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JUDUL: CARBON DIOXIDE (CO₂) LASER CUT QUALITY OF ACRYLIC USING DIFFERENT FEED RATE AND CONSTANT POWER LEVEL

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CARBON DIOXIDE (CO₂) LASER CUT QUALITY
USING DIFFERENT FEED
RATE AND CONSTANT POWER LEVEL

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

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SUPERVISOR DECLARATION

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STUDENT DECLARATION

I declare that this dissertation entitled “*Carbon Dioxide (CO₂) Laser Cut Quality Using Different Feed Rate and Constant Power Level*” 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 concurrently submitted in candidature of any other degree.

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To my beloved Mother and Father

Mr. Mohd Ali Bin Shaari

Mdm. Siti Ain Sarah Binti Abas

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ABSTRACT

In manufacturing industries, laser is uniquely versatile tool for processing a remarkable range of metals, alloys, ceramics, glasses, polymers and composites. Light can be produced in pulsed or continuous form with different wavelength and power level. Laser processing has greater advantages compared to the traditional methods of industrial fabrication. It can be a profitable replacement for an existing technique. This differs to the traditional machine tools that are normally designed for a particular purpose. There are a large number of parameters that control the laser cutting process. Each parameter has its own function which can affect the processing operation. The most important parameters to be considered is the laser power level range because there is significant relationship between power level and feed rate. The different laser cut power level range will produce different type of results depends on the feed rate. So, in this project sample of acrylic were cut on a CO₂ laser cutting system with the variation in feed rate value and constant power level. The effect of both factors on width of heat-affected zone (HAZ), and striation frequencies have been studied. Manual calculation was used to develop graph that describes the effect on both factors on laser cut quality. As a result, the increased in feed rate were led to the decrease of the width of the heat-affected zone. The striation frequencies were increased with the increased of feed rate. Its means that, feed rate has important has a major effect on both the width of HAZ and striation frequency. To obtain better result, environmental effects such as room temperature, air ventilation, air humidity and lightning condition should be considered.

ABSTRAK

Di dalam industri pembuatan, laser digunakan secara meluas untuk memproses pelbagai jenis logam, aloi, seramik, kaca, polimer dan komposit. Sinaran dalam bentuk denyutan ataupun berterusan terhasil dalam pelbagai julat panjang gelombang dan kuasa. Laser mempunyai kelebihan jika dibandingkan dengan kaedah-kaedah tradisional yg digunakan dalam industri. Ia boleh digunapakai sebagai pengganti kepada kaedah-kaedah yang sedia ada. Terdapat banyak pembolehubah yang mengawal pemprosesan menggunakan laser. Setiap pembolehubah mempunyai fungsi tersendiri dimana setiap pembolehubah ini mampu memberi kesan kepada operasi proses yang dijalankan. Kuasa dan halaju potongan merupakan pembolehubah yang paling penting dalam proses yang melibatkan laser. Penggunaan kuasa laser yang berbeza akan menghasilkan hasil potongan yang berbeza bergantung kepada halaju potongan yang digunakan. Oleh sebab itu, di dalam projek ini, akrilik akan dipotong menggunakan sistem laser karbon dioksida (CO₂) dengan menggunakan halaju potongan yang berbeza dibawah satu nilai kuasa yang tetap. Kesan terhadap zon kesan haba (HAZ) dan frekuensi pengoresan akan dianalisis. Pengiraan secara manual akan digunakan untuk menghasilkan graf yang menunjukkan hubungan antara kedua-dua pembolehubah terhadap kualiti potongan. Peningkatan dalam halaju potongan akan menyebabkan pengurangan dalam zon kesan haba (HAZ) dan peningkatan dalam frekuensi pengoresan. Ini bermakna, halaju potongan memainkan peranan penting dalam pembentukan HAZ dan frekuensi pengoresan. Hasil eksperimen yang lebih baik boleh diambil sekiranya faktor-faktor persekitaran seperti suhu bilik, pengudaraan, kelembapan udaram dan keadaan pencahayaan dapat dikawal.

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LIST OF SYMBOLS

mm	-	Millimetre
W	-	Watt
μ	-	Micron, 1×10^{-6}
cm	-	Centimetre
m	-	Metre
lb	-	pound
in	-	inch
$^{\circ}\text{F}$	-	Degree Fahrenheit
hr	-	hour
ft	-	Feet
s, sec	-	Second
Hz	-	Hertz

LIST OF ABBREVIATIONS

CO ₂	-	Carbon Dioxide
HAZ	-	Heat Affected Zone
He	-	Helium
Ne	-	Neon
DFB	-	Distributed Feedback
N ₂	-	Nitrogen
PMMA-		Polymethy Methacrylate

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Laser is an acronym of Light Amplification by the Stimulated Emission of Radiation. It is electrical-optical devices that produce coherent radiation. The concept use in developing laser is the concept of stimulated emission which was first suggested by Albert Einstein in 1916.

Lasers are commonly seen in several ordinary commercial applications, such as bar code scanners, laser pointers, CD players, CD-ROMs, videodiscs, laser surgery, and laser-light shows. However, lasers have many other applications as well such as machining process in manufacturing industries. The example of application of laser in machining process is laser cutting process. In this process, laser beam is utilized as a machining tool.

In industrial field, laser is a flexible machine tool. In manufacturing industries as example, laser is uniquely versatile tool for processing a remarkable range of metals, alloys, ceramics, glasses, polymers and composites. Light can be produced in pulsed or continuous form with different wavelength and power level. Laser processing has greater advantages compared to the traditional methods of industrial fabrication. It can be a profitable replacement for an existing technique. This is differs to the traditional machine tools that are normally designed for a particular purpose. They are also perform to the most exacting standards but they can only perform a particular task.

Acrylics are esters of acrylic acids, which are the products formed by the reaction of an acrylic acid and alcohol. The esters of acrylic acid polymerize readily to form exceptionally clear plastics. Acrylic is a useful, transparent thermoplastic that resembles glass, but has properties that make it more superior to glass in many ways. It can be describes as new world material because it was first was developed by DuPont in 1944 and was first commercially produced in 1950 [11].

Acrylic is defined as a manufactured fiber in which the fiber forming substance is any long-chain synthetic polymer composed of at least 85% by weight of acrylonitrile units. Acrylic fibers create a fine, soft and luxurious fabric with the bulk and hand of wool. The most common acrylic plastic is polymethyl methacrylate (PMMA), which is sold under the brand names of Plexiglas, Lucite, Perspex, and Crystallite.

Nowadays, acrylic can be considered as one of the widest material used in industries. Its application is not only covered human daily life, its also applied in military, aircraft applications, construction and etc. During World War II, acrylic glass was used for periscope ports on submarines and for windshields, canopies, and gun turrets on airplanes. Today, acrylic is used more than ever. Virtually all major public aquariums is now built from acrylic.

There are many ways to process the acrylic. One of it is by using laser cutting process. In determining the quality of the cutting, some parameters should be considered. Problem statement will explain about the further information regarding to this project.

1.2 PROBLEM STATEMENT

There are a large number of parameters that control the laser cutting process. Each parameter has its own function which can affect the processing operation. In this project, the most important parameters to be considered is the laser power level range because there is significant relationship between power level and feed rate. The different

laser cut power level range will produce different type of results depends on the feed rate [7].

In laser cutting process, there are various kinds of cut quality parameters. So, in this research, only two laser cut parameters will be investigated which are; striation frequency and the width of heat affected zone (HAZ). These all parameters are depending on feed rate and power level.

1.3 OBJECTIVES

The objectives of this study are:

- i. To analyze the effect of different feed rate values with a constant power value to the width of heat-affected zone (HAZ).
- ii. To analyze the effect of different feed rate values with a constant power value to the striation frequency.

