CARBON DIOXIDE (CO_2) LASER CUT QUALITY OF ACRYLIC USING DIFFERENT FEED RATE AND CONSTANT POWER

ABD HALIM BIN ABDULLAH @ SHAFEI

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS

JUDUL: **CARBON DIOXIDE (CO$_2$) LASER CUT QUALITY OF ACRYLIC USING DIFFERENT FEED RATE AND CONSTANT POWER**

SESI PENGAJIAN: 2008/2009

Saya, **ABD HALIM BIN ABDULLAH @ SHAFEI (860220-11-5097)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda / ~~Sarjana / Doktor Falsafah~~)* ini disimpan di perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan ($\sqrt{}$)

☐	**SULIT**	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐	**TERHAD**	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan)
$\sqrt{}$	**TIDAK TERHAD**	

Disahkan oleh:

_____   _____
(TANDATANGAN PENULIS)   (TANDATANGAN PENYELIA)

Alamat Tetap:

745-A KG LOSONG HAJI MAT SHAFIE   **PN. NURUL SHAHIDA BT. MOHDSHALAHIM**
21000 KUALA TERENGGANU   (Nama Penyelia)
TERENGGANU

Tarikh: **07 NOVEMBER 2008**   Tarikh: **07 NOVEMBER 2008**

CATATAN: * Potong yang tidak berkenaan.

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

◆ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

CARBON DIOXIDE (CO$_2$) LASER CUT QUALITY OF ACRYLIC USING
DIFFERENT FEED RATE AND CONSTANT POWER

ABD HALIM BIN ABDULLAH

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 project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree Bachelor of Mechanical Engineering.

Signature   : ………………………………………..

Name of Supervisor   : PN. NURUL SHAHIDA BINTI MOHD SHALAHIM

Position   : LECTURER

Date   :

Signature   : ………………………………………..

Name of Panel   : PN. SITI HARYANI BINTI TOMADI

Position   : LECTURER

Date   :

STUDENT'S DECLARATION

I declared that this dissertation entitled "Carbon Dioxide (CO_2) Laser Cut Quality of Acrylic using different feed rate and constant power" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not currently submitted in candidature of any other degree.

Signature   : …………………………………………..

Name   : ABD HALIM BIN ABDULLAH @ SHAFEI

ID Number   : MA 05067

Date   :

To my beloved father and mother

Abdullah @ Shafei bin Abu Bakar

Wan Mariam binti Wan Sulaiman

ACKNOWLEDGEMENT

Praise to Allah S.W.T, the Most Merciful and the Most Compassionate for giving me healty and streng to finish my final year project and completing the report. Peace upon Him, Muhammad S.A.W, the messenger of Allah.

Firstly, I would like to thanks to my supervisor and co-supervisor, Madam Nurul Shahida binti Mohd Shalahim and Mr. Mahendran Samykano for their guidance, supporting, advising and encouragement during this final year project. Also to Mr. Khairul Fikri bin Muhamad and Mr. Nafrizuan bin Mat Yahya as my reference beside my supervisor. Thier contribution and cooperation during my research was really helpful and I really appreciate it.

Secondly, I would like to thanks all lectures and associate in Faculty of Mechanical Engineering, Universiti Malaysia Pahang and my thanks also extend to all my friends who helped me in many ways especially for suporting which gave me a lot of confidence to finish this project.

Finally, I wish to convey my heartfelt thanks to my beloved parents, Abdullah bin Abu Bakar and Wan Mariam binti Wan Sulaiman who gave me encouragement and constant supprot during my strunggle to completing this project.

ABSTRACT

Laser are widely used as cutting tools that obtain high quality end product. Laser can cut many type of material includes metals, plastic, rubber, and ceramics. In this project, the samlpes of acrylic (Polymethyl Methacrylate, PMMA) were cut used Carbon Dioxode (CO_2) laser cutting machine with different feed rate and affect of feed rate on cut quality has been studied. The cut qualities examined were surface roughness and kerf width. Optimum power of CO_2 laser machine at FKM lab used is about 25.5W. In checking cut quality process, Perthometer was used to measured surface roughness and Image Analyzer was used to measured kerf width. The both cut qaulity parameters are analyzed and graph were plloted between feed rate versus cut quality. From the graph, reelationship between feed rate and cut quality were discused. As a result, increasing feed rate led to increasing on surface roughness and the kerf width decrease when the feed rate increase. The top and bottom surfaces of the acrylic specimen indicated that the top kerf width was slightly larger than the bottom kerf width. For get good cut quality, surface roughness and kerf width are kept at minimum value. From the result, it can conclude that feed rate has effect on surface roughness and kerf widt quality. To obtain better result, the experiment is able to improve in term use another method to analyzed result and consider more parameter that can effect the cut quality.

ABSTRAK

Laser digunakan secara meluas sebagai alat memotong yang menghasilkan kualiti produk yang tinggi. Laser boleh memotong pelbagai bahan termasuk besi, plastik, getah dan seramik. Projek ini mengunakan bahan akrilik yang dipotong menggunakan mesin pemotong laser (CO_2) dengan menggunakan halaju pemotongan yang berbeza dan kesan halaju pemotongan pada kualiti pemotongan akan dikaji. Kualiti pemotongan yang dikaji ialah kekasaran permukaan dan lebar alur. Optimum kuasa yang digunakan pada mesin pemotongan di makmal FKM ialah 25.5Watt. Dalam proses menyemak kualiti pemotongan, Perthometer digunakan untuk mengukur kekasaran permukaan dan Image Analyzer digunakan untuk mengukur lebar alur. Kedua-dua kualiti pemotongan dianalisis dan membuat graf antara halaju pemotongan melawan kualiti pemotongan. Daripada graf tersebut, hubungan antara halaju pemotongan dan kauliti pemotongan telah dibincangkan. Sebagai keputusan, peningkatan halaju pemotongan menyebabkan peningkatan pada kekasaran permukaan. Lebar alur menurun dengan peningkatan halaju pemotongan. Bahagian atas dan bawah permukaan spesimen akrilik menunjukkan bahagian atas lebar alur sedikit lebih besar daripada bahagian bawah lebar alur. Untuk mendapatkan kualiti pemaotngan yang bagus, kekasaran permukaan dan lebar alur mestilah pada jumlah yang rendah. Daripada keputusan, dapat disimpulkan iaitu halaju pemoyongan memberi kesan pada kekasaran permukaan dan lebar alur kualiti. Untuk mendapatkan keputusan yang lebih baik, eksperimen ini mampu ditingkatkan dengan menggunakan keadah lain untuk menganalisis keputusan dan menimbangkan lebih banyak parameter yang boleh memberi kesan pada kualiti pemotongan.

TABLE OF CONTENTS

CHAPTER 3   METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

CNC	-	Computer numerically-controlled
PMMA	-	Polymethyl methacrylate
CO_2	-	Carbon dioxide
mm/s	-	Millimetre per second
HAZ	-	Heat affected zone
Laser	-	Light amplification by simulated emission of radiation
DFB	-	Distributed feedback laser
%	-	Percentage
CAD	-	Computer-aided design
N_2	-	Nitrogen
LIDAR	-	Light detection and ranging
W	-	Watt
μs	-	Microsecond
mm	-	Millimetre
μm	-	Micrometre
Ra	-	Roughness average

CHAPTER 1

INTRODUCTION

1.1   INTRODUCTION

Nowaday, laser cutting is a one of tecnology that uses a laser as a cutter to cut materials, and is usually used in industrial manufacturing. Laser cutting will produce high quality surface finish. That why laser cutting is one of the important applications in industry. Industrial laser cutters are used to cut flat sheet material.

Laser cutting is a common manufacturing process employed to cut many types of materials. Materials which may be laser cut include ferrous metals, non-ferrous metals, stone, plastic, rubber, and ceramics. Laser cutting works by directing a high power pulsed laser at a specific location on the material to be cut. The energy in the laser beam is absorbed into the surface of the material, and the energy of the laser is converted into heat, which melts or vaporizes the material. Additionally, gas is focused or blown into the cutting region to expel or blow away the molten metal and vapour from the cutting path.

There are several advantages of laser cutting over mechanical cutting, since the cut is performed by the laser beam, there is no physical contact with the material, therefore, contaminates cannot enter or embed into the material. Laser cutting can produce high accuracy cuts, complex shapes, cut several oarts simultaneously, produce clean cutting edges which require minimal finishing, as well as, low edges loads during cutting, which will reduce distortions. Besides that, laser cutters have a variety of advantages over other manufacturing technologies. They usually can accept data directly from a personal computer. Unlike computer numerically-

controlled (CNC) mills, they are safe, clean, and require little maintenance. In addition, they are fairly fast in operation, and can cut a wide variety of flat materials. One of the disadvantages of laser cutting may include the high energy required.

Lasers work best on materials such as carbon steel or stainless steels. Metals such as aluminum and copper alloys are more difficult to cut due to their ability to reflect the light as well as absorb and conduct heat. This requires lasers that are more powerful.The width of laser cut or kerf, and quality of the cut edges, are effected by power of the laser, laser of the beam pulses, and the motion of the laser beam, and work-piece.

The main purpose of this project is to study the cutting quality of acrylic (Polymethyl Methacrylate, PMMA) using Carbon Dioxide (CO_2) laser cutting machine. Acrylic is a useful, clear plastic that resembles glass but has properties that make it superior to glass. It is stronger than glass, making it more impact resistant and not easy to break it compare than glass. The good cut quality of acrylic can increase the quality of prodoct and increase productivity.

For this project, some parameters should be considered to show different result when different feedrates apply. The next subtopic will explain about the parameters that should be considered in this project.

1.2 PROBLEM STATEMENT

In industries there are so many machining cutting processes. The application of that machine depends on work piece to cut. Laser is one of the machine cutting processes. Laser cutting can maximize the productivity and increase quality of product made by laser cutting process.

A CO_2 laser will be used in this project to cut the acrylic with optimum power of 25.5Watt. This project is to study the effect of feed rate on laser cutting quality parameters to determine the best or limit level of feed rate to get good cutting finishing.

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

In this project, the most important parameter to be considered is the laser feed rate level range. The cutting quality produced is different with different feed rate level we used. Besides that, the power of laser must consider in this project.

1.3   OBJECTIVE'S OF THE STUDY

The objectives of this study are :

1.3.1   To study about Carbon Dioxide (CO_2) laser cutting machine and its function.

1.3.2   To study the laser cut quality based on the feed rate of the Carbon Dioxide (CO_2) laser machine.

1.4   PROJECT SCOPES

The scopes of this study are:

1.4.1   Study the laser cutting quality parameters such as kerf width and surface roughness.

1.4.2   Using acrylic (Polymethyl Methacrylate, PMMA) as the material and cut using CO_2 laser cutter machine.

1.4.3   Run the experiment using five value of feed rate (1.136, 1.190, 1.250, 1.316, 1.389, 1.471, 1.563, 1.667, 1.786, 1.923, and 2.083 mm/s) with a constant power value (25.5Watt).

1.4.4   Analyzing the data using manual calculation.

1.5   THESIS ORGANIZATION

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

Chapter 1 consists the introduction of this project, objective, problem statement, project scopes and thesis organization. The introduction includes the information about laser as a cutting apparatus and steel as a work piece.

Chapter 2 discusses about the literature review of the project. The theories and research components about the CO_2 laser machine, acrylic properties and laser cut quality will be mentioned. This chapter also includes the finding from previous case study based on laser cut quality.

Chapter 3 explains the methodology of this study. The proposed working method, procedures of the project and the data collection will be described. The flow chart of the project progress also shows in this chapter.

Chapter 4 presents the finding and result from the experiment will be show in the tables, figures and photos of work piece, any calculation and graph. The discussion of the results also include in this chapter.

Chapter 5 is the final in this thesis will conclude overall finding and result. Besides that, the recommendation also include in this chapter for future study and further research.

CHAPTER 2

LITERATURE REVIEW

2.1   INTRODUCTION

This chapter will explain more detail about this research. Any information related about laser machine and material will discuss include history, application, laser working principle, characteristics and parameters quality. This chapter also refers to previous study based on laser cutting. The figure 2.1 below shows the outline of Chapter 2.

```
                          ┌─────────────────┐
              ┌──────────│   Introduction   │──────────┐
              │           └─────────────────┘           │
              ▼                    │                     ▼
  ┌───────────────────────┐       │        ┌───────────────────────────┐
  │ Laser :               │       │        │ Acrylic(Polymethyl        │
  │ - Introduction        │       │        │ Methacrylate, PMMA) :     │
  │ - History             │       │        │  - Introduction           │
  │ - Types of laser      │       │        │  - Properties of acrylic  │
  │ - Working principal   │       │        │  - Applications           │
  │ - Laser cutting       │       │        └───────────────────────────┘
  │   process             │       │                     │
  └───────────────────────┘       │                     ▼
              │                    │        ┌───────────────────────────┐
              ▼                    ▼        │ Quality parameters :      │
  ┌───────────────────────┐  ┌─────────┐   │  - Introduction           │
  │ CO₂ Laser :           │  │         │   │  - Surface rougness       │
  │  - Introduction       │  │ Conclusion  │  - Kerf width             │
  │  - Applicatons        │  └─────────┘   └───────────────────────────┘
  └───────────────────────┘
```
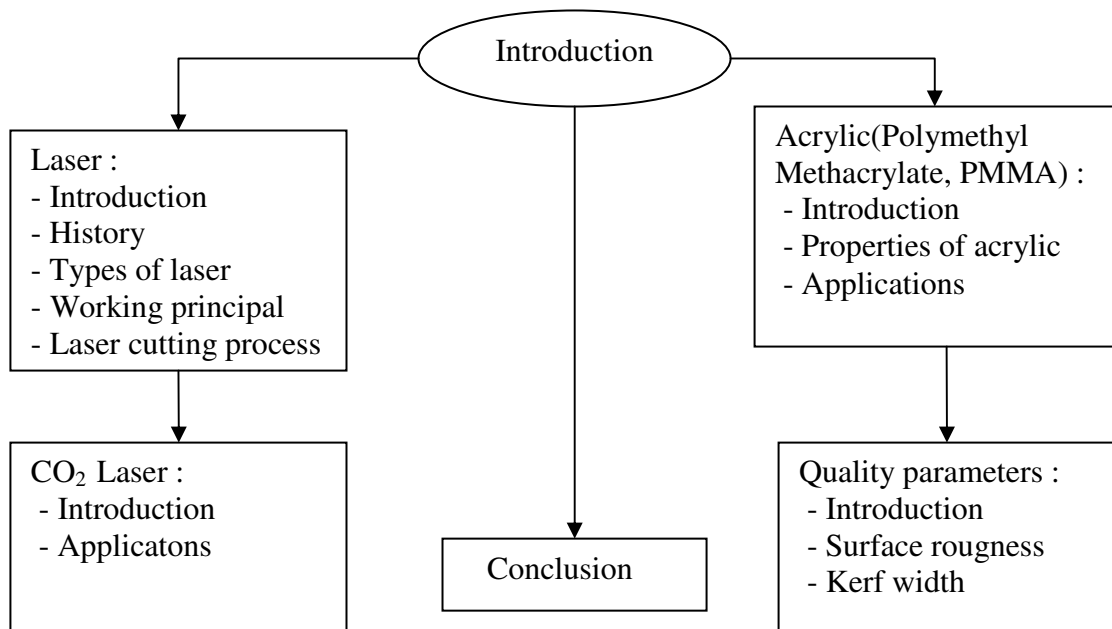
Figure 2.1 : Flowchart of Chapter 2

