser cutting process due by enough distribution power to generate cut perfectly [5, 6].

## 4.8 ERROR DISCUSSION

According to figure 4.4 and 4.6 obtained line graph were not smooth. This is because of some error occurred during cutting process and measurement process. It's also noticed that the rapidly differences value gained of kerf width from 27 W and 28.5 W.

During the cutting process, the laser system used to cut the work piece is not good enough to undergo cutting process but highly capable to engraving the material. The laser system used is not capable to cut material with high melting point thus the usage of cutting process is limited in term of type material and thickness. Hence a better laser cut system needed to avoid this circumstance.

Sample material study was cut into small pieces which  $4\text{mm} \times 4\text{mm}$  using laser system. This circumstance offer error during taken the measurement of surface roughness and kerf width. Within this small dimension, the specimens that will put into Perthometer will not grip properly and affects the surface roughness reading.

Environment factor is generally considered to be one of the crucial factors that cannot be control during the experimental process. The environmental factor such as vibration, air ventilation, temperature possibly offers error during conducted the experiment.

## CHAPTER 5

### CONCLUSION AND RECOMMENDATION

#### 5.1 CONCLUSION

Basically, this study is successfully achieving the objective with the acceptable result or outcome. This experiment analyzes the cut quality based on vary power applied for Acyclic using laser cutting machine. Manual calculation is used in analyzing and determines the effect of power towards surface roughness and kerf width.

From the experiment, the result can be summarizing into two aspects which are the effect of power to surface roughness and effect of power to kerf width. The errors may occur because of environmental factor, poor condition of machines, unsuitable geometry dimension and lack of experience to handle the laser cutting machine. These problems are interpreted as the error effect to overall results.

It was determined that power gives a vital influence on surface roughness and kerf width in laser cutting process. Increasing the power led to decreasing on surface roughness, Ra and led to increasing on kerf width.



## 5.2 RECOMMENDATIONS

Based on the discussion overview of this study, the efficient and accurate result can be obtained following this recommendation made. The suggestions are as follows:

- a) Analysis another kind of cut quality such as Heat Affected Zone (HAZ) and Striation Frequency.
- b) Using the higher power of laser cutting system that can be cut various materials with high melting point such as steel, titanium, and aluminium.
- c) Using EDM which can assist for better obvious and accurate image structure of cut quality.
- d) Determine and analyze combines of effects power and feed rate using another method such as RSM, ANOVA, Taguchi and hybrid.

## REFERENCES

- [1] J. A. Brydson, 1995, 1999, *Plastics materials* (seven edition), Former Head of the Department of Physical Sciences and Technology, Polytechnic of North London (now known as the University of North London).
- [2] N. Rajaram, J. Sheikh-Ahmad, S.H Cheraghi (11 November 2002). *CO2 laser cut quality of 4130 steel.*
- [3] Caiazzo, F. Curcio, G. Daurelio, and F. Memola Capece Minutolo (30 April 2004) *Laser cutting of different polymeric plastics (PE, PP and PC) by a CO<sub>2</sub> Laser beam.*
- [4] B Tirumala Rao and A K Nath Melt flow (24 may 2001) characteristics in gas- assisted laser cutting.
- [5] M.Kumar and A K Nath, "*Optimization study of an ultraviolet preionized TEA CO<sub>2</sub> laser*", Opt.Engg., 33, 1885,1994.
- [6] K.Abdel Ghany\* , M. Newishy *Cutting of 1.2mm thick austenitic stainless steel sheet using pulsed and CW ND:YAG laser* (8 January 2004).
- [7] Cihan Karatas et al. Laser cutting of steel sheets : *Influence of workpiece thickness and Beam waist position on kerf size and stria formation* (17 Ferbruary 2005).
- [8] A. Almeida, F. Carvalho, P.A Carvalho, R. Vilar. Laser developed Al-Mo surface alloys: Microstructure, mechanical and wear behavior. *Surface & coating Technology* 200, 2006, 4782-4790.
- [9] E.J.A. Armarego, R.H. Brown, *The Machining of Metals*, Prentice-Hall, New Jersey, 1969.

- [10] Heinrich M. Jaeger, Sidney, Nagel, Robert P. Behringer, “The Physics of Granular Materials”, Physics Today, 32-38, (April 1996).
- [11] Edson Costa Santos, Masanari Shiomi, Kozo Osakada, Tahar Laoui. Rapid manufacturing of metal components by laser forming. International Journal of Machine Tools & Manufacture 2005 1-9.
- [12] [http://en.wikipedia.org/wiki/Carbon\\_dioxide\\_laser](http://en.wikipedia.org/wiki/Carbon_dioxide_laser).
- [13] [http://www.twi.co.uk/j32k/protected/band\\_3/kspah004.html](http://www.twi.co.uk/j32k/protected/band_3/kspah004.html).
- [14] [http://www.polymerweb.com/\\_datash/pmma.html](http://www.polymerweb.com/_datash/pmma.html).
- [15] <http://www.yemmhart.com/materials/origins/fabrication.html>.
- [16] [http://en.wikipedia.org/wiki/Acrylic\\_glass](http://en.wikipedia.org/wiki/Acrylic_glass).
- [17] <http://en.wikipedia.org/wiki/Laser>.
- [18] <http://www.sintecoptronics.com/ref/co2cutting.html>.