1.4 SCOPES

This research is carried out to verify the laser cut quality by follows the according scopes:

- i. Analyze two laser cut quality parameters.
 - Striation frequency
 - The width of heat affected zone (HAZ)
- ii. Run the experiment using ten values of feed rate (1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, and 1900) with a constant power value (25.5 W).
- iii. Using Carbon Dioxide (CO₂) laser cutter machine and acrylic (Polymethyl Methacrylate, PMMA) as the material to be cut.
- iv. Analyzing the data by using manual calculation.

1.5 THESIS ORGANIZATION

This thesis is divided into five chapters and each chapter has its own function. These all chapters are arranged chronologically.

Chapter 1 is the introduction to this research. It will explain briefly about why this research is conducted. Besides, it also will illuminate the importance of this research. Problems and limitation of this research are also described in this chapter.

The definitions, history and its development of the research components will be briefly described in Chapter 2. The research components mentioned are Carbon Dioxide (CO₂) Laser Machine, acrylics sheet, laser cut quality (striation frequency and heat affected zone, HAZ). Besides, the cutting parameters such as power level and feed rate will be simply explained. This chapter will also describe about the significance theories and formulas from the late studies.

Generally, Chapter 3 will explain about the method that will be used and the procedures of the experiment. Safety and any precaution steps are also included in this chapter.

Findings from the experiment will be displayed and elaborated in Chapter 4 through tables, figures, pictures and calculations. The discussion of the findings will also be included in this chapter.

Finally, Chapter 5 is the conclusion of the research. Future recommendations are also suggested in this chapter for further research in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, all the component of the research will be explained briefly. All information about the machine and material used, parameters and any significance theories will be describes briefly starting from its definitions, history, developments, manufacturing, working principles, compositions, structure and properties.

Figure 2.0 below shows the flow chart for this chapter.

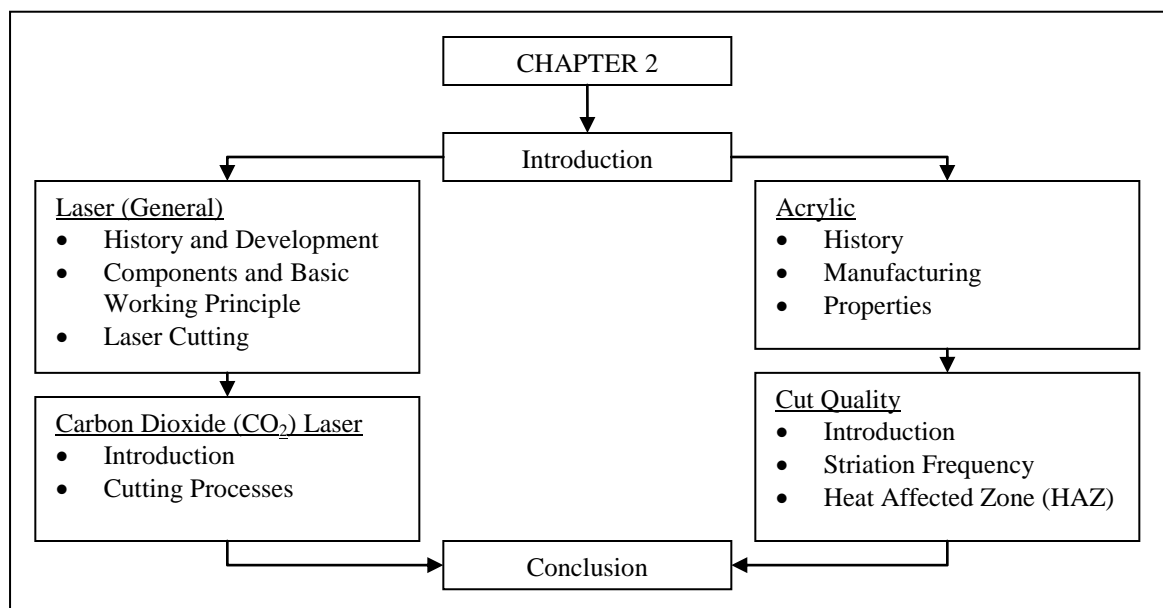


Figure 2.1: Chapter 2 outline

2.2 LASER

2.2.1. History and Development

Albert Einstein first suggested the phenomenon of stimulated emission in a 1916 paper proving Planck's law of radiation. The idea, however, was considered odd and the event of photon interaction with an excited state atom rare. After that, scientists begin to create inverted populations with more atoms in the excited state than the ground state so that absorption would not dominate the process and stimulated emission could occur [3].

The precursor to the define laser was the maser (Microwave Amplification by the Stimulated Emission of Radiation). The impetus for the development of the maser seems to be the interest in microwave radiation following the utility it found in radar technology in World War II. Maser was first created by Charles H. Townes in 1954 when he has succeeded in producing an inverted population by isolating excited ammonia molecules.

Soon after masers became a reality, scientist started to look at the possibility of stimulated emission in other regions of the electromagnetic spectrum. Charles H. Townes and Arthur Schawlow, began to investigate the possibility of optical and IR masers. Both of them published the first detailed proposal for building an optical maser (later to be renamed a laser) in a December 1958. Just before 1960, Theodore Maiman has created the first working laser. Maiman's laser was a "pink" ruby rod with its ends silvered placed inside a spring-shaped flashlamp.

At the end of 1960, Ali Javan, William Bennet, and Donald Herriot made the first gas laser using helium and neon. This type of laser (a He-Ne laser) became the dominant laser for the next 20 years until cheap semiconductor lasers took over in the middle of 1980. C. Kumar N. Patel noticed that atomic gas laser were limited in power, so he began to work with carbon dioxide (CO₂) and carbon monoxide lasers which he

mixed with nitrogen, helium and water to fine tune the laser properties. Thus, in 1964, Kumar Patel made the first high powered gas lasers [12].

Table 2.1 shows about the development of the laser from its early findings until the end 20th century.

Table 2.1: Table of laser development from early finding until the end of 20th Century [13].

Year	Impetus	Findings
1917	Albert Einstein	Idea published
1954	Charles .A. Townes	First maser based on ammonia molecules.
1958	L. Schawlow and Charles H. Townes	Propositions and calculations for the realization of masers for light and infrared
1960	T. H. Maiman Ali Javan	First laser; consist of a ruby bar with two parallel faces as resonator and a pulsed flashbulb as optical pumping source. First gas laser with continuous stimulated emission.
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 and R. Stolen	First silicon laser.
1994	K. Ann	First single-atom laser.

2.2.2. Basic Component and Working Principle

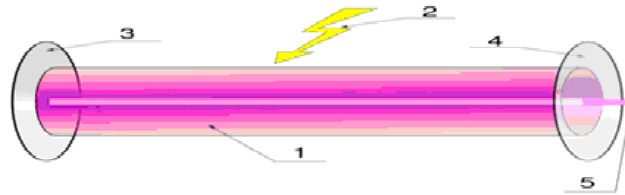


Figure 2.2: Basic laser component [14].

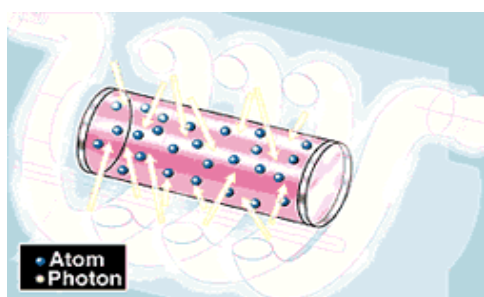
Table 2.2: Basic laser components [14].