2.2 LASER

2.2.1 Introduction

Laser are widely used in industry as cutting tools due to ultra flexibility of the cutting conditions, obtaining high quality end product, quick set up, non-mechanical contact between the workpiece and the tool, and small size of the HAZ. A laser is an electronic optical device that produces coherant radiation. An acronym LASER is stand for "Light Amplification by Stimulated Emission of Radiation," is a device that produces a concentrated, coherent beam of light by stimulating molecular or electronic transitions to lower energy levels, causing the emission of photons [3,4]. A typical laser emits light in narrow and produces low divergence beam of laser.

2.2.2 History of Laser

Table 2.1: Compiles histories of laser [12].

Year	Founders	Findings
1916	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 Willian R. Bennet and Ali Javan	First gas laser with continuous stimulated emission. Made first gas laser using helium and neon
1964	Kumar Patel	Gas (CO_2) 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.

Table 2.1 shows the history and deveploments of laser. Laser is founded by Albert Einstein in 1916. In his paper, Zur Quantentheorie der Strahlung in 1917 (On the Quantum Theory of Radiation), 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 for the absorption, spontaneous, and stimulated emission.

In 1954, Charles A. Townes and graduate students James P. Gordon and Herbert J. Zeiger produced the first microwave amplifier, a device operating on similar principles to the laser, but amplifying microwave rather than infrared or visible radiation. Townes's maser was incapable of continuous output. In 1955 Prokhorov and Basov suggested an optical pumping of multilevel system as a method for obtaining the population inversion, which later became one of the main methods of laser pumping.

Townes reports that he encountered opposition from a number of eminent colleagues who thought the maser was theoretically impossible -- including Niels Bohr, John von Neumann, Isidor Rabi, Polykarp Kusch, and Llewellyn H. Thomas. The term "laser" was first introduced to the public in Gould's 1959 conference paper "The LASER, Light Amplification by Stimulated Emission of Radiation.

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".

Later in 1960 the Iranian physicist Ali Javan, working with William R. Bennett and Donald Herriot, made the first gas laser using helium and neon. Javan later received the Albert Einstein Award in 1993 [2].

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 (77 K).

In 1970, Zhores Alferov in the Soviet Union and Izuo Hayashi and Morton Panish of Bell Telephone Laboratories independently developed laser diodes continuously operating at room temperature, using the heterojunction structure.

2.2.3 Types of Laser

There are many different types of lasers. The laser medium can be a solid, gas, liquid or semiconductor. Lasers are commonly designated by the type of lasing material employed such as [13]:

i. Solid-state lasers have lasing material distributed in a solid matrix (such as the ruby or neodymium:yttrium-aluminum garnet "Yag" lasers). The neodymium-Yag laser emits infrared light at 1,064 nanometers (nm).

ii. Gas lasers (helium and helium-neon, HeNe, are the most common gas lasers) have a primary output of visible red light. CO_2 lasers emit energy in the far-infrared, and are used for cutting hard materials.

iii. Excimer lasers use reactive gases, such as chlorine and fluorine, mixed with inert gases such as argon, krypton or xenon. When electrically stimulated, a pseudo molecule (dimer) is produced. When lased, the dimer produces light in the ultraviolet range.

iv. Dye lasers use complex organic dyes, such as rhodamine 6G, in liquid solution or suspension as lasing media. They are tunable over a broad range of wavelengths.

v.   Semiconductor lasers, sometimes called diode lasers, are not solid-state lasers. These electronic devices are generally very small and use low power. They may be built into larger arrays, such as the writing source in some laser printers or CD players.

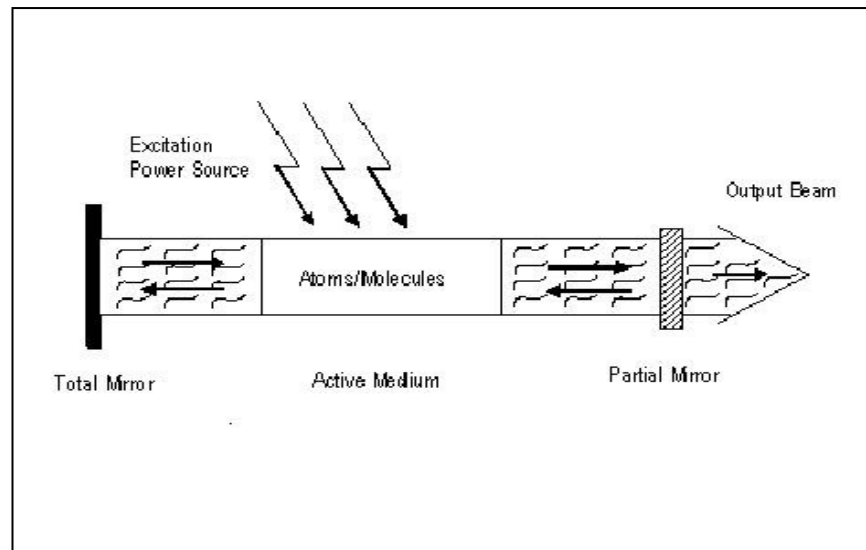## 2.2.4   Laser Working Principal

Figure 2.2: Basic component of laser [12].

Figure 2.2 above shows the basic component of laser. The component consist pumping source, total mirror, partial mirror, active medium and laser beam. Pumping source produce the light to excite the atom in laser medium to produce the photon. The back mirror has 100% reflection and front mirror has 95% reflection. The beam will produce as a output of laser.

When power is supplied by pumping source, the atom and molecules in laser medium will excite. The atom will absorb energy from the pumping source and start to excite to higher level and will produce the photons. At certain level, the atom will stimulate emission with another photon from other atom. An instense pulse of light (photons) will be realised is of single wavelength, thus allowing or minimum divergence.

When the light pulse build up to higher power, energy store in the medium will reflected by back mirror that has 100% reflection and will drain through front mirror that has 95% reflection, so that the beam of laser will produced. The laser light beam is coherent and has high energy content. When focused on a surface, laser light creates the heat used for welding, cutting and drilling [12].

2.2.5   Laser Cutting Process

Cutting with laser is both fast and accurate. Laser cutting will provide clean, smooth cuts that are very precise and accurate. Laser cutting can be describe as a vaporization process. As the beam moves, the heat from the laser actually vaporizes the workpiece as it passes by. Laser cutting is a hot cutting manufacturing and fabricating process using an industrial laser for the cutting of material. The beam of the laser is an extremely coherent radiation of a wavelength, meaning the beam will not dissipate like conventional light beams. The focused beam of the laser makes it best suited for the energy transfer necessary to cut metals by melting or burning the material along a cut line. Assist gas sweeps the cut area clean. The cutting process is precision controlled through a combination of CNC and the CAD computer systems.

Distinct advantages exist for using laser cutters over other cutting methods. Excellent control of the laser beam with a stable motion system achieves an extreme edge quality. Laser-cut parts have a condition of nearly zero edge deformation, roll-off or edge factor. Laser cutters have higher accuracy rates over other methods using heat generation, as well as water jet cutting. Laser cutting is faster than conventional tool-making techniques and has a quicker turnaround for parts regardless of complexity because design changes can be easily accommodated [11,14].

Laser cutting does have a few disadvantages. The material being cut gets very hot, so in narrow areas thermal expansion may be a problem. Distortion can be caused by oxygen, which is sometimes used as an assist gas, because it puts stress into the cut edge of some materials; this is typically a problem in dense hole patterns. Lasers also

require high energy, making them costly to run. Lasers are not very effective on metals such as aluminum and copper alloys due to their ability to reflect light as well as absorb and conduct heat. Neither are lasers appropriate to use on crystal, glass and other transparent materials.

Lasers, even low-powered ones, are potentially hazardous to a person's eyesight. The laser beam can focus on an extremely small spot on the retina, causing permanent burn damage in seconds. Infrared and ultraviolet lasers are even more dangerous because the "blink reflex" protects the eyes only if the light can be seen. Lasers are divided into five safety classes based on wavelength and maximum output power. Lasers in Class I are inherently safe because of a low output power or an enclosure that cannot be opened in normal operation without the laser automatically switching off. In Class II, the blinking reflex will prevent eye damage; most laser pointers are in this class. The lasers in Class IIIa have large beam diameters and are mostly dangerous in combination with optical instruments, which change beam diameter. If the beam of a laser in Class IIIb enters the eye directly or is reflected into the eye, damage can result. Class IV lasers are highly dangerous. Damage to the eyes and skin can be caused even by indirect scattering of light from the beam [5].

Laser generates high intensity beam of infrared light that produces from collision of photon. This beam is focused onto the surface of specimen by convergence lens as shown in figure 2.3 below. Before cutting process, the specimen is heated and establishes a much localized melt. The molten material produced on cut edge and will eject away by assist gas that through out from nozzle, so that the beam can through the specimen. When the beam through the specimen, the cutting process will begin [5].
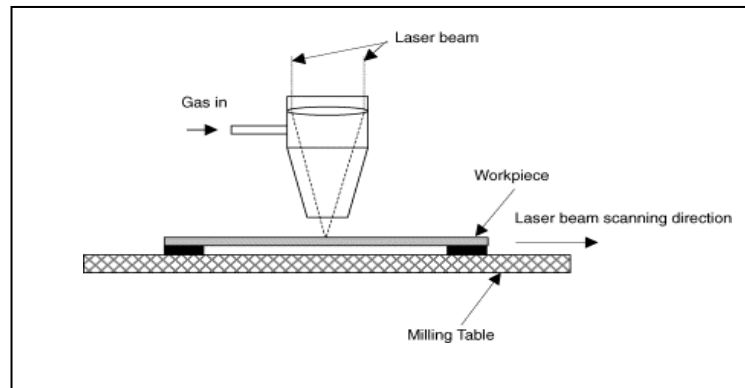
Figure 2.3: The cutting process.

2.3   CARBON DIOXIDE (CO$_2$) LASER

2.3.1   Introduction

The Carbon Dioxide (CO$_2$) laser was one of the earliest gas lasers to be developed invented by Kumar Patel of Bell Labs in 1964 [12], and is still one of the most useful. CO$_2$ lasers are the highest-power continuous wave lasers that are currently available. They are also quite efficient, ease of construction and have continuous power capability. The ratio of output power to pump power can be as large as 20% [15].

The CO$_2$ laser produces a beam of infrared light with the principal wavelength bands centering around 9.4 and 10.6 micrometers. CO$_2$ laser consist three mixture gases as a medium which are CO$_2$, N$_2$ and He. CO$_2$ is the primary lasing medium where N$_2$ and He to improve excite CO$_2$ to produce photon, and also to improve efficiency and extend lifetime [15].

2.3.2 Applications

Because of the high power levels available (combined with reasonable cost for the laser), CO_2 lasers are frequently used in industrial applications for cutting and welding, while lower power level lasers are used for engraving. There are some examples of CO_2 lasers applications in industries such as [16]:

i.   Medical:

The highly collimated beam of a laser can be further focused to a microscopic dot of extremely high energy density. This makes it useful as a cutting and cauterizing   instrument. Lasers are used for photocoagulation of the retina to halt retinal hemorrhaging and for the tacking of retinal tears. Higher power lasers are used after cataract surgery if the supportive membrane surrounding the implanted lens becomes milky.

ii.   Welding and cutting :

The highly collimated beam of a laser can be further focused to a microscopic dot of extremely high energy density for welding and cutting. The automobile industry makes extensive use of carbon dioxide lasers with powers up to several kilowatts for   computer controlled welding on auto assembly lines.

iii.   Military :

Because the atmosphere is quite transparent to infrared light, CO_2 lasers are also used for military range finding using LIDAR techniques. LIDAR (Light Detection and Ranging) is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The prevalent method to determine distance to an object or surface is to use laser pulses.

iv.   Barcode scanners :

Supermarket scanners typically use helium-neon lasers to scan the universal barcodes to identify products. The laser beam bounces off a rotating mirror and scans the code, sending a modulated beam to a light detector and then to a computer which has the product information stored. Semiconductor lasers can also be used for this purpose.

v.   Heat treatment :

Heat treatments for hardening or annealing have been long practiced in metallurgy. But lasers offer some new possibilities for selective heat treatments of metal parts. For example, lasers can provide localized heat treatments such as the hardening of the surfaces of automobile camshafts. These shafts are manufactured to high precision, and if the entire camshaft is heat treated, some warping will inevitably occur. But the   working surfaces of the cams can be heated quickly with a carbon dioxide laser and hardened without appreciably affecting the remainder of the shaft, preserving the precision of manufacture.