Number	Component
1	Active Laser Medium
2	Laser Pumping Energy
3	High Reflector Mirror (100% Reflection)
4	Output Coupler (95% Reflection Mirror)
5	Laser Beam (Output)

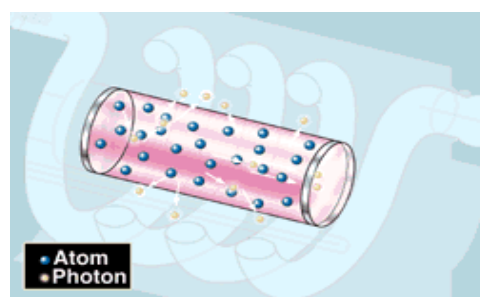
Generally, laser consists of five basic components as shown in Figure 2.2. A laser consists of a gain medium inside an optical cavity which functioned as energy supplier to the gain medium. The gain medium is a material which can be divided into gas, liquid, solid or free electrons with appropriate optical properties. Basically, a cavity consists of two mirrors arranged such that light bounces back and forth, each time passing through the gain medium. Typically, one of the two mirrors is the output coupler which is partially transparent. The output or the laser beam is emitted through this output coupler.

The working principles of each types of laser are basically the same. Lasers are possible because of the way light interacts with electrons. Electrons exist at specific

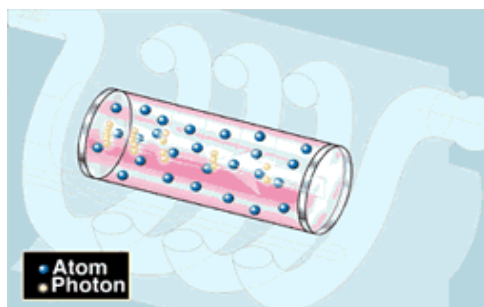
energy levels or states characteristic of that particular atom or molecule. The energy levels can be imagined as rings or orbits around a nucleus. Electrons in outer rings are at higher energy levels than those in inner rings. Electrons can be bumped up to higher energy levels by the injection of energy for example, by a flash of light. When an electron drops from an outer to an inner level, excess or extra energy is given off as light. The wavelength or color of the emitted light is related to the amount of energy released. Depending on the particular lasing material being used, specific wavelengths of light are absorbed to energize or excite the electrons and specific wavelengths are emitted when the electrons fall back to their initial level [3].



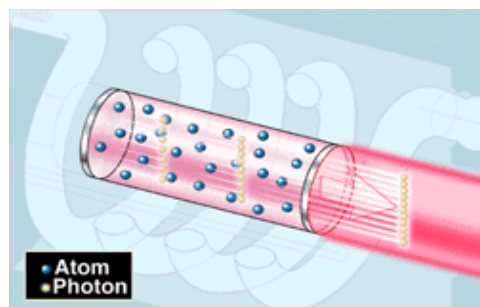
Process 1: Atom Excitation



Process 2: Photon Productions



Process 3: Reflection



Process 4: Laser Beam Production

Figure 2.3: Graphical laser working principle [15].

Generally, there are four main processes in generating the laser beam as shown in Figure 2.3. In process 1, high-voltage electricity causes the medium (solid, liquid, gas etc.) to emit an intense burst of light and exciting some of the atoms in the medium to

higher energy levels. Process 2 is the photon production process which at a specific energy level, some atoms emit particles of light called photons. At first, the photons are emitted in all directions. Photons from one atom stimulate emission of photons from other atoms and the light intensity is rapidly amplified. Next, mirrors at each end reflect the photons back and forth, continuing this process of stimulated emission and amplification. This is shown in process 3. Finally, the last process is laser beam production (process 4) which is the photon leaves through the partially reflected mirror (95% reflection) at one end and the light produced is the laser beam [15].

2.2.3. Laser Cutting Process

In the laser cutting process, a kerf is created through relative motion between the laser beam and the workpiece surface. This process allows intricate two-dimensional shapes to be cut on a workpiece. The physical mechanisms for material removal and energy losses are similar to those for drilling, where the incoming laser beam energy is balanced by the conduction heat, energy from melting or vaporization of material, and heat losses to the environment.

The width produced by the laser beam is narrower than those achieved with mechanical cutting. This results in less wasted material. When cutting fibrous materials such as composites, the laser beam vaporizes the volume of material to be removed, thereby eliminating the residue and debris that remains after mechanical cutting.

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

Laser beams may be used in combination with a gas stream, such as oxygen, nitrogen, or argon for cutting thin sheet materials. Gas streams also have the important

function of blowing away molten and vaporized material from the workpiece surface [12].

2.3 CARBON DIOXIDE (CO₂) LASER

2.3.1. Introduction

The great interest in carbon dioxide lasers comes from their continuous power capability, high efficiency and ease of construction. Three gases (CO₂, N₂ and He) are mixed and fed into one end of a discharge tube at a certain pressure. The gas flows down the end of the tube in about one second and is pumped out the far end with a mechanical fore pump. An electrical discharge is maintained between the metallic end flanges of the tube. The ballast resistance is required because of the negative dynamic resistance of the discharge. With a fully reflecting mirror on the left and a partially transmitting mirror on the right, the device becomes a laser which radiates in the far infrared at 10.6μ.

2.3.2. Cutting Process

The beam from the laser is focused on to the surface of the material being cut by using a lens as a reflector. The focused laser beam heats the material surface and a local melt capillary is quickly established throughout the depth of the material. The diameter of this capillary is usually just slightly greater than the diameter of the focused laser beam. Majority of CO₂ laser cutting is performed using an assist gas. The significant function of gas assisted laser cutting is that the molten material is ejected from the base of the capillary by a jet of gas coaxial with the laser beam. For some materials this gas can further assist the process by chemical (exothermic) reaction as well as physical work. The cut is generated by both moving the focused laser beam across the surface of the stationary material or by keeping the laser beam stationary and moving the workpiece. Hybrids or combination of these two options are also possible. In this way simple and complex linear cuts or two dimensional parts can be produced [2].

2.4 ACRYLIC

2.4.1. History

Acrylic was first studied in 1901 by Dr. Otto Rohm. He continued his studies on this material (acrylic) and eventually in 1927, Rohm together with Hass commenced limited production of poly(methyl acrylate) under the trade names Acryloid and Plexigum. About 1930, R. Hill and W. Bauer independently prepared a rigid and transparent which is polymethyl methacrylate or known as acrylic [1]. By 1936, American, British, and German companies were producing acrylic. During World War II, acrylic glass was used for periscope ports on submarines and for windshields, canopies and gun turrets on airplanes.

Acrylonitrile, the substance from which acrylic fibers are produced, was first made in 1893 in Germany and was used as another chemical in research for the DuPont Company. In 1944, acrylic was developed by DuPont Company and was first commercially produced to human daily life in 1950. Until today, acrylic is known as one of the most popular materials used in human daily life [11].

2.4.2. Manufacturing

Acrylic plastic polymers are formed by the reaction of a monomer, such as methyl methacrylate, with a catalyst. A typical catalyst would be an organic peroxide. The catalyst starts the reaction and enters into it to keep it going, but does not become part of the resulting polymer. Acrylic plastic sheets are formed by a process known as bulk polymerization. In this process, the monomer and catalyst are poured into a mold where the reaction takes place. Two methods of bulk polymerization may be used: batch cell or continuous. Batch cell is the most common because it is simple and is easily adapted for making acrylic sheets in thicknesses from 0.06 to 6.0 inches (0.16-15 cm) and widths from 3 feet (0.9 m) up to several hundred feet.

2.4.3. Properties

Acrylic is useful in human daily life because of its properties that are suitable in making products. Its transparent in physical look and its properties which is majorly better than glass are the main factor why acrylic usage are growing wider day by day. Table 2.3 shows the selected acrylic properties.

Table 2.3: Properties of Acrylic [16].

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

2.5 CUT QUALITY

2.5.1. Introduction

Cut quality is defined as quality of the final product. Cut quality is not only depends on their physical characteristic but also their composition and structure. In laser cutting, there are many cut quality parameter can be found such as burrs, kerf, pitting, roughness, groove lag, perpendicularity, heat affected zone (HAZ) width, surface conditions, striation and others. In this project, there are only two cut qualities have been considered which are:

- i. striation frequencies
- ii. HAZ width

Those parameters will be defined as below.

2.5.2. Striation Frequencies

Striation is considered as one of the important quality characteristics and its formation is strongly related to the cutting and workpiece parameters. One of the deficiencies in laser cutting quality is the large size of striation formed at the cut edges. Striation formation is related to the slow drifts and disturbances in various parameters during the laser cutting process. Slight variations in laser power, cutting speed and energy coupling factor modify the kerf width size considerably, in which case the striation size increases during the cutting process [9].

2.5.3. Heat Affected Zone (HAZ)

Laser cutting does produce a heat affected zone (HAZ). HAZ is the zone or region which experienced temperatures below melting point, but high enough to cause microstructural changes in the materials and it occurs when the temperature of the

materials rises above the critical transformation point. In laser cutting, HAZ is localized near the cutting zone. The chemical composition of the region is same as base metal, but this region has been heat treated so that its properties and structure have been altered. Generally, HAZ is determined according to its width. The HAZ width increase as the energy input per unit length and cut thickness increases [2].

2.6 CONCLUSION

Laser can be considered as a new generation technology. The development of laser is still running until today. In maximizing the cut quality in CO₂ laser cutting process, many factor should be consider for example, cutting surface and assist gas used.

In the next chapter which is chapter 3, the machine, apparatuses, procedures and methods used will be briefly explained as well as safety and precaution steps.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Based on Chapter 2 as the guidelines, Chapter 3 will explain about how this experiment will be conducted. All processes involved in this experiment will be stated clearly as well as the safety precaution steps. In this experiment, 10 specimens are going to be analyzed where each specimen will be cut by using the same power level but 10 different feed rate values. Each specimen will be analyzed based on the desired cut quality.

Figure 3.1 and Figure 3.2 show about the flow chart of the FYP overall process and the flow chart of the experiment.