2.4   ACRYLIC (POLYMETHYL METHACRYLATE, PMMA)

2.4.1   Introduction

Acrylics are polyester based on acrylic acids (propenoic acid - $CH_2=CHCO_2H$), that is they are the products formed by the reaction of an acrylic acid and alcohol. The esters of acrylic acid polymerise readily to form exceptionally clear plastics. There are two basic types of acrylic, extruded and cell cast. Extruded or "continuous cast" acrylic is made by a less expensive process. It's softer, can scratch easier and may contain impurities. Cell cast acrylic is a higher quality acrylic and U.S domestic cell cast is good choice for applications that required the best. Imported cell cast acrylic is often manufactured to lesser standards. Acrylic plastic produce in various shape and various colour but its commonly comes in transparent. Acrylic plastic sheets are formed by a process known as bulk polymerization [17].

2.4.2   Properties of Acrylic

Acrylics is widely used in industry because it is a useful, clear plastic that resembles glass but has properties that make it superior to glass in many ways. Acrylic also insulates better than glass and lighter than glass, that why it is chosen over glass in many reason. Common brands of high grade acrylic include Polycast, Lucite and Plexiglass [18].

A transparency rate of 93% makes acrylic the clearest material known. Very thick glass will have a green tint, while acrylic remains clear. This makes working with acrylic much easier. There are also no seams in acrylic structures, as chemical welding at the molecular levels actually melts seam into one piece of solid material, so welded and polished are invisible. The physical properties of the acrylics (such as gloss, hardness, adhesion and flexibility) can be modified by altering the composition of the monomer mixture used in the polymerisation process.Table 2.2 shows the properties of acrylic.

Table 2.2: Properties of an acrylic [19].

Physical Properties	Metric	English
Density	0.940 – 1.21 g/cc	0.0340 – 0.0437 lb/in^3
Melt flow	0.112 – 27.0 g/10min	0.112 - 27.0 g/10min
Mechanical Properties	**Metric**	**English**
Tensile strength, ultimate	19.3 – 90.0 Mpa	2800 – 13100 psi
Tensile strength, yield	5.72 – 85.0 Mpa	830 – 12300 psi
Tensile creep modulus, 1hour	1800 – 2700 Mpa	261000 – 392000 psi
Thermal Properties	**Metric**	**English**
Thermal conductivity	0.187 – 0.216 w/m-k	1.30-1.50 BTU-in/hr-ft²-°F
Melting point	130 – 157 °C	266 – 315 °F
Processing Properties	**Metric**	**English**
Processing temperature	-48.0 – 256 °C	-54.4 – 509 °F
Feed temperatue	200 – 220 °C	392 – 428 °F
Optical Properties	**Metric**	**English**
Refractives index	1.38 – 1.54	1.38 – 1.54
Corrosion resistance	Good	
Chemical resistance	Godd	
Process ability	Good	

2.4.3 Applications

In the present day, the applications of acrylic are widely used to change in glass applications. Acrylic is used to make various products such as shower doors, bath enclosures, windows and skylight. It is many stronger than glass, making it much more impact resistance and there for safer. Falling against an acrylic shower door will not likely break it.

Acrylic widely used in applications requiring clear durable surface such as in the aircraft and automobile industries. Acrylic also used for sight gauges, windshields, meter faces, protective covers, safety shields, tanks, desk tops, displays, trays, and chair pads [18].

2.5 CUTTING QUALITY

2.51 Introduction

Cut quality can be described as quality of product we get after the cutting process. In laser cutting process, many manufacture are using trial and error method to find a suitable laser cutting parameter to get good cut quality. This method not only wastes time but increase the cost of the production. During cutting process, the parameters of laser cutting must consider to produce good product. In laser cutting process, proper selection of laser and workpiece parameters (cutting parameters) increases the laser cutting efficiency and improves the end product quality. In this project, there are only two cutting qualities have been considered which are:

i. Surface roughness
ii. Kerf width

2.5.2 Surface Roughness

Roughness consists of surface irregularities which result from the various machining process. These irregularities combine to form surface texture. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviation are large, the surface is rough and the surface is smooth when the deviation is small. The height, shape, arrangement and direction of these surface roughness irregularities on the workpiece depend upon a number of factors such as feed rate, cutting speed and depth of cut [1]. Figure 2.4 shows the example of surface roughness structure.
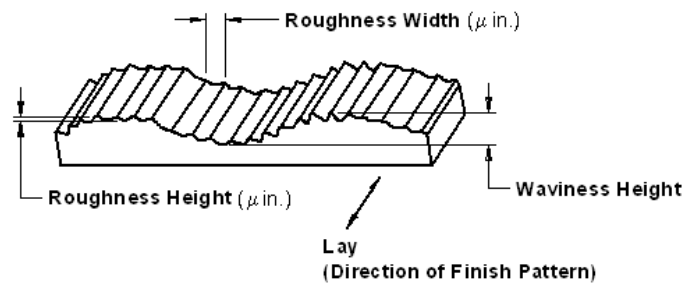

Figure 2.4: Example of surface roughness structure.

2.5.3 Kerf Width

Kerf is a groove, slit, or notch made by a cutting tool such as a laser cutter or the width of a groove made by a laser cutting tool. In the laser cutting process, the kerf was form is depend upon laser cutting parameter such as power, feed rate, the lens focal distance, the type of cutting gas used in the laser, the properties of the material being cut, the workpiece thickness. Figure 2.5 shows the example of kerf width was form by laser cutting tool [20].
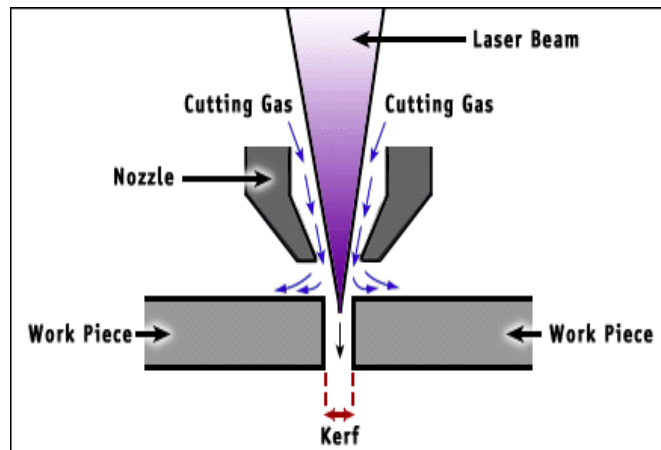
Figure 2.5: Example of kerf width

2.6 CONCLUSION

The overall literature review in this chapter explains the concept of laser, the characteristics of acrylic as a specimen and the cutting quality parameter. To get maximum cutting quality, the acceptable limit of power and feed rate of CO_2 laser will be obtained. Chapter 3 will explain about the proposed working method and procedures used in this project.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is the systematic study of method that is can be or have been applied within a discipline. Methodology is very important in research and study to perform the best method used during design or doing analysis. The proper methodology approaches will appear the good result and excellent performance of design.

3.2 PROJECT METHODOLOGY

Based on Chapter 2 as guidelines, flow process of this project will be explained detail in this chapter. Proper experiment set up is chosen based on the suitability of each method to the experiment. The figure 3.1 below shows the general flow chart of this project and the figure 3.2 will be show the experimental flow chart.
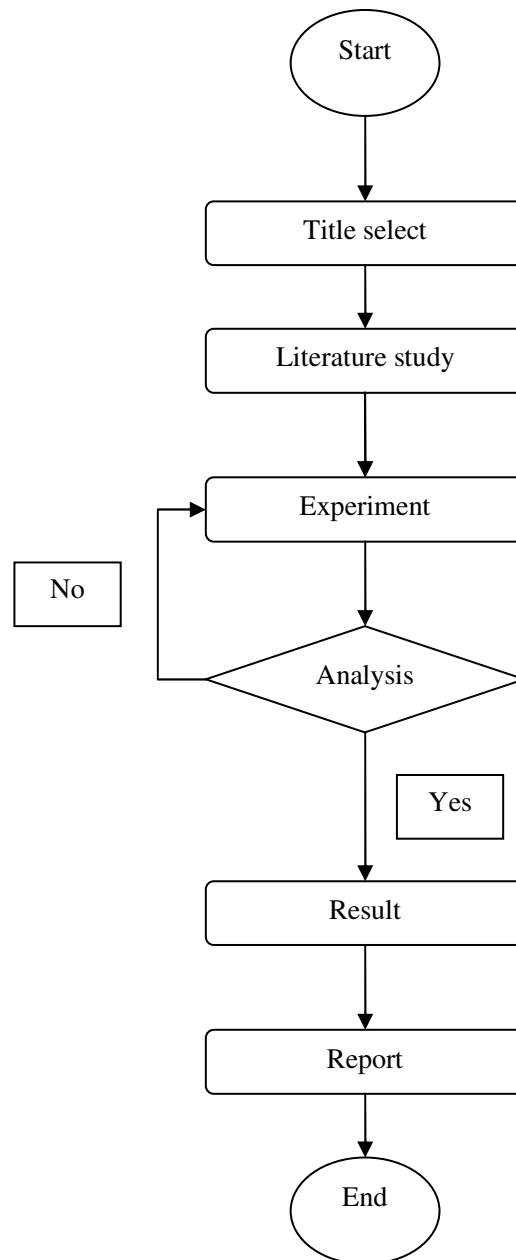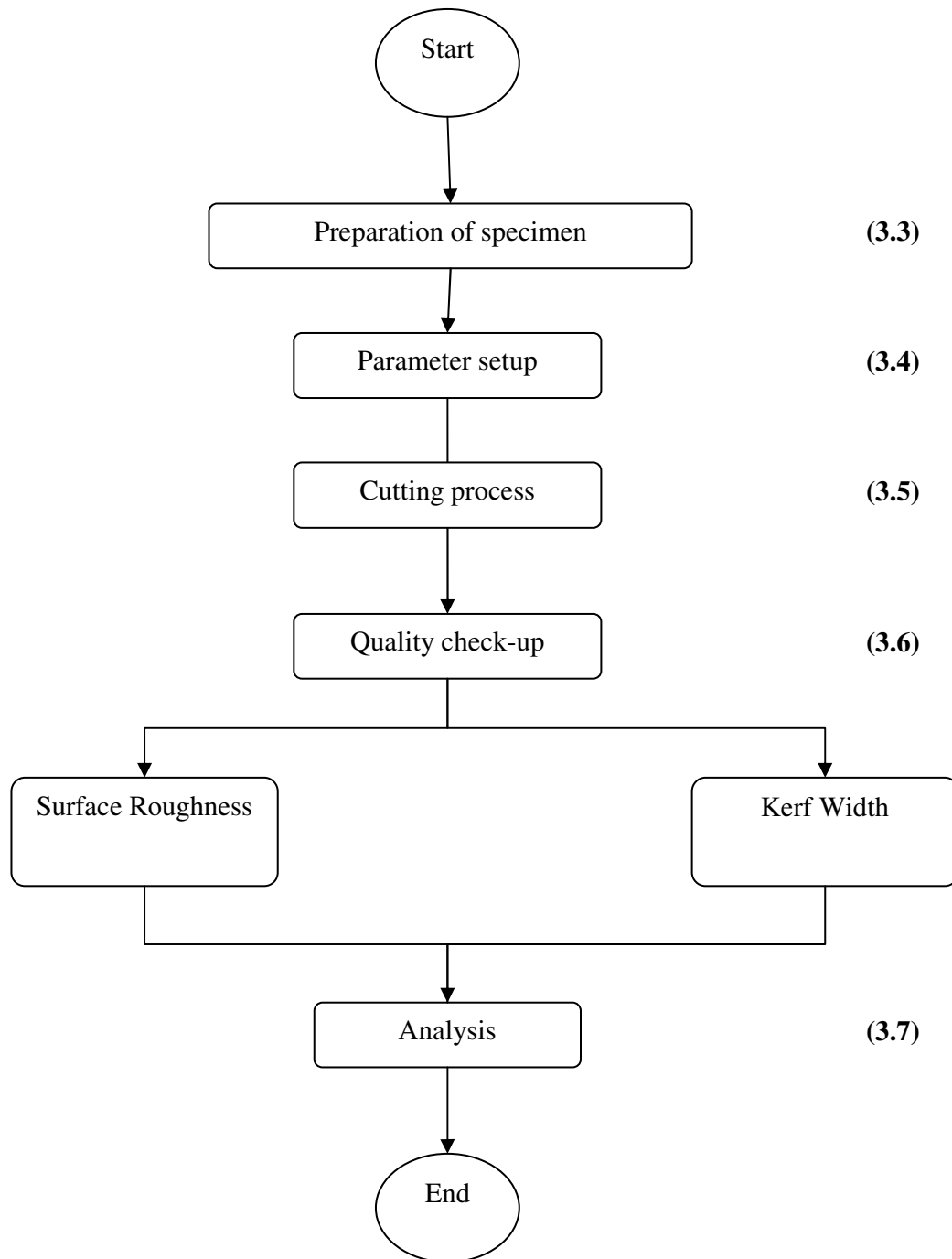
Figure 3.1: General flow chart

```
                              ┌─────────┐
                              │  Start  │
                              └────┬────┘
                                   │
                                   ▼
        ┌──────────────────────────────────────────┐
        │          Preparation of specimen          │        (3.3)
        └─────────────────────┬────────────────────┘
                              │
                              ▼
                   ┌─────────────────────┐
                   │    Parameter setup   │                   (3.4)
                   └──────────┬──────────┘
                              │
                              ▼
                   ┌─────────────────────┐
                   │    Cutting process   │                   (3.5)
                   └──────────┬──────────┘
                              │
                              ▼
                   ┌─────────────────────┐
                   │   Quality check-up   │                   (3.6)
                   └──────────┬──────────┘
```