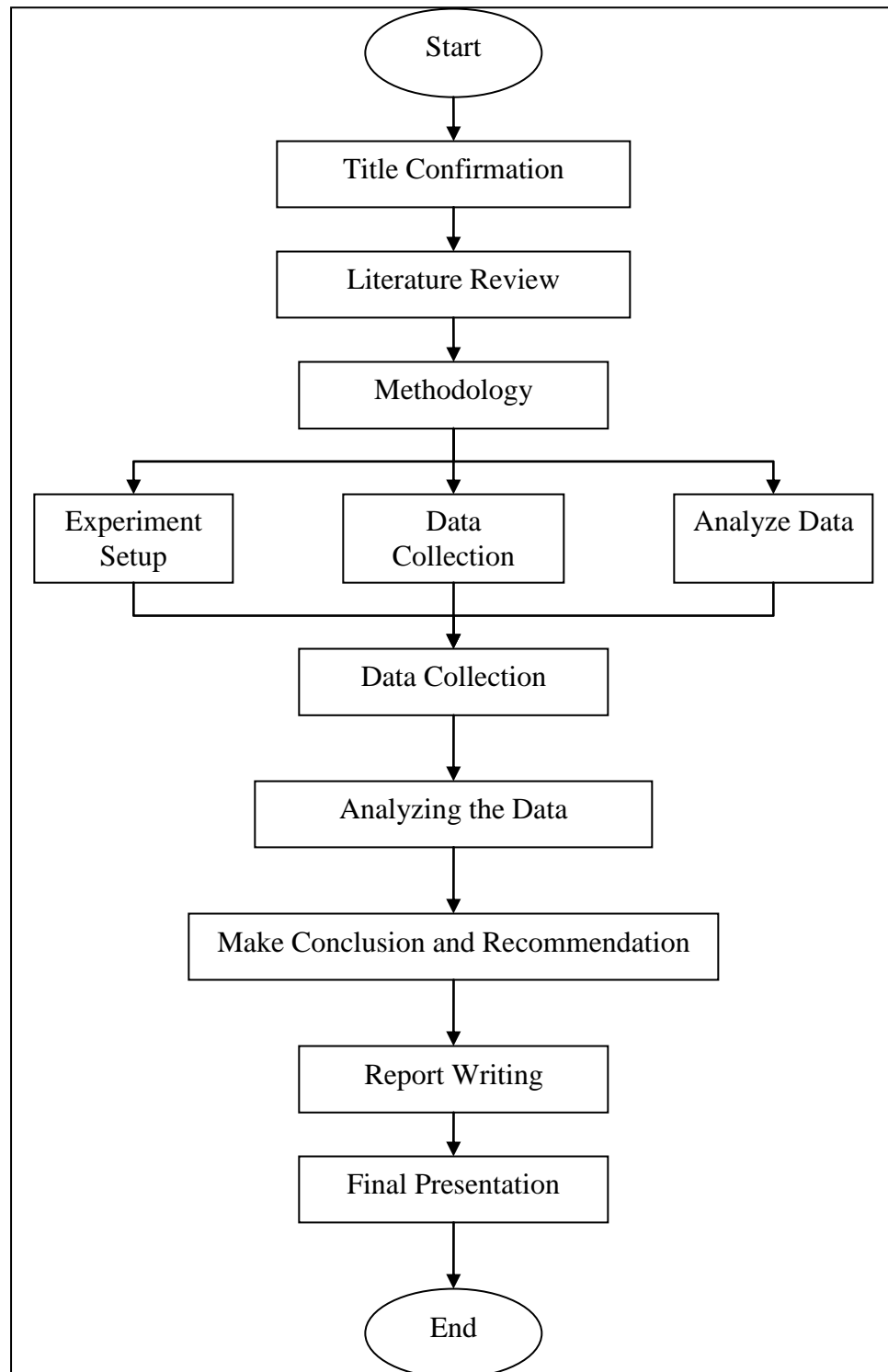


Figure 3.1: Flow Chart of the Overall FYP Process

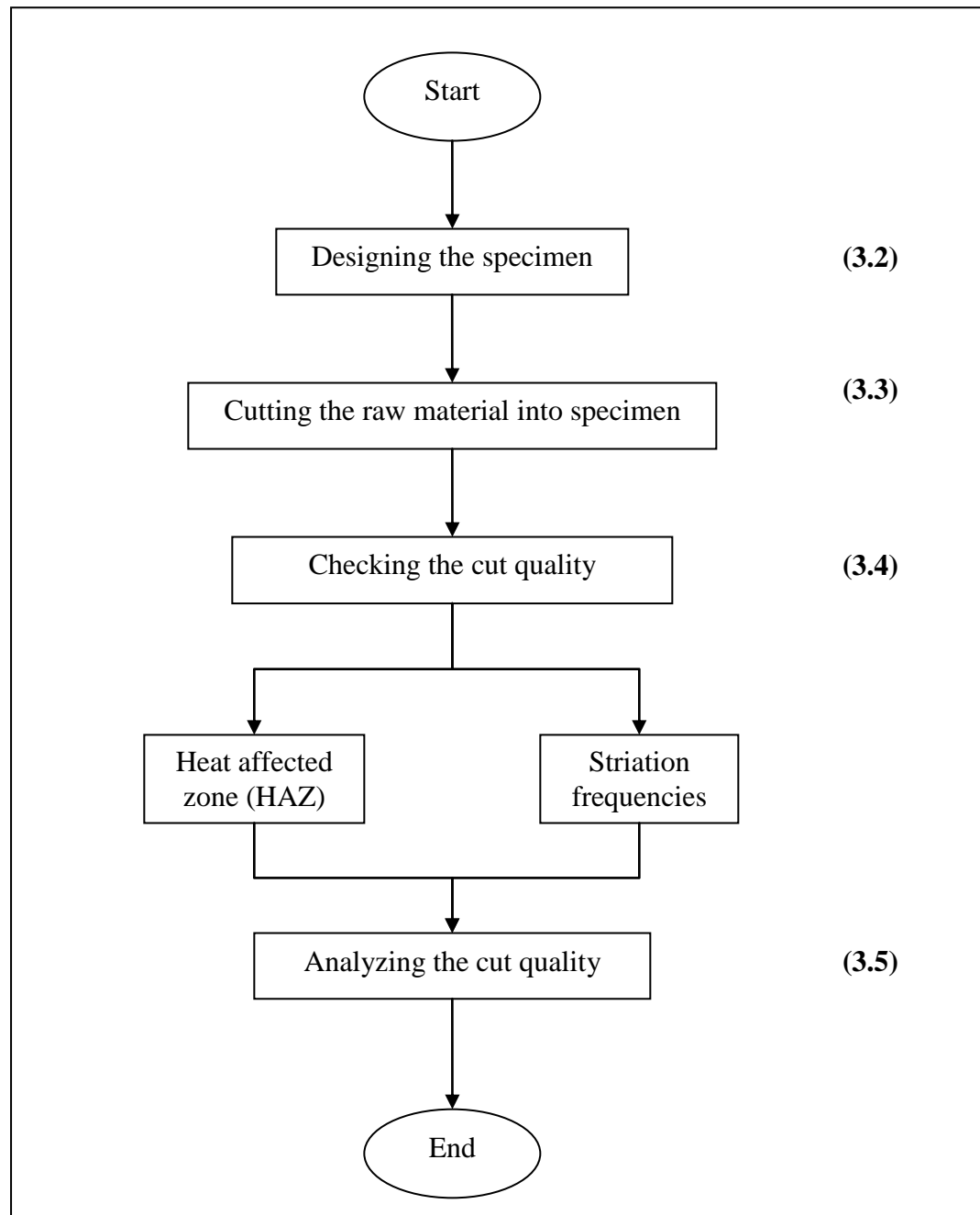


Figure 3.2: Flow Chart of the Experiment

3.2 DESIGNING THE SPECIMEN

Before begins the experiment, suitable shape of specimen has to be prepared. As explained in Chapter 1, this experiment will use acrylic (PMMA) as the material to be cut.

Specimen is design by using SOLIDWORK Software. Figure 3.2 shows the features of the specimen.

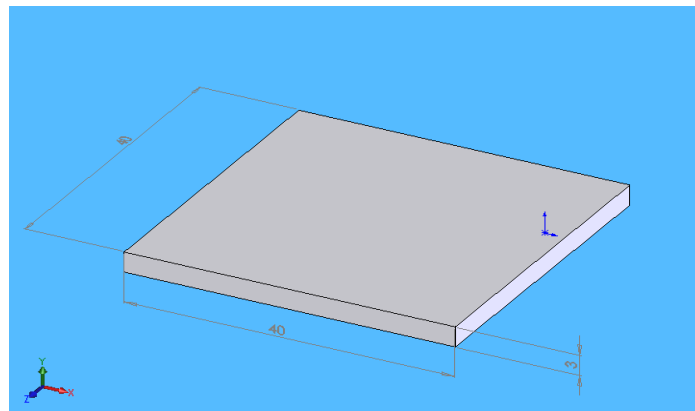


Figure 3.3a: Isometric View of the Specimen.

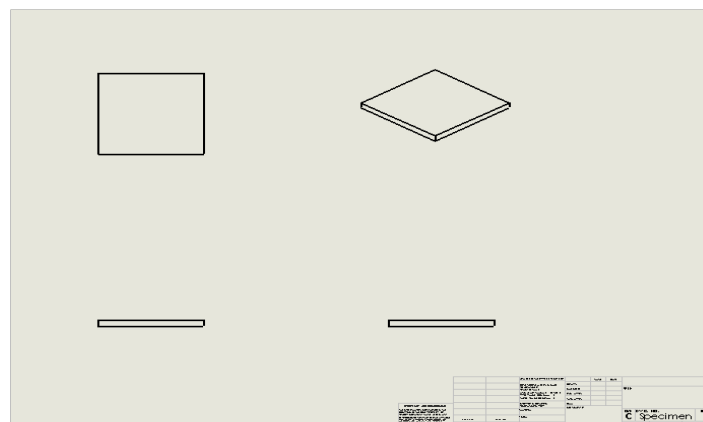



Figure 3.3b: Orthographic View of the Specimen

3.3 CUTTING RAW MATERIAL INTO SPECIMEN

After designing the specimen, the next step is cutting it. In this process, the laser cutting machine has to be program so that it can cut raw material into desired design. First of all, the laser machine power has to be set into 85% of its maximum power. This is because, according to the FKM laboratory instructor whose have the experience in handling the laser cutting machine, the optimum power to cut acrylic is 85% of its maximum power. Table below shows the general specifications for the laser cutting machine that will be use.

Table 3.1: Laser Cutting Machine General Specification

Specification	Data
Name	ILIOS CO ₂ Laser Marking System
Picture	 <p>Figure 3.4: ILIOS CO₂ Laser Marking System</p>
Laser Source	
Wavelength	10.57 – 10.63 μm
Power Output (Continuous)	30W (Maximum)
Mode Quality	TEM ₀₀ , 95% Purity

Beam Quality	M2 < 1.1
Power Stability	
From Cold Start	± 5%
After 2 minutes	± 3%
Marking Head	
Aperture	15mm
Interface	XYZ-100 16-bit Digital
Objective Lens	F = 100mm
Maximum Field Size	70 x 70 mm
Marking speed	3500mm per sec
Writing Speed	>600 possible
- Good Quality	400 char per sec
-Excellent Quality	350 char per sec

The raw material will be cut into 10 specimens as noted in the chapter 2 before. Figure 3.4 shows about the flow chart of the cutting process.

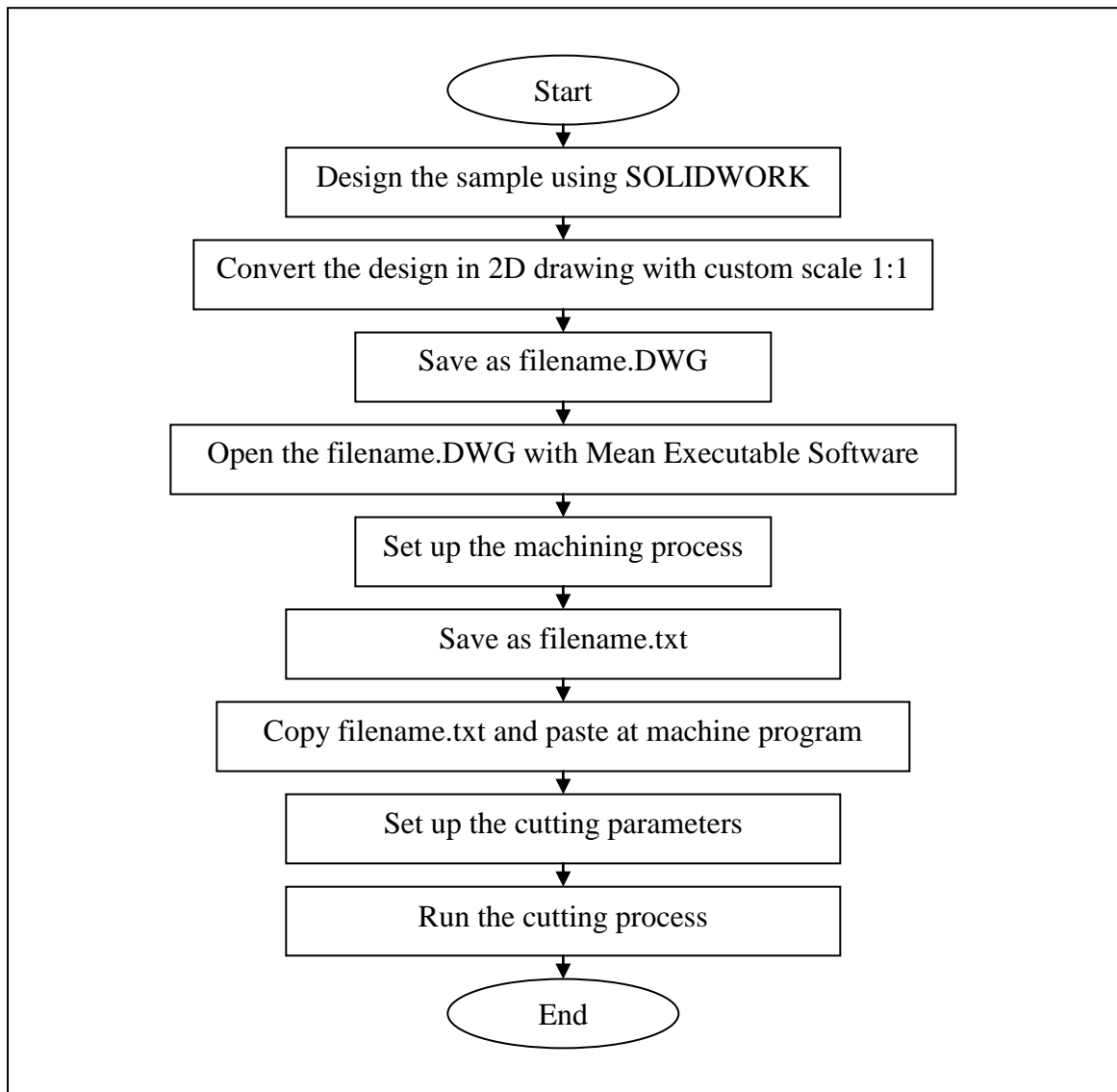


Figure 3.5: Flow Chart of the Cutting Process

3.4 CHECKING THE CUT QUALITY

The next step is checking the cut quality. In this process, the same specimen will be analyzed to determine the desired cut quality but to check the cut quality of each specimen, different technique will be used. The process of checking the cut quality will be explained as below.

3.4.1 Checking the Width of Heat Affected Zone (HAZ)

Image Analyzer will be used to determine the HAZ. The specimen will be drag into the image analyzer where the part which HAZ occur (along the cut surface) will be examined. Three reading will be taken along the part so that, the average of the reading is represent the width of HAZ of the specimen.

3.4.2 Checking the Striation Frequencies

Striation frequencies can be determined also by using the Image Analyzer Machine. Striation spacing was measured at seven different locations along the cut. Then, the distance for 2 striations was measured using the Image Analyzer Machine. The striation frequency was calculated by dividing the number of striations per unit length by the feed rate.

$$\text{Striation frequency (Hz)} = \frac{\text{No. of Striations} \times \text{Feed Rate}}{\text{Length of two striations}} \quad (3.1)$$

3.5 ANALYZING THE CUT QUALITY

In this experiment, manual calculation method is going to be used to analyze the data. From the data, two graphs can be developed which are:

- i. Heat Affected Zone (HAZ) Versus Feed Rate
- ii. Striation Frequencies Versus Feed Rate

From the two graphs obtained, the relationship between feed rate and the two cut quality parameters can be determine.

Tables 3.1, 3.2 and 3.3 show how the data of both cut qualities are collect.

Table 3.2: Table of data for the width of heat-affected zone

Feed rate		The width of Heat-Affected Zone (mm)			
Delay(μ s)	(mm/s)	Reading 1	Reading 2	Reading 3	Average
1900					
1800					
1700					
1600					
1500					
1400					
1300					
1200					
1100					
1000					

Table 3.3: Table of data for length of 10 striations.

Feed rate		Length of 10 Striation (mm)			
Delay(μ s)	(mm/s)	Reading 1	Reading 2	Reading 3	Average
1900					
1800					
1700					
1600					
1500					
1400					
1300					
1200					
1100					
1000					

Table 3.4: Table of data for striation frequency.

Feed Rate Delay(μ s)	mm/s	Average Length of 10 Striation (mm)	Striation Frequency (Hz)
1900			
1800			
1700			
1600			
1500			
1400			
1300			
1200			
1100			
1000			

3.6 SAFETY AND PRECAUTION STEPS

The safety and precaution steps are the important matters that have to be considered. Every process involve during the experiment has own safety and precaution steps. Below are the safety and precaution steps for every process involve in this experiment.

3.6.1 Safety and Precaution Steps for Cutting the Raw Material into Specimens.

Below is the list of safety and precaution steps to be followed during the cutting process.

- i. Personnel must wear eye protection when in the same area as an exposed laser beam. CO₂ laser radiation can be reflected from metallic object even though the surface is darkened. Direct or diffuse laser radiation can inflict serve corneal injuries leading to permanent eye damages or blindness.

- ii. Acrylic processing can generate air contaminant that is toxic. Material Safety Data Sheets (MSDS) for acrylic must be thoroughly evaluated and adequacy of provisions for fume extraction, filtering, and venting should be considered.
- iii. Do not place any miscellaneous item along the cutting path.

3.6.2 Safety and Precaution Steps for Analyzing the Specimen.

Below is the list of safety and precaution steps to be followed during the analyzing process.

- i. Make sure that lightning condition is in well condition so that clearer image can be display.
- ii. Take the image from the middle of the cut surface because the feed rate at the middle is much stable compared to both ends.
- iii. Measurement must be taken carefully so that parallax error can be reduced.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

After the entire requirement to run the experiment has been completed, Chapter 4 will show the data obtained from the experiment. Results will be shown in tabular form and the relationship between parameters will be shown in graph form. This chapter will also explain about the results. All calculation which is related to this experiment will be shown.

Through out this chapter, the relationship between effect of feed rate on HAZ and striation frequencies will be discussed. Error occurs during the experiment process will be discussed also in this chapter.

4.2 CONVERTING THE FEED RATE UNIT FROM DELAY (Pulse) INTO (mm/s)

Before analyze the results, the suitable unit for parameter especially feed rate has to be converted. This is because, to determine the striation frequency, the feed rate has to be in distance over time (mm/sec or mm/min). The feed rate from delay (μ s) to (mm/s) can be converted by using equation below.

$$\text{Feed rate} = \frac{1}{2 \times \text{Delay}} \times \frac{50}{10000} \quad (4.1)$$

From the equation 4.1 above, 50 and 10000 are the constant where 50 is the distance (in millimeter) that the laser machine travel during one revolution of the servo-motor and 10000 is the constant that have been set up in the laser machining program.

Sample of Calculation

$$\text{Feed rate} = \frac{1}{2 \times \text{Delay}} \times \frac{50}{10000}$$

$$\text{Feed rate} = \frac{1}{2 \times 1000} \frac{(\text{pulse})}{(\mu\text{s})} \times \frac{50 (\text{mm})}{10000 (\text{pulse})}$$

$$\text{Feed rate} = \underline{2.5 \text{ mm/s}}$$

By using the equation 4.1 above, all value of feed rate use has been converted and table 4.1 shows all the value of feed rate that use in this experiment.

Table 4.1: Table of converted feed rate

Feed Rate	
Delay (Pulse)	(mm/s)
1000	2.50
1100	2.27
1200	2.08
1300	1.92
1400	1.79
1500	1.67
1600	1.56
1700	1.47
1800	1.39
1900	1.32

4.3 EXPERIMENTAL RESULTS

4.3.1 Processing the Specimens.

In this experiment, specimens were cut into square shape. The specimens were cut into this particular shape because data of each three sides will be taken so that, the average results can be obtain.

There are several steps has to be followed in order to cut the raw material into specimen. PCNC-Laser Cutting Machine were use to cut the raw material into specimen. The first step only included with software measurement. The drawing of the specimen was saved in DWG format and then, opened the DWG file with Art Cam Pro V.9.1. The step will be show with the figure below.