Start

Preparation of specimen   (3.3)

Parameter setup   (3.4)

Cutting process   (3.5)

Quality check-up   (3.6)

Surface Roughness

Kerf Width

Analysis   (3.7)

End

Figure 3.2: Flow chart of experimental setup

3.3   PREPARATION OF SPECIMEN

The acrylic will be used as a specimen. The dimension of this specimen is 40mm x 40mm and 3mm of thickness. The specimen is drawing by using CAD software (SOLID WORK) and convert to ART CAM Pro V.9.1 software. Figure 3.3 shows the design of the specimen.
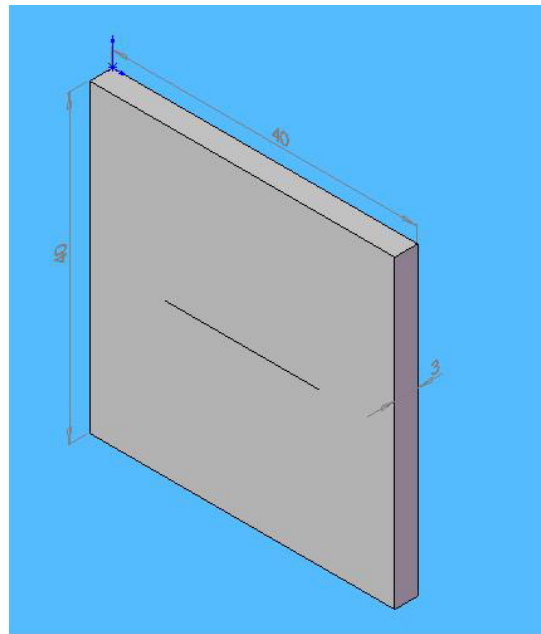

Figure 3.3: Design of the Specimen

3.4   PARAMETER SETUP AND EXPERIMENT

Based on the problem statement, research on the project is started. At this stage, all information for literature review is collected and analyze. This information consist material to be selected and the equipment to be used in detail. All the parameters will be used were prepared since the experiment will be started. A CO_2 laser machine in FKM lab delivered output power of 30W was used in this experiment but for safety and precaution steps only 25.5W was used in this cutting process.

Before cut the specimen using laser machine, the procedure to use laser machine should follow properly and at least understanding the specification of the laser machine to make sure the cutting process is exactly right base on the machine capable of. Table 3.1 below represents the general specification of the laser cutting machine.

Table 3.1: The general specification of the laser cutting machine

Specification	Data
Laser Source	
Wavelength	$10.57 - 10.63$ μm
Power Output (Continuous)	30W
Power Stability	
- From Cold Start	$\pm 5\%$
- After 2 minutes	$\pm 3\%$
Mode Quality	TEM, 95% purity
Beam Quality	$M2 < 1.1 \pm 0.1$
Polarization	Linear, horizontal
Marking Head	
Aperture	15mm
Interface	XY2-100 16-bit Digital
Objective Lens	f = 100mm
Maximum Field Size	70 x 70 mm
Mark speed	3500mm per sec
Writing Speed	>600 possible
- good quality	400 char per sec
- excellent quality	350 char per sec
Power Supply	
Voltage	85-264 Vac, single phase
Frequency	50/60 Hz
Operating Temperature	$-10-+70^{o}C$
Humidity	$20 - 95\%$ RH (non condensing)

3.5   CUTTING THE SPECIMEN

In this process, the specimen was prepared will cut using the CO_2 laser machine that controlled by computer. The raw material will cut to eleven specimens with used different feed rate which dimension 40mm x 40mm as shown in figure 3.3. This cutting process used eleven different feed rate values. The constant power will be set into 25.5Watt. Before start the cutting process, the laser machine was setup properly. Design the specimen using SOLIDWORK software and convert the design into 2D drawing with custom scale. Then file will be saved as filename.DWG. Open the filename.DWG with Mean Executable Software. Setup machining process and save that file as filename.txt. Setup the cutting parameter properly and run the experiment.

3.5.1   Cutting Step

Figure below show the example of cutting step. After the design in SOLIDWORK software saved with DWG format, that file will open with Art Cam Pro V.9.1. The step will shows with the figure below.
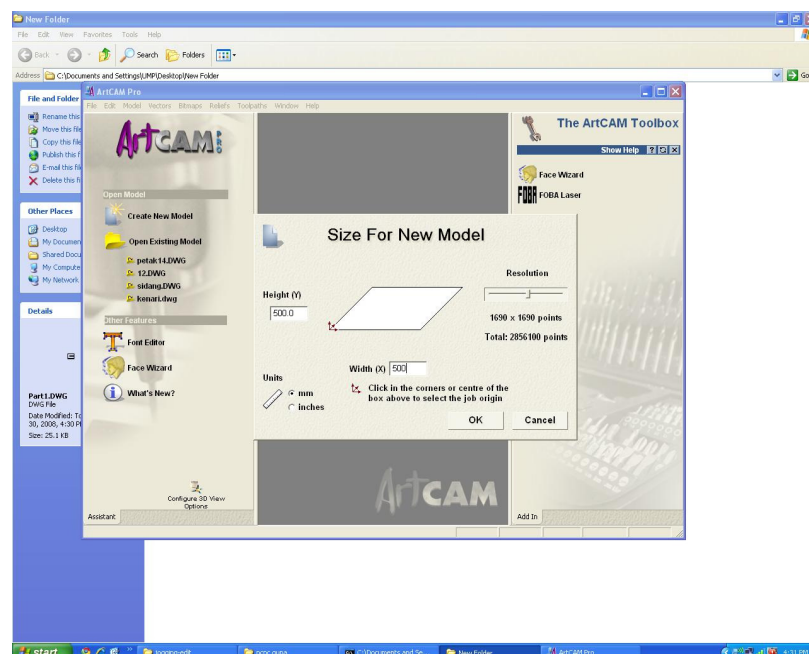
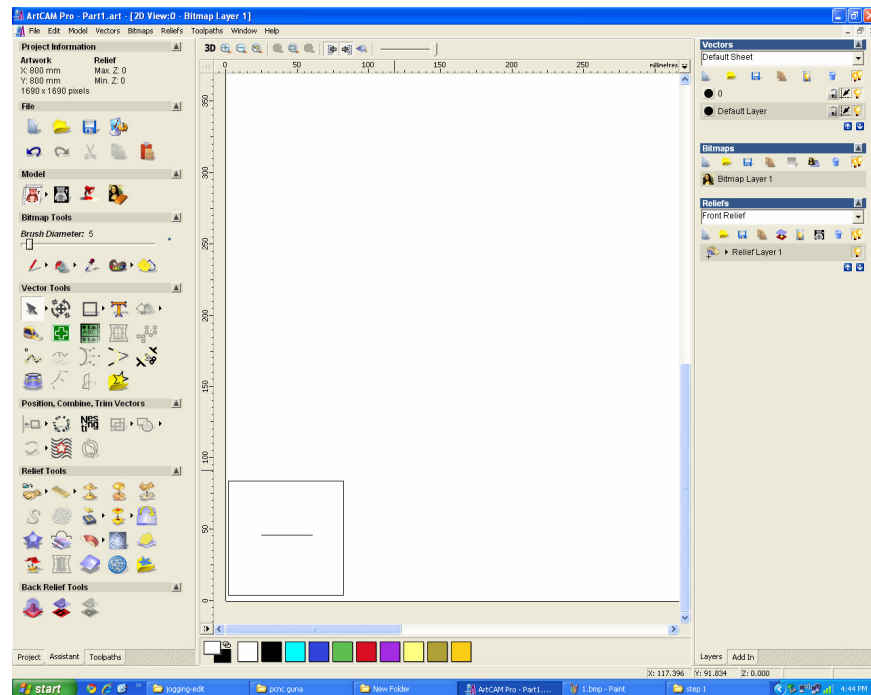**Figure 3.4:** Setup the dimension of width and height in millimeter is 500mm.

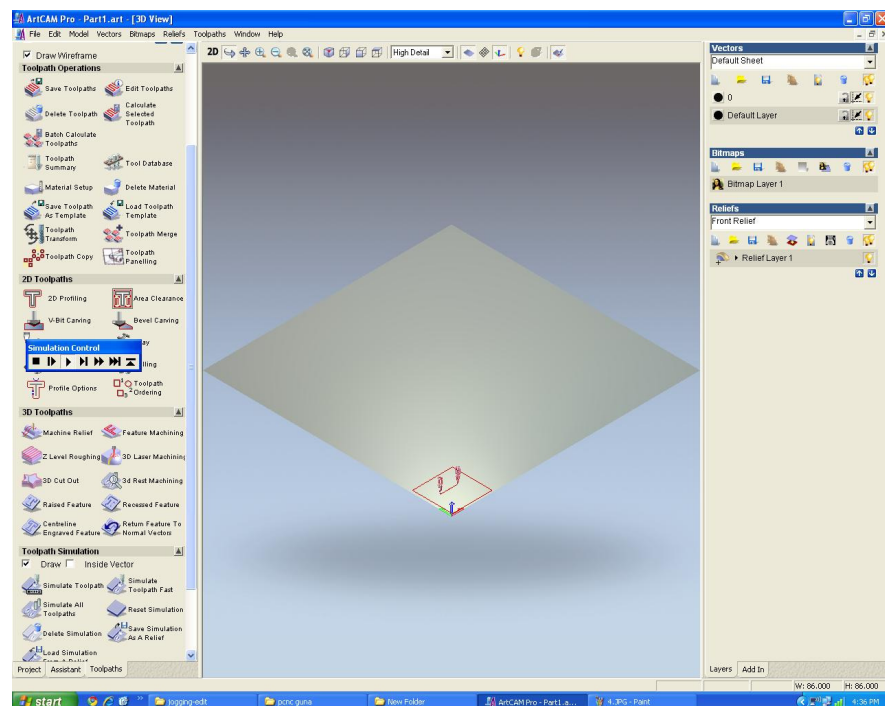**Figure 3.5:** Edit the drawing part with deletes all unnecessary line or drawing.

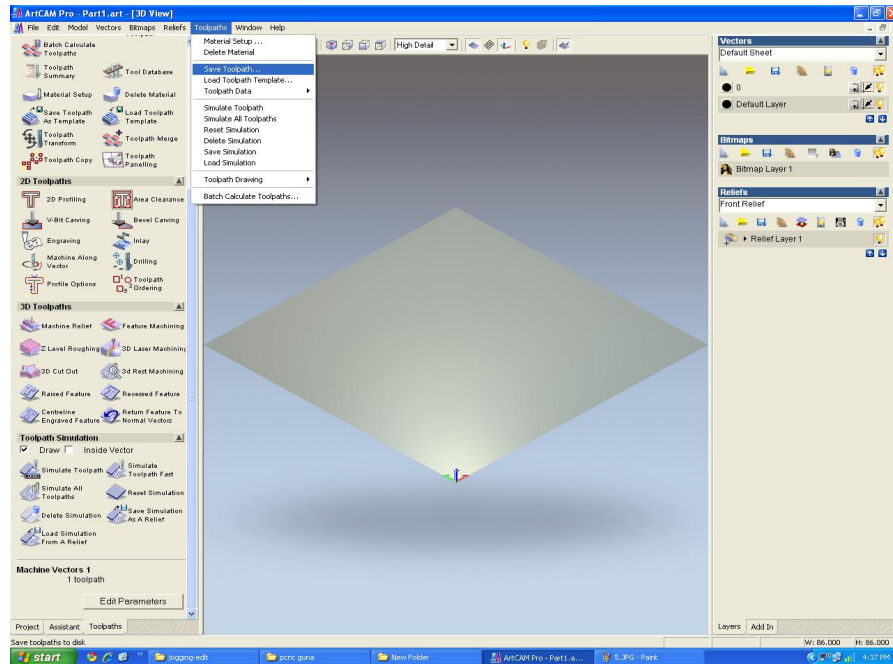

Figure 3.6: Step how to simulation for cutting process.

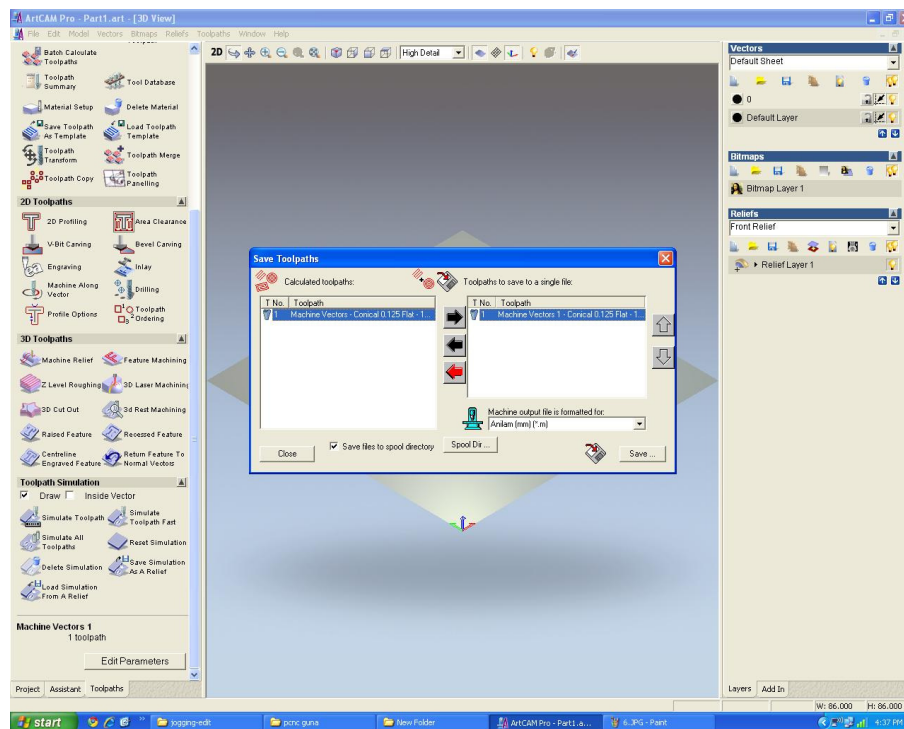**Figure 3.7:** Show the first step how to save the tool path.

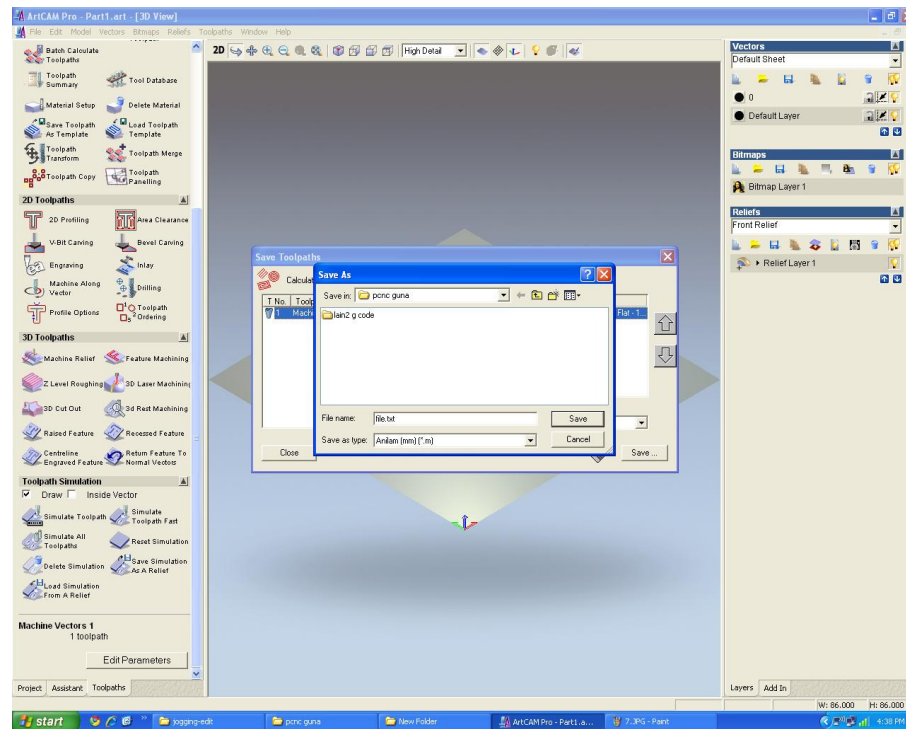**Figure 3.8:** Show the second step to save the tool path.

Figure 3.9: Step to save the tool path after simulation. The Art Cam format will be saving as txt. file example file.txt.
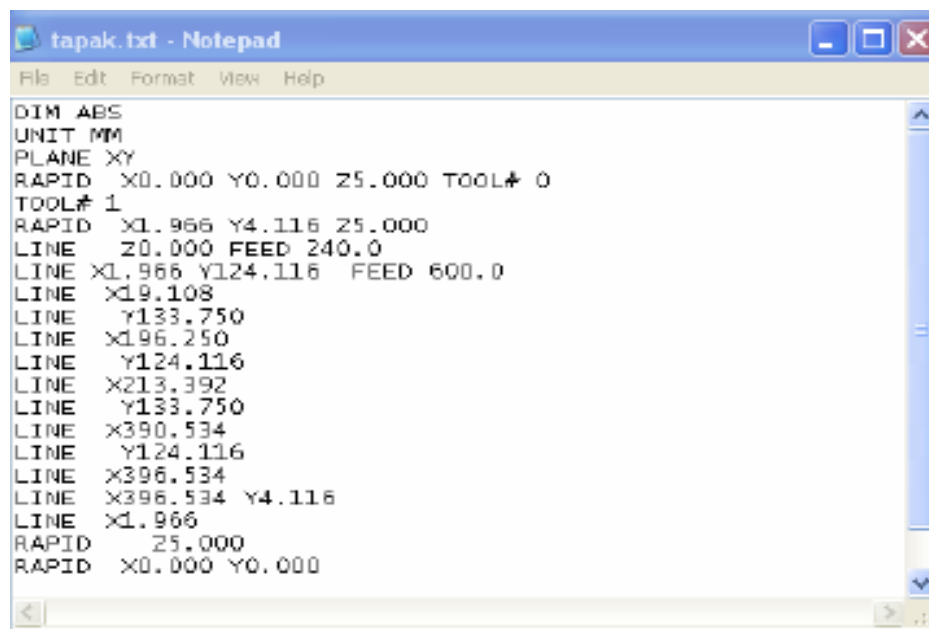

Figure 3.10: Edit G- code before run in PCNC.

3.6   CHECKING THE CUT QUALITY

After the cutting process done, the next step is checking the cut quality of the specimens. In this process, the laser cut quality was monitored by measuring surface roughness and kerf width. The process of checking the cut quality was used different equipment. The surface roughness tester that used in to check the surface quality is Perthometer and Image Analyzer was used to measure the kerf width. The detail of that process will explained as below.

3.6.1   Surface Roughness

Surface roughness can be determined by using surface roughness tester Mahrsurf XR 20 with Perthometer S2. The cut edge of specimen will measure into three points and the average of roughness surface can be determined. The data output will present in term of graph by Perthometer. Before measured the surface of specimens, the Perthometr machine should be setup to get the roughness average, Ra approximately about 2.4µm using tester sample. Figure 3.11 shows the Perthometer machine that been used. Figure 3.12 shows the specimen setup to measured surface roughness.
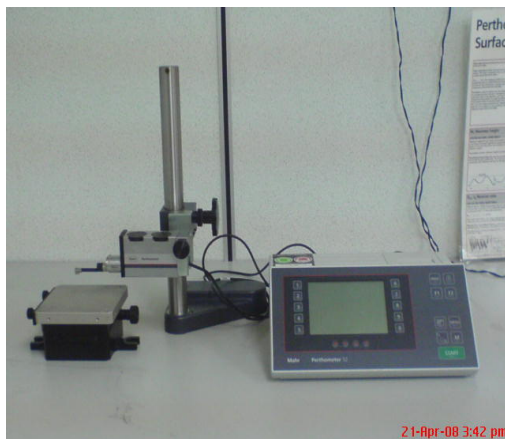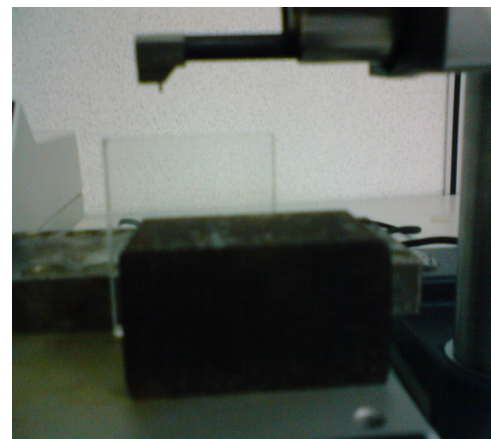

Figure 3.11: Perthometer machine   **Figure 3.12:** Specimen setup

3.6.2 Kerf Width

Kerf width can be measured by using Image Analyzer machine. The specimen will focus by image analyzer with 5X (five calibration) and the distance for kerf width will measured in 3values and the average will taken. The measured of kerf width will take on top surface and bottom surface of the specimens. Figure 3.13 shows the Image Analyzer machine.

Figure 3.13: Image Analyzer machine

3.7 ANALYZING THE CUT QUALITY

After the checking cut quality process done, the data was analyzed by manual calculation method. The results will shows in terms table and graph. From the result, the relationship between feed rate and the cut quality parameter can be determined and effect of different feed rate on surface roughness and kerf width quality will discuss.

3.8 CONCLUSION

As a conclusion, the purposed of the project methodology and the information in this chapter is to guide the flow of project process to analyze the laser cut quality that was start from cutting process and analyze the results. The cutting process is the most important process to get the best result. However checking the cut quality is also important process because can affect the result if not followed the procedure during checking process. Chapter 4 will explain about the result and discussion.

CHAPTER 4

RESULTS AND DISCUSSION

4.1   INTRODUCTION

This chapter will discuss about the result and discussion of this project. In this chapter, the result is gained from Image Analyzer to measure kerf width and Perthometer machine to measure surface roughness. From eleven samples of specimens, three values have been collected from each specimens and the average of this value will calculated. This result will shows in tables which table for surface roughness result and kerf width result. The results are then analyzed and graphs were plotted that are surface roughness versus feed rate and kerf width versus. feed rate.

Through out this chapter, the relationship between effect of feed rate to surface roughness and kerf width quality will discuss. Quality of kerf width will discuss in term top and bottom surface of the specimen. There are also some error that occurred during experiment process will be discussed in the end of this chapter.

4.2   CONVERTING THE FEED RATE UNIT

The unit of feed rate of laser cutting machine at FKM lab that used in this project used in delay (µs). The unit of feed rate has been set up in the laser machining program. Before analyze the results, the unit of feed rate should be convert from delay (µs) to (mm/s) using equation 4.1 below.

$$Feedrate = \frac{1\,pulse}{2 \times Delay} \times \frac{Xmm}{10000\,pulse} \qquad (4.1)$$

From the equation 4.1, X is the distance that the laser can cut during one revolution of the servo-motor. The distance was measured manually when the delay in laser machine program was set up. When the delay was set up from 1200µs to 2200µs, the distance that laser can travel during cutting process is constant which is the distance value is 50mm. The 10000 pulse is the constant value that has been set up in the laser machine program.

The different delay was set up in eleven values to get different feed rate. The delay was set up in file pcline.h in the laser machine program. Figure 4.1 shows to change the feed rate to get different feed rate during cutting process. The value of delay changed in the delay's column and was set up from   1200µs to 2200µs. These are step to convert feed rate from delay (µs) to (mm/s) using the equation 4.1.

Sample of Calculatio

$$Feedrate = Frequency \times \frac{Dis\tan ce}{Pulse}$$

$$Feedrate = \frac{1\,pulse}{2 \times Delay} \times \frac{Dis\tan ce}{Pulse}$$

$$Feedrate = \frac{1\,pulse}{2 \times 1200\mu s} \times \frac{50mm}{10000\,pulse}$$

$$Feedrate = (416.667)\frac{pulse}{s} \times (5.0 \times 10^{-3})\frac{mm}{pulse}$$

$$Feedrate = 2.083mm/s$$

Change feed rate in delay column

Figure 4.1: Step to change the feed rate

All the value of feed rate that have been converted will shown in table 4.1. From the table 4.1, the feed rate value in mm/s is increase when the delay is decrease. When the delay used in laser machining program is about 1200µs, the feed rate or cutting speeds is higher than delay about 2200µs. That means when 1200µs used, the laser machine can cut or travel about 2.083mm in one second. Compare when 2200µs used, the distance that the laser can cut only about 1.136mm in one second.

Table 4.1: Table of converted feed rate

Feed Rate	
Delay (µs)	**(mm/s)**
1200	2.083
1300	1.923
1400	1.786
1500	1.667
1600	1.563
1700	1..471
1800	1.389
1900	1.316
2000	1.250
2100	1.190
2200	1.136

4.3   EXPERIMENTAL RESULT

Based on methodology, the laser cutting parameters were setup properly. Guided from instructor, the laser cutting conditions was setup before cutting process. Table 4.2 shows the laser cutting conditions. Figure 4.2 shows the laser cutting machine that used in this project and figure 4.3 shows the head of laser where the laser beam produce and through out from nozzle to cut the material.

Table 4.2: Laser cutting conditions

Parameter	Value
Material and thickness	acrylic (Polymethyl Methacrylate, PMMA)(3mm)
Delay	1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100 and 22000 µs
Feed rate (cutting speed)	1.136, 1.190, 1.250, 1.316, 1.389, 1.471, 1.563, 1.667, 1.786, 1.923, 2.083 (mm/s)
Power	Optimum power (85%) , 25.5 W
Frequency	50/60 Hz
Operating temperature	-10 - +71 degree/c
Wavelength	10.57 – 10.63 µm
Nozzle standoff height	9.7cm

Figure 4.2: Ilios CO_2 Laser Marking Machine 30 Watts

Figure 4.3: Head of laser

Cutting process will be starting to cut the raw material to specimens into square shape and the slit in the middle of the specimens. The data of surface roughness will be taken from three sides of the specimens and the distance of the slit will measured to get data of kerf width. Figure 4.1 shows the sample of specimen.
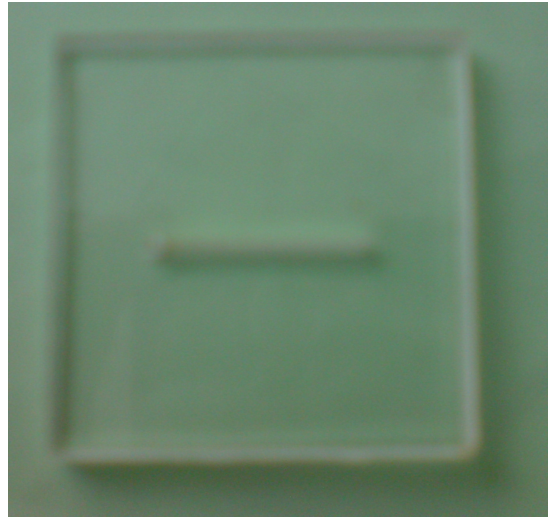
Figure 4.4: The sample of specimen