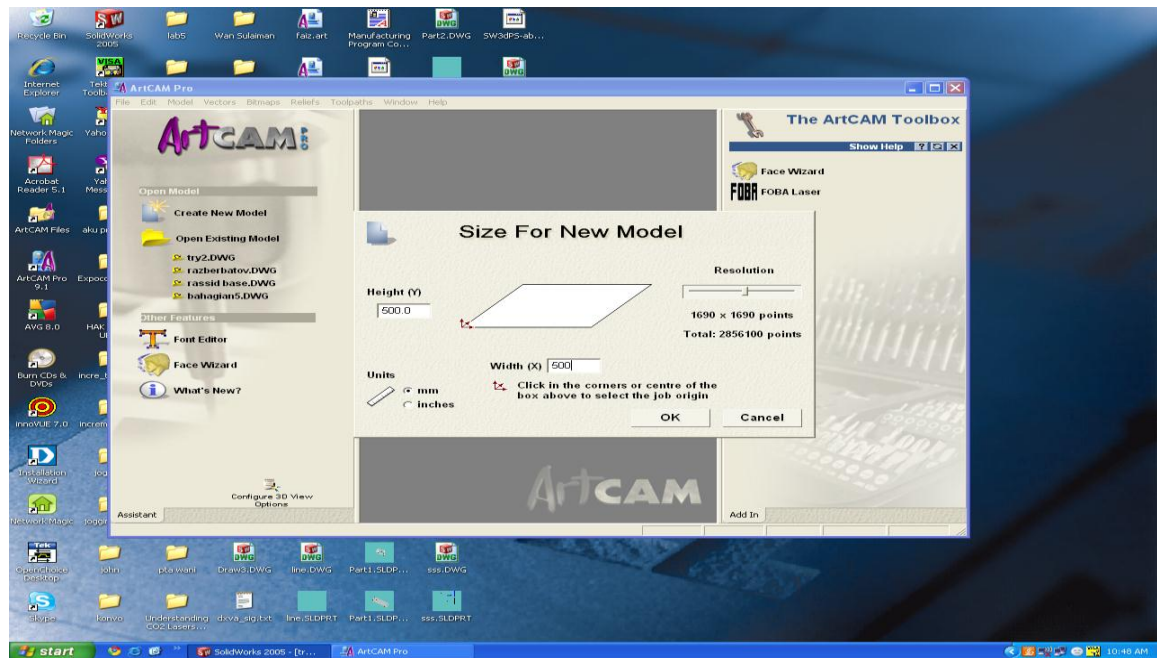


Figure 4.1 (a): Cutting step 1 (Define height and width)

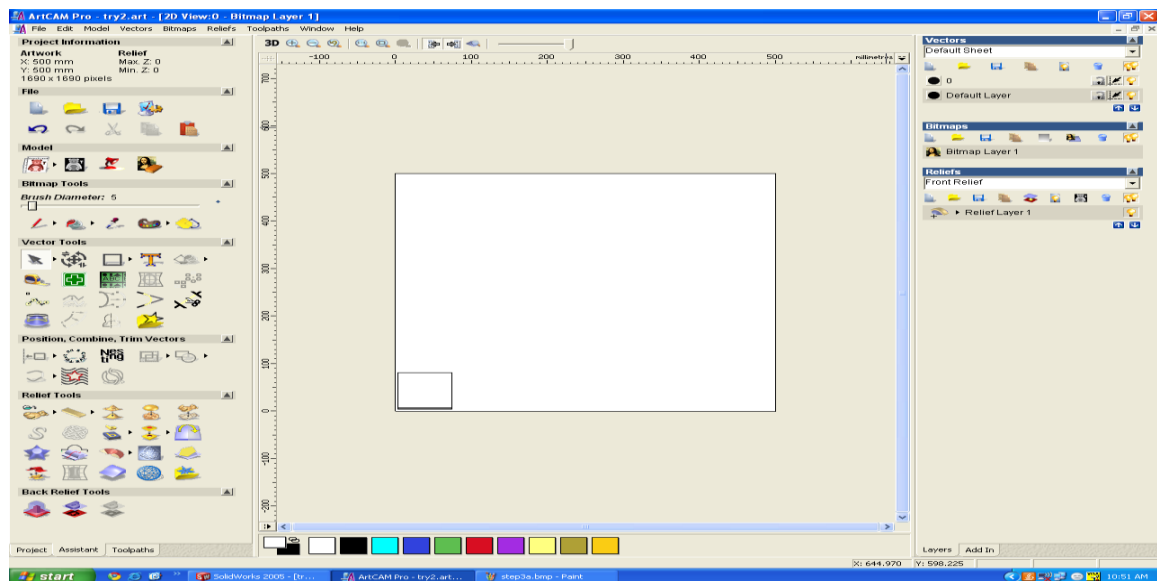


Figure 4.1 (b): Cutting step 2 (Unnecessary drawing removal)

Figure 4.1 (b), show the result after all the unnecessary drawing were removed. The desired specimen drawing were dragged to the origin so that, waste material can be decrease.

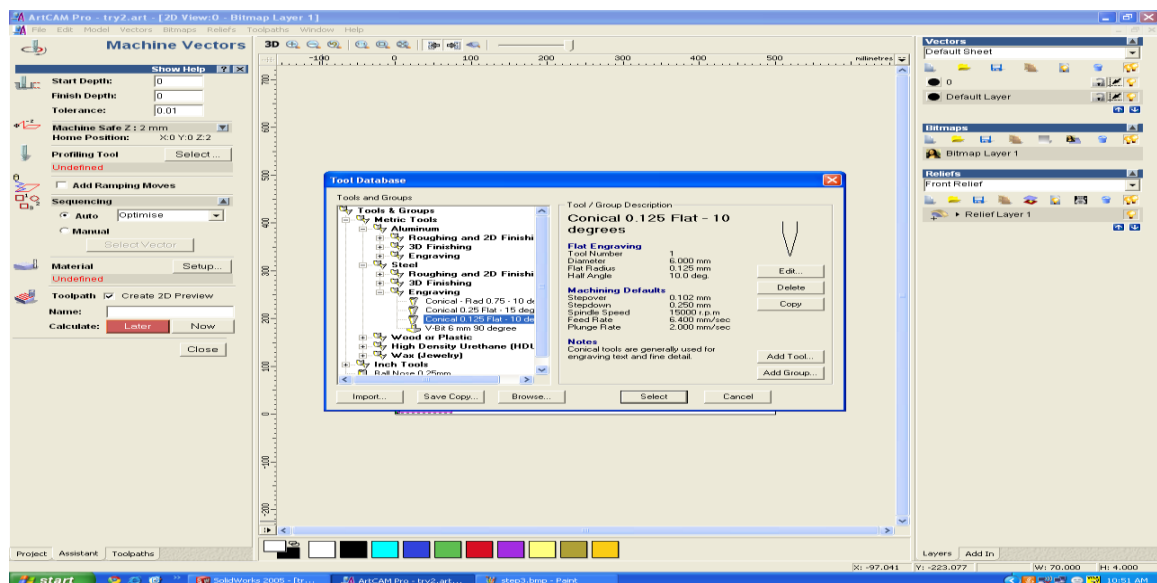


Figure 4.1 (c): Cutting step 3 (cutting tool selection)