4.3.1 Effect of Feed Rate on the Surface Roughness

From the experiment, the surface roughness was measured used surface roughness tester Mahrsurf XR 20 with Perthometer S2 and the data were collected and show in table 4.3 below. Based on data in the table 4.3, the graft that represents the relationship between feed rate and surface roughness will be plot. Figure 4.5 and figure 4.6 shows the sample of image of surface structure that have cut using laser machine. From the figure 4.5 and figure 4.6, the surface structure produce is different when the different feed rate used.
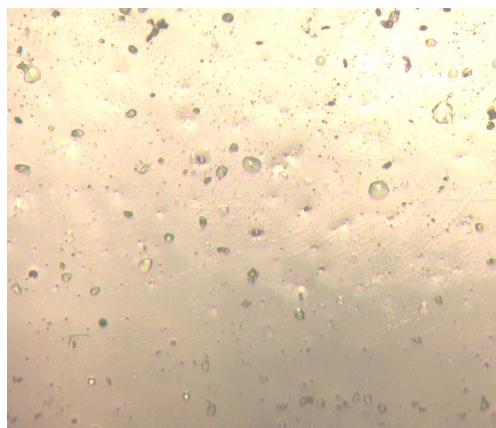
Figure 4.5: Surface structure at feed rate 1.250mm/s
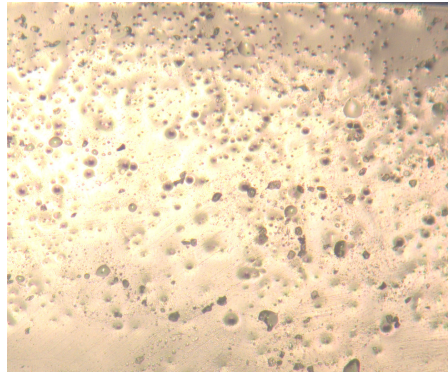
Figure 4.6: Surface structure at feed rate 2.083 mm/s

Table 4.3: Result of the Surface Roughness

No.	Feed rate (mm/s)	Reading (µm)			
		Reading 1	**Reading 2**	**Reading 3**	**Average**
1	1.136	0.104	0.127	0.096	0.1090
2	1.190	0.099	0.187	0.073	0.1197
3	1.250	0.103	0.174	0.139	0.1387
4	1.316	0.231	0.102	0.141	0.1580
5	1.389	0.171	0.146	0.153	0.1567
6	1.471	0.218	0.136	0.147	0.1670
7	1.563	0.164	0.169	0.186	0.1730
8	1.667	0.242	0.177	0.173	0.1973
9	1.786	0.271	0.110	0.361	0.2473
10	1.923	0.285	0.282	0.278	0.2817
11	2.083	0.380	0.364	0.331	0.3583

The effect of different feed rate on surface roughness is shown in figure 4.7. The graft gained from averaging three value of surface roughness from eleven specimens. X-axis representing as feed rate in mm/s and Y-axis represent as surface roughness in µm. From this figure, the graph was drastically increase from feed rate 1.563mm/s to 2.083mm/s while from the feed rate 1.136mm/s to 1.471mm/s the graph was slightly increase with increasing feed rate.
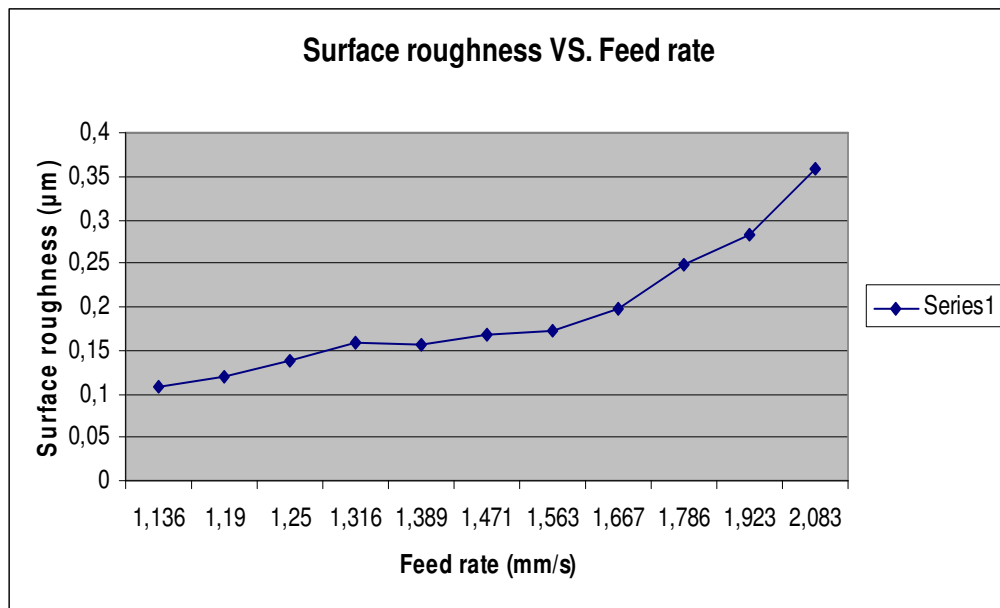
Figure 4.7: Graph of Surface Roughness versus Feed Rate

4.3.2   Effect of Feed Rate on the Kerf Width

From the experiment, the distance of kerf width was measured used Image Analyzer and the data were collected and show in table 4.4 below. Based on data in the table 4.4, the graft that represents the relationship between feed rate and kerf width will be plot. Figure 4.8 shows the sample image of top kerf width and figure 4.9 shows the sample image of bottom kerf width that have cut using laser machine.
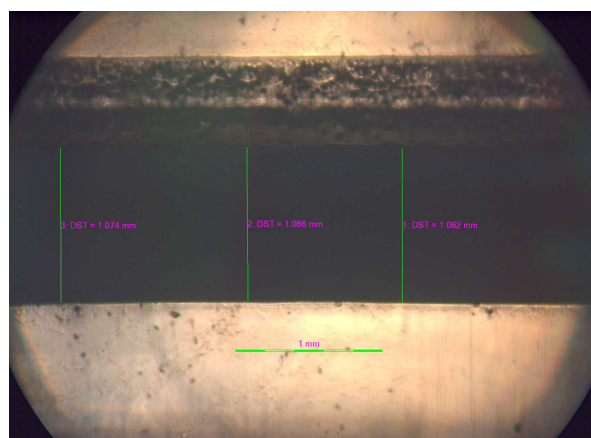
Figure 4.8: The sample of top kerf width at feed rate 1.471mm/s
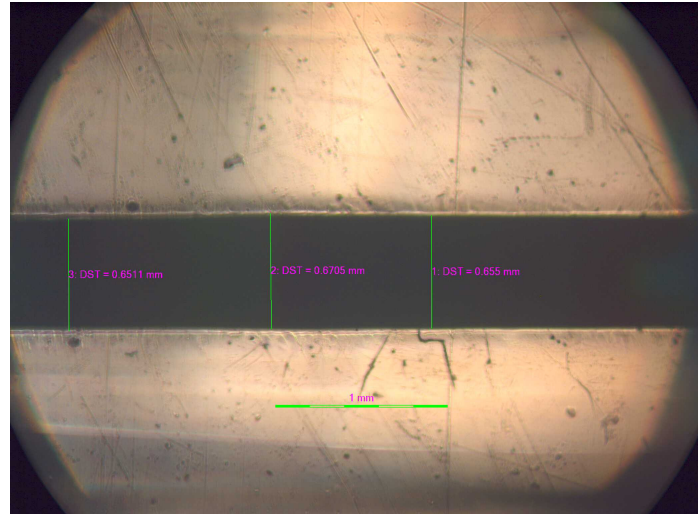
Figure 4.9: The sample of bottom kerf width at feed rate 1.136mm/s

Table 4.4: Result of the Top kerf Width

No.	Feed rate (mm/s)	Reading (µm)			
		Reading 1	**Reading 2**	**Reading 3**	**Average**
1	1.136	1.143	1.139	1.132	1.138
2	1.190	1.132	1.128	1.143	1.134
3	1.250	1.108	1.101	1.112	1.107
4	1.316	1.085	1.058	1.077	1.073
5	1.389	1.062	1.070	1.070	1.067
6	1.471	1.062	1.066	1.074	1.067
7	1.563	1.054	1.062	1.077	1.064
8	1.667	1.062	1.054	1.027	1.048
9	1.786	1.027	1.035	1.031	1.031
10	1.923	1.027	1.023	1.035	1.028
11	2.083	0.999	1.023	1.012	1.011

The effect of different feed rate on top kerf width is shown in figure 4.10. Each data point in this figure obtained by averaging three measured of kerf width as shown in figure 4.8. X-axis is representing as feed rate in mm/s while the Y-axis represent as kerf width at top surface in mm. From the figure 4.10 below, the graph were not smooth while at feed rate 1.19mm/s to 1.316mm/s the graft was drastically decrease with increasing feed rate.

Figure 4.10: Graph of Top Kerf Width versus Feed Rate

Table 4.5: Result of the Bottom Kerf Width

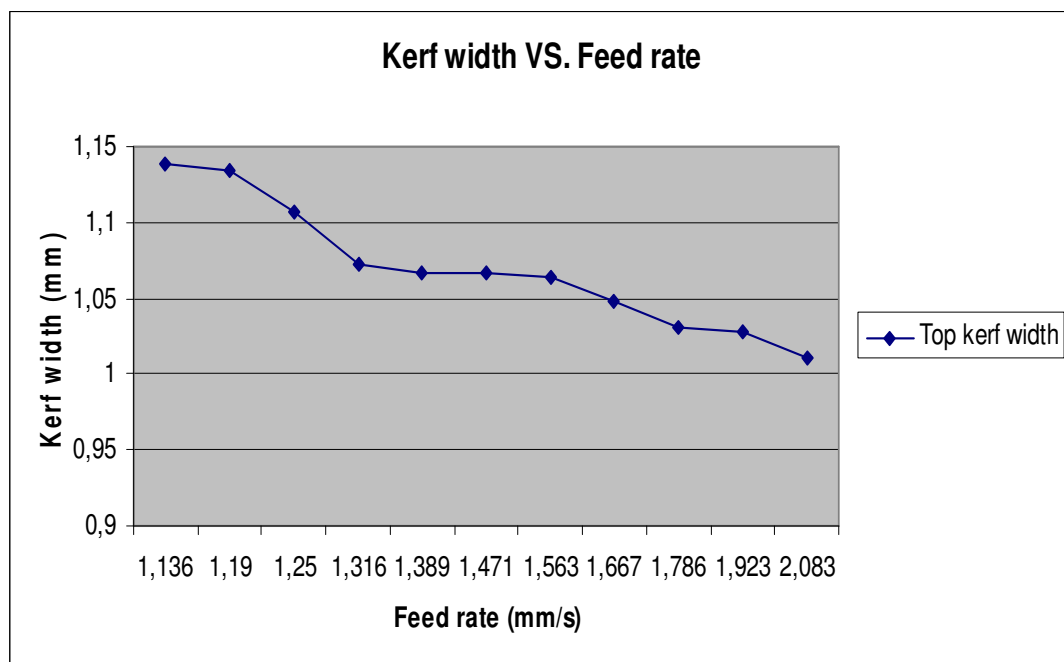| No.	Feed rate (mm/s)	Reading (µm)			
		Reading 1	Reading 2	Reading 3	Average
1	1.136	0.6550	0.6705	0.6511	0.6589
2	1.190	0.6472	0.6395	0.6279	0.6382
3	1.250	0.6434	0.6511	0.6162	0.6369
4	1.316	0.6124	0.6279	0.6317	0.6240
5	1.389	0.5930	0.5969	0.6124	0.6008
6	1.471	0.6046	0.6007	0.5891	0.5981
7	1.563	0.5891	0.5814	0.5930	0.5878
8	1.667	0.5814	0.5736	0.5775	0.5775
9	1.786	0.5659	0.5852	0.5775	0.5762
10	1.923	0.5891	0.5969	0.5775	0.5878
11	2.083	0.5775	0.5814	0.5697	0.5762

The effect of different feed rate on bottom kerf width is shown in figure 4.11. Each data point in this figure obtained by averaging three measured of kerf width as shown in figure 4.9. X-axis is representing as feed rate in mm/s while the Y-axis represent as kerf width at bottom surface mm. From the figure 4.11 below, the graph were not smooth while at certain point it slightly decrease and also drastically decrease at certain point. From feed rate 1.14mm/s to 1.39mm/s, increasing feed rate cause the graph drastically decrease and from feed rate 1.47mm/s to 2.08mm/s the graph was slightly decrease with increasing feed rate.
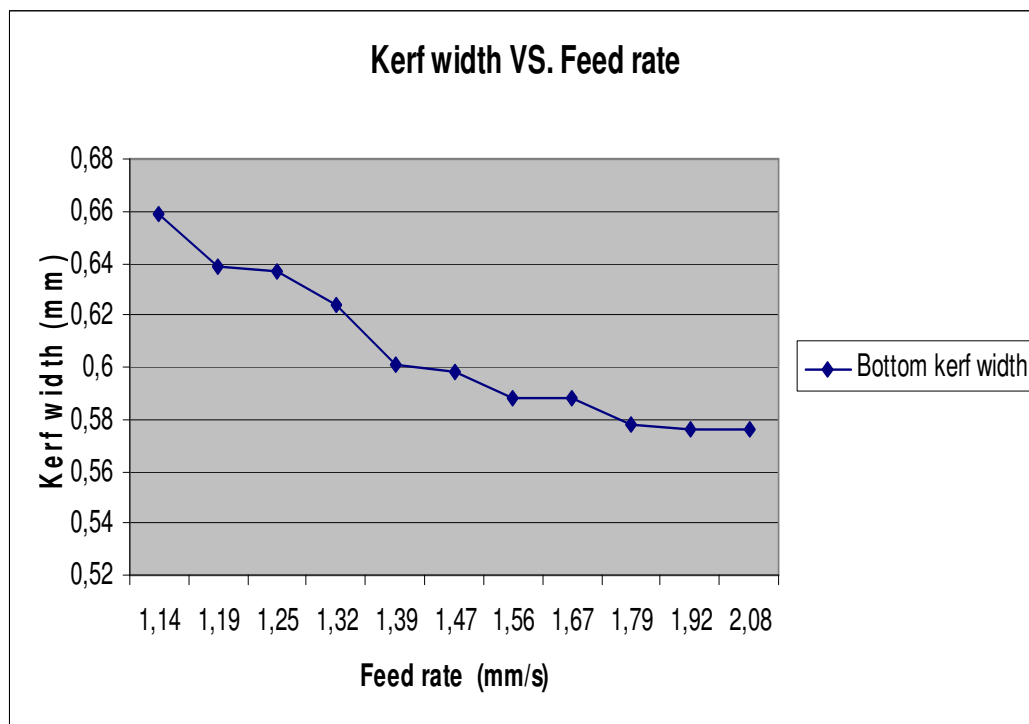
Figure 4.11: Graph of Bottom Kerf Width versus Feed Rate

4.4   EXPERIMENTAL DISCUSSION

From the result and data collection there are some interested outcome should be discussed. There are effect of different feed rate on surface roughness, effect of different feed rate on top and bottom surface of kerf width, the comparison between actual design that have done cut used laser machine with Solid Work design, and also error during experiment will discussed.

4.4.1   Effect of Feed Rate on the Surface Roughness

The results from the surface roughness measurements are shown in table 4.2. From these result, graph in figure 4.7 was plotted gained from eleven points by averaging three surface roughness measurements for each sample. From the graph plotted, the relationship between surface roughness and different feed rate can observe obviously. The surface roughness will increase with increasing the feed rate. From figure 4.5 and 4.6 can prove these result witch is smooth surface produce when used low feed rate. In general, increasing the feed rate led to increasing of surface roughness. These results are in agreement with the result in references [6,7].

From the graph in figure 4.7, the result for surface roughness at maximum feed rate used in this project (2.083mm/s) is 0.3583 µm while the result at minimum feed rate used in this project (1.136mm/s) is 0.1090 µm. At low feed rate cause the value of surface roughness or surface average, Ra smaller. That means the smaller value of Ra contributes smooth surface or good surface quality.

At low feed rate, the molten area of the specimens during cutting process can be broadening. The heat transfer from laser beam to specimen surface higher then the acrylic specimen can melted more material and the complete cutting is obtained. At the maximum feed rate, 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. The acrylic specimen still can cut at this condition but it will produce rough surface.

From the result analyzed, its can be simplified that higher feed rate is not suitable to get good surface. If the maximum feed rate is exceeded then cutting reaction cannot penetrate to the bottom of the surface specimen. The laser beams just can engrave the specimen not to cut the specimen. The minimum feed rate also not suitable for cutting process because when feed rate is to slow it cause the side of specimen burn. It can conclude that only at certain range of feed rate suitable used during laser cutting process based on the power supply to get the smooth and good surface.

4.4.2   Effect of Feed Rate on the Kerf Width

The results from kerf width measurement are shown in table 4.3 for top surface and in table 4.4 for bottom surface. From the result, graph in figure 4.10 and figure 4.11 were plotted gained from eleven points by averaging three distance of kerf width measurement for each sample. From the graphs plotted, the relationship between kerf width and different feed rate can observe obviously. The kerf width measurement at the top and bottom surface of the specimens was similar which is increasing feed rate led to decrease the kerf width. But the data indicated that the top kerf width was slightly larger than bottom kerf width. Therefore top kerf width result shown in figure 4.7 and the bottom kerf width result shown in figure 4.8.

From the graph in figure 4.10, the result for top kerf width at maximum feed rate used in this project (2.083mm/s) is 1.011mm while the result at minimum feed rate used in this project (1.136mm/s) is 1.138mm. From the graph in figure 4.11, the result for bottom kerf width at maximum feed rate (2.083mm/s) is 0.5762mm while the result at minimum feed rate (1.136mm/s) is 0.6589mm. At low feed rate cause the value of top and bottom kerf width higher. The smaller value of kerf width produces good width and accurate cut edge.

Decreasing kerf width values are due to decreasing heat transfer from laser beam to surface of specimen. At low feed rate, the heat transfer increase to specimen surface and more material is melted. These results are agreement with published result in references [7,9] that in the case of lower feed rate, the material is heated up to the ignition temperature within a relatively wide zone around the laser beam.

Kerf width measurements at the top and bottom surfaces of the specimen indicated that the top kerf width was slightly larger than that at the bottom. These findings are agreement with published result in references [8,10] which is when the laser beam through the specimen, the laser beam loss of beam intensity, the laser beam also defocusing and loss of gas pressure across the thickness of the specimen. From the result analyzed, its can be simplified that higher feed rate is more suitable to get the good width and cut edge.

4.4.3   Comparison Between Actual Design and Solid Work Design

Normally in the cutting process have some problem that will affect cutting quality. The cutting process not gives exactly dimension of cutting required. The dimensions of specimen that required in SOLID WORK not accurate as actual design (specimen) while the dimension of actual specimen less than design in SOLID WORK. These defect because the laser beam is not sharp and defocusing to specimen surface. It maybe because the effect of stand of high between the nozzle and specimen surface that will make the laser beam not focusing on specimen surface properly. In this case will be problem when to assemble process or part design. The part can created a gap or space between one parts to another part. It also can affect the join hole created in cutting process.

4.4.4   Error Discussion

From figure 4.7, figure 4.10 and figure 4.11 obtained line graph were not smooth. This is because some error occurred during cutting process and checking the quality process.

The laser cutting machine that used in this project is not good enough to cut the material because this laser was design to engraving the material but this it can also cut the material that have low melting point such as acrylic sheet. This laser machine also always used and make the laser beam not sharp enough to cut acrylic sheet especially for the higher thickness. The suitable laser should be used for cutting to get good cut quality.

During checking quality process, there has some error during taken the surface roughness measurement because the Perthometer not work properly because have some problem and affects when measured the surface roughness. Besides that environmental factor such as lack of experience to handle machine, vibration during measured surface roughness, temperature surrounding and poor condition also should be considered to avoid the affect the result.

4.5   CONCLUSION

Overall of this chapter gave result and discussed the result were analyzed. The results that get from this project were agreement with previous study and published result. This chapter also discussed some error that obtained during cutting process and checking quality process. Many procedure should be follow properly and the factor that can affect cut quality should be consider during cutting process and checking quality process to get the good cut quality. Overall of this project result and finding will conclude in Chapter 5.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1   INTRODUCTION

This project has achieved two objectives which are to study about Carbon Dioxide (CO_2) laser cutting machine and to study the laser cut quality based on the feed rate of the Carbon Dioxide (CO_2) laser machine.

5.2   CONCLUSION

The effect of different feed rate with constant power on the quality of surface roughness and kerf width of acrylic cut used laser machine were studied in this project. Based on the outcome from the result and discussion, this study is successfully achieving the objective with the acceptable result compare with theoretical and previous study.

According to result from experiment, it is found that feed rate had effect on the surface roughness quality. Increasing the feed rate with constant power led to increasing surface roughness. From this experiment used the constant power at 25.5W, the optimum feed rate to get the good surface roughness is at range 1.136mm/s to 1.316mm/s because at this range level of feed rate led to slightly increasing surface roughness. But for the best feed rate according this experiment project is 1.136mm/s at power 25.5W to get good on surface roughness.

Feed rate had minor effect on kerf width quality. Increasing the feed rate with constant power led to decreasing kerf width. From this experiment, the optimum feed rate is 2.083mm/s to get smaller kerf width.
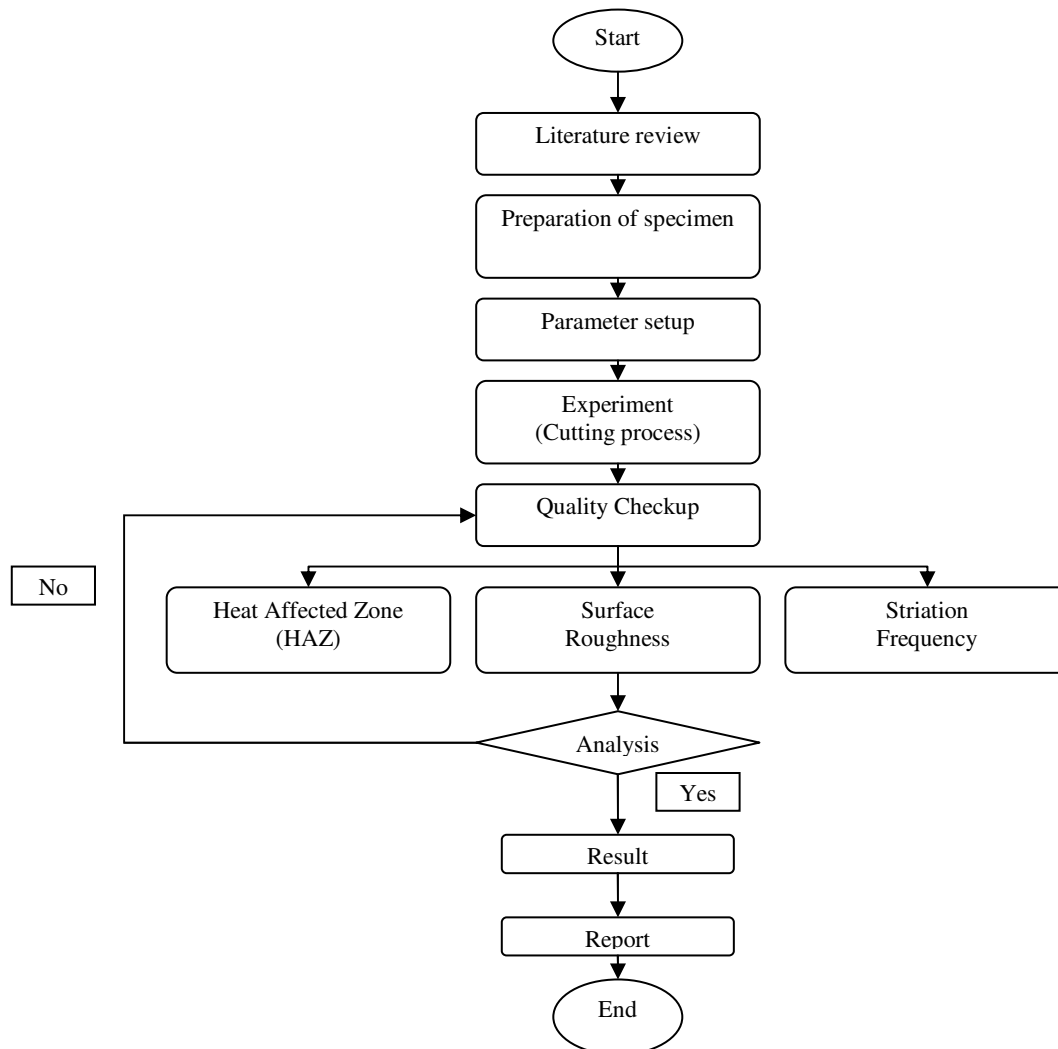
5.2   RECOMMENDATION

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

i.   Consider more parameter that will be effect the cutting quality such as power, stand of height nozzle to work piece surface and thickness of material.

ii.   Use another method to analyze the data such as regression analysis, ANOVA, and Response Surface Methodology (RSM) to get the optimum level of feed rate and power to get good cut quality.

iii.   Use laser cutting machine that provide good condition such as higher power that can be cut other material and sharpness in focusing on work piece surface.

iv.   Use Scanning Electron Microscope (SEM) to see more accurate image structure of cut quality.

REFERENCES

[1] John C. Ion (2005).Laser Processing of Engineering Materials: Elsevier
     Butterworth – Heinemann.

[2] Maiman, T.H. (1960) "Stimulated Optical Radiation in Ruby". Nature, **187** 4736,
     pp. 493-494.

[3] Gould, R. Gordon (June 1959). "The LASER, Light Amplification by Stimulated
     Emission of Radiation". The Ann Arbor Conference on Optical Pumping.

[4] G.P. Karman, G.S. McDonald, G.H.C. New, J.P. Woerdman, (11 November
     1999) "Laser optic: Fractal modes in unstable resonator ", Nature, Vol. 402, 138.

[5] Jarold E. Baker, (Nov 10 1998). Laser Machining Process and Theory:
     Department of Aerospace Engineering University of Kansas

[6] Jae-Hoon Lee1, Jeong Suh1, Dong-Sig Shin1, Jeng-O Kim1, Young-Moon
     Lee2, (January 2003), Development of Laser Process and System for Stencil
     Manufacturing, International Journal of the Korean Society of Precision
     Engineering Vol. 4, No. 1.

[7] N. Rajaram, J. Sheikh-Ahmad *, S.H. Cheraghi, (11 November 2002), C02
     laser cut quality of 4130 steel. Department of Industrial and Manufacturing
     Engineering, Wichita State University, Wichita.

[8] N. Rajendran and M.B. Pate, (1998) The effect of laser beam velocity on cut
     quality and surface temperature. American Society of Mechanical Engineers,
     Heat Transfer Division **104**.

[9] U. Dilthey, M. Faerber and J. Weick, (1992) Laser cutting of steel—cut quality
     depending on cutting parameters. Welding in the World **30** 9/10.

[10] W.M. Steen and J.N. Kamalu. In: M. Bass, (1983) Editor, Laser Cutting, Laser Materials Processing **vol. 3**, North Holland, New York.

[11] William M. Steen, (1994) "Laser Material Processing", London, Spring-Verlag, 2nd Printing.

[12] http://en.wikipedia.org/wiki/Laser.

[14] http://www.columbia.edu/cu/mechanical/mrl/ntm/pgIndex.html

[15] http://en.wikipedia.org/wiki/Kumar_Patel

[16] http://wikipedia.org/wiki/Carbon_dioxide_laser.

[17] http://www.answers.com/topic/acrylic-plastic.

[18] http://www.wisegeek.com/what-is-acrylic.htm

[19] http://www.matweb.com/search/DataSheet.aspx?MatGUID

[20] http://www.teskolaser.com/laserglossaryk.html

APPENDIX A1

General flow chart of this project.

APPENDIX A2

Gantt Chart For Final Year Project 1

NO	TASK	FYP 1 – Semester 2 2007/2008 (Week)															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Briefing of the FYP 1	■															
	Title confirmation	■															
	Set up time for every meeting	■															
2	Discussion with supervisor		■														
	Prepare Gantt Chart		■														
3	Finding an information related with topic			■													
	Overview presentation about laser			■													
4	Discuss project progress				■	■											
	Prepared Chapter 1				■	■											
5	Literature review						■	■	■	■	■						
							■	■	■	■	■						
6	Briefing of laser machine										■	■	■				
	Methodology										■	■	■				
7	Writing FYP 1 report and proposal												■	■			
													■	■			
8	Submit FYP 1 report and proposal														■		
															■		
9	Prepared for presentation															■	
	Meck presentation to Supervisor															■	
10	Final presentation FYP 1																■
																	■

APPENDIX A3

Gantt Chart For Final Year Project 2

NO	TASK	FYP 2 – Semester 1 2008/2009 (Week)															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Discussion with supervisor	■	■	■	■	■	■	■	■	■	■	■	■				
2	Run the experiment:		■	■	■	■	■										
	- Cutting process		■	■	■	■	■										
	- Qut quality		■	■	■	■	■										
	- Analizing data		■	■	■	■	■										
3	Result and Discussion							■	■	■	■	■	■				
4	Writing Chapter 4 and									■	■	■	■				
	Chapter 5									■	■	■	■				
5	Prepare for final presentation											■	■				
6	Final presentation													■			
7	Writing full report														■	■	
8	Submit full FYP report																■

APPENDIX A4

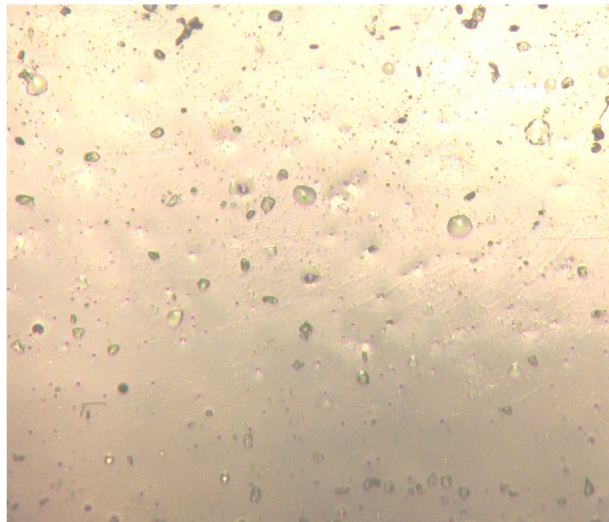**Image of Surface Roughness**
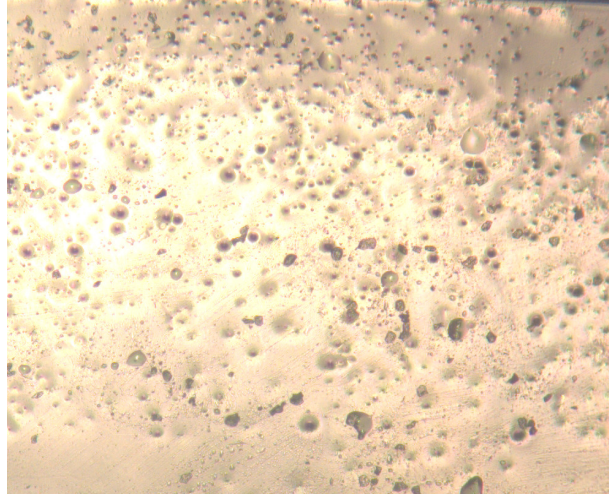
Feed rate = 2.083mm/s
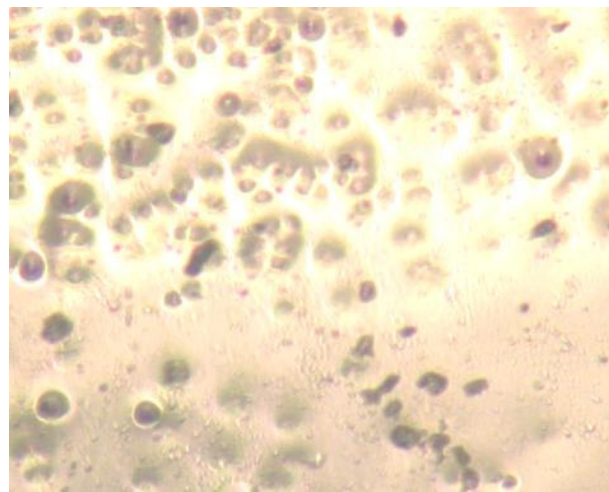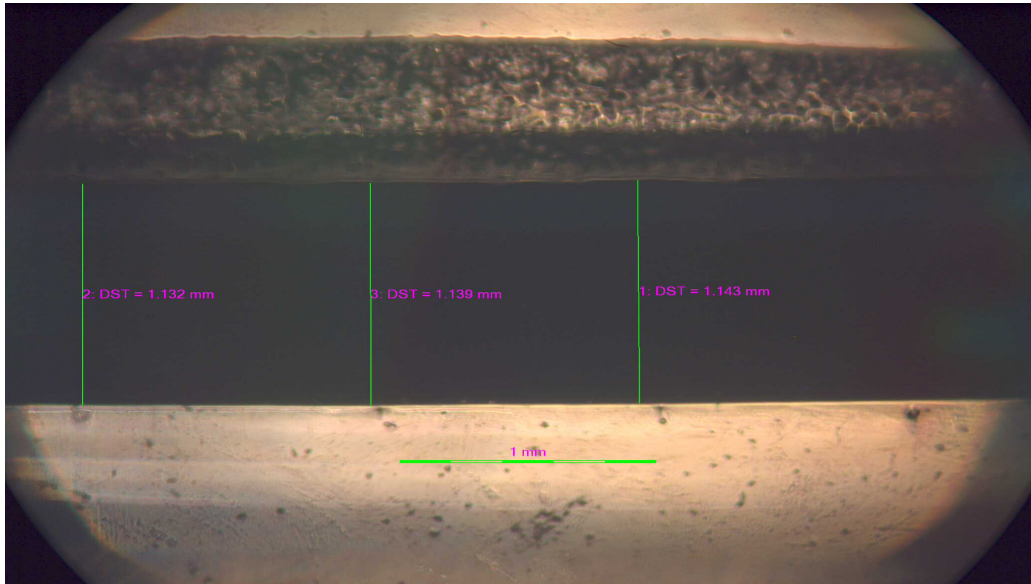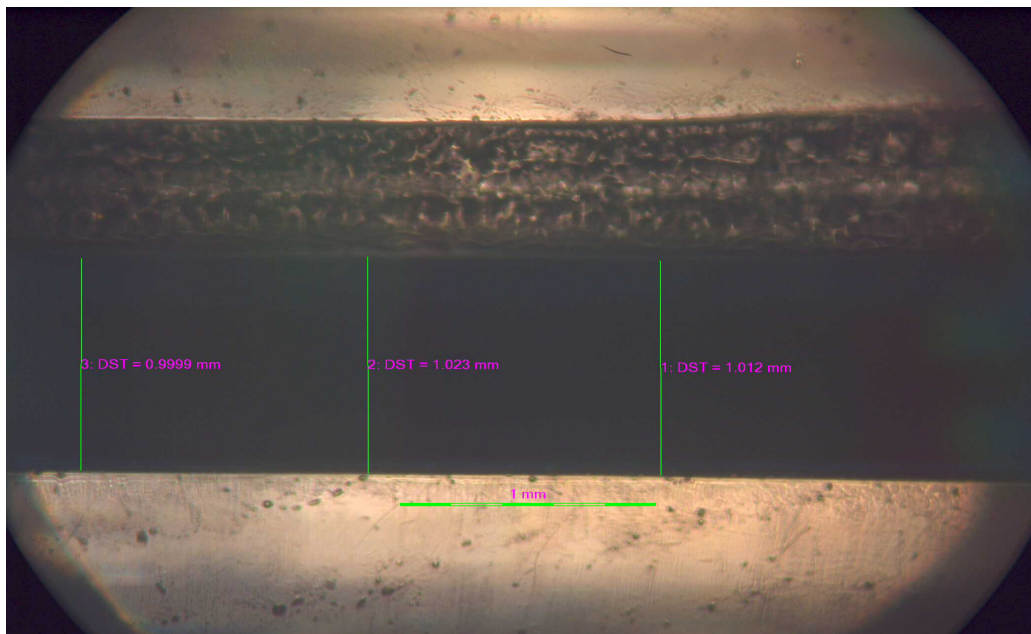

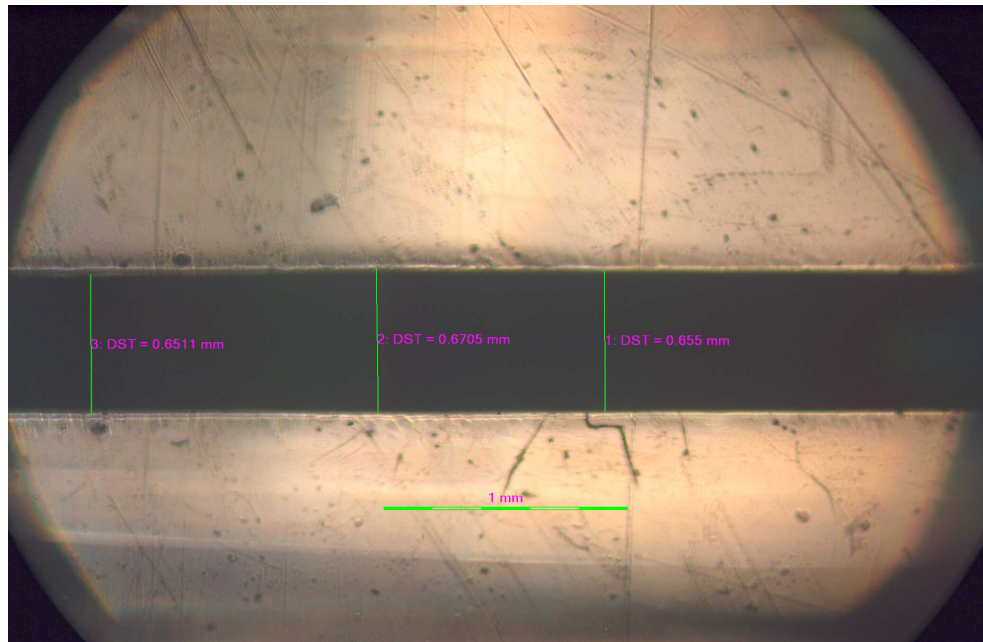Feed rate = 1.786mm/s
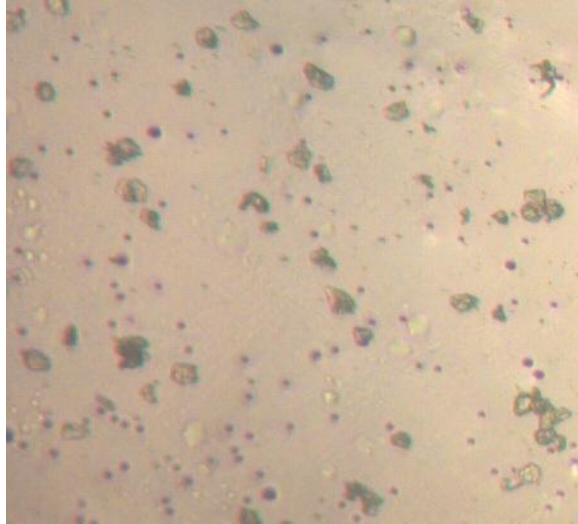
Feed rate = 1.250mm/s

Feed rate = 1.136mm/s

APPENDIX A5

Image of top kerf width

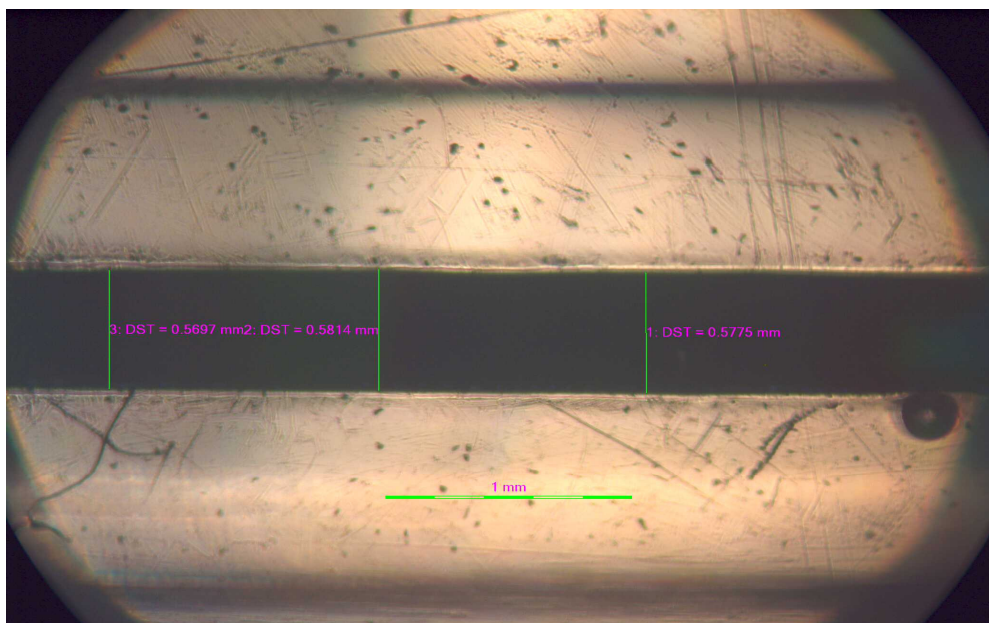Feed rate = 1.136mm/s

Feed rate = 2.083mm/s

APPENDIX A6

Image of bottom kerf width

Feed rate = 1.136mm/s

Feed rate = 2.083mm/s