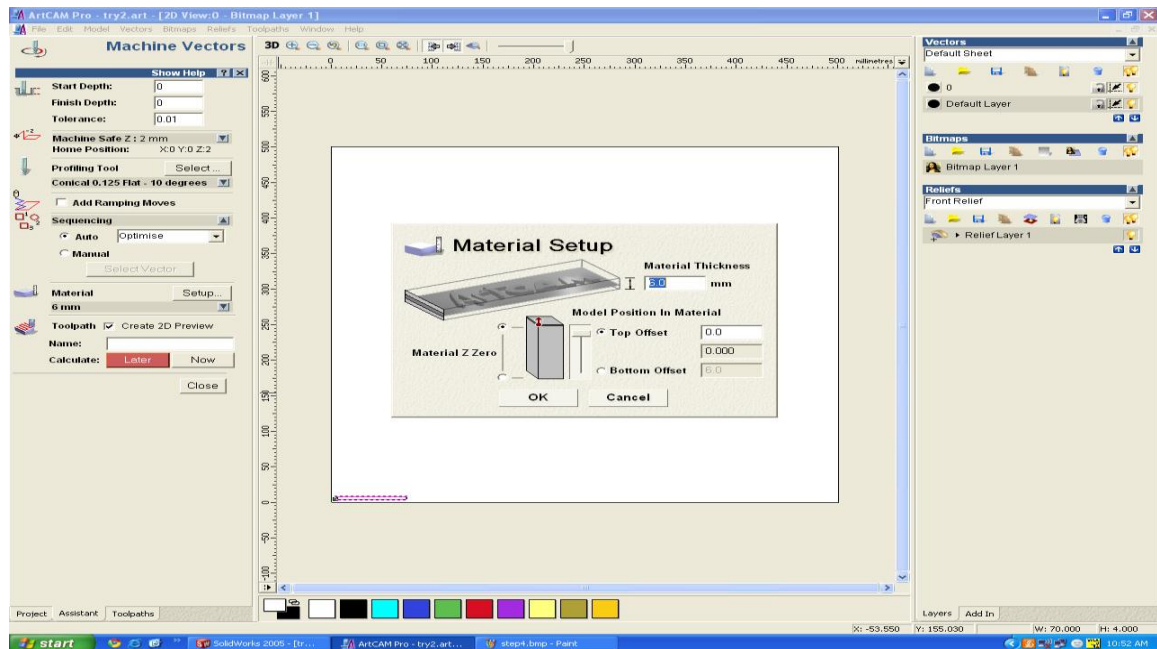


Figure 4.1 (d): Cutting step 4 (define thickness of the material)

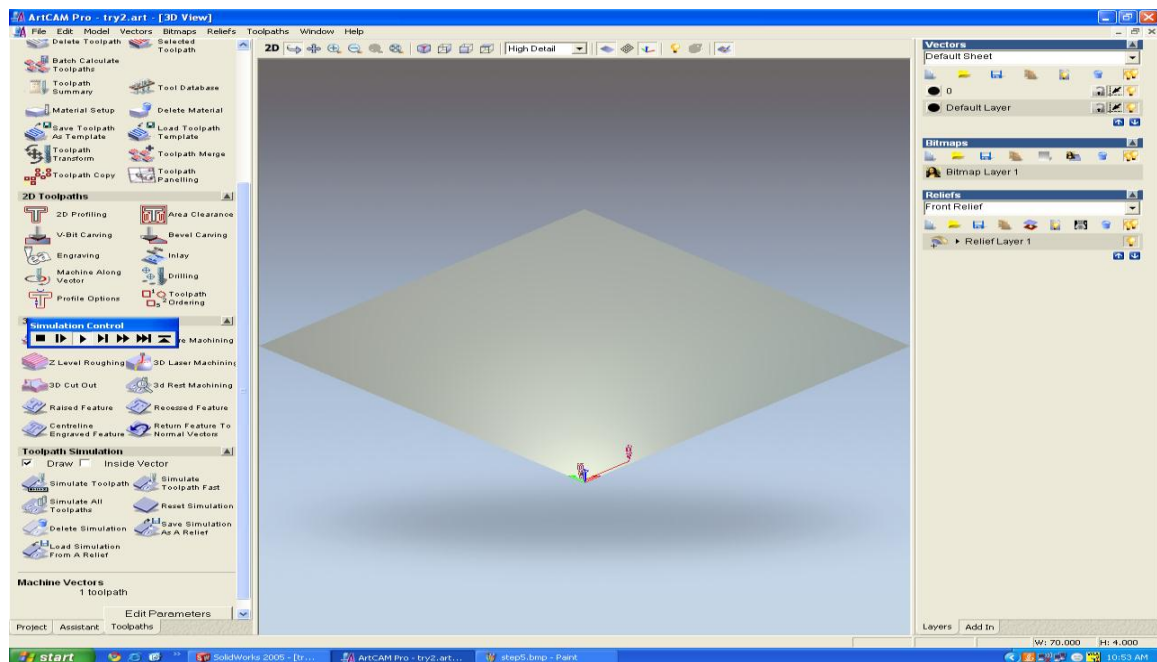


Figure 4.1 (e): Cutting step 5 (cutting simulation)

The screenshot shows a Windows XP desktop environment. A file explorer window is open, displaying a list of files and folders. A Notepad window is also open, showing the contents of a file named 'try2.txt'.

File Explorer Window:

- Address: C:\Documents and Settings\JMP\Desktop\Program Mesin\pcnc guna
- Files and Folders Tasks:
 - Rename this file
 - Move this file
 - Copy this file
 - Publish this file to the Web
 - E-mail this file
 - Print this file
 - Delete this file
- Other Places:
 - Program Mesin
 - My Documents
 - Shared Documents
 - My Computer
 - My Network Places
- Details:
 - try2.txt
 - Text Document
 - Date Modified: Today, October 10, 2008, 10:55 AM
 - Size: 207 bytes

Notepad Window (try2.txt):

```

File Edit Format View Help
RAPID <X0.000 Y0.000 Z2.000 TOOL# 0
RAPID <X2.870 Y4.876 Z2.000
LINE Z0.000 FEED 120.0
LINE <X72.870 FEED 384.0
LINE Y8.876
LINE <X2.870 Y4.876
LINE Z2.000
RAPID <X0.000 Y0.000 |
  
```

The file explorer window shows a list of files and folders, including 'lan2 g code', 'pcnc.exe', 'IO.DLL', 'gcode.bak', 'PCLINE.bak', 'pcnc.bak', 'Tgen.bak', 'gcode.h', 'fsh.h', 'IOCPH.H', 'pcnh.h', 'anuar.txt', 'anugerah.txt', 'ar.txt', 'Arab.txt', 'arman.txt', 'arya.txt', 'asa.txt', 'athahika.txt', 'atok.txt', 'atuli.txt', 'atut.txt', 'fadhur.txt', 'Far.txt', 'FAIZ DESIGN.txt', 'FAIZ.TXT', 'Fahri.txt', 'ff.txt', 'fisha.txt', 'FKM.txt', 'front wan.txt', 'Front.txt', 'g.txt', 'khar.txt', 'masraf.txt', 'malof.txt', 'Middle.txt', 'mali.txt', 'merf.txt', 'mukh.txt', 'muradi.txt', 'murad2.txt', 'murad3.txt', 'murad4.txt', 'samri.txt', 'sample1.txt', 'sample.txt', 'sayal.txt', 'sayat.txt', 'selamat datang palah.txt', 'sesku.txt', 'Side.txt', 'sign smidex.txt', 'Small.txt', 'smidex trophy.txt', 'spaner2.txt', 'spaner21.txt', 'spaner.txt', 'stamido.txt', 'suka-suka.txt', 'tabung.txt', 'tapak.txt', 'kapak.txt', 'temp1.txt', 'tertinggal.txt', 'test.txt', 'testtime.txt', 'text.txt', 'tiper.txt', 'tok.txt', 'tokma.txt', 'tool.txt', 'tooling.txt', 'Top.txt', 'total.txt', 'trophy engrave.txt', 'trophy.txt', 'try2.txt', 'try.txt', 'tulan.txt', 'ump baru.txt', 'unt.txt', 'yuzni.txt', 'zali.txt', 'zali.txt', 'zz.txt', 'zz.txt', 'zz.txt', 'PC_NC_SUO'.

Figure 4.1 (g): Cutting step 7 (example of the G-code)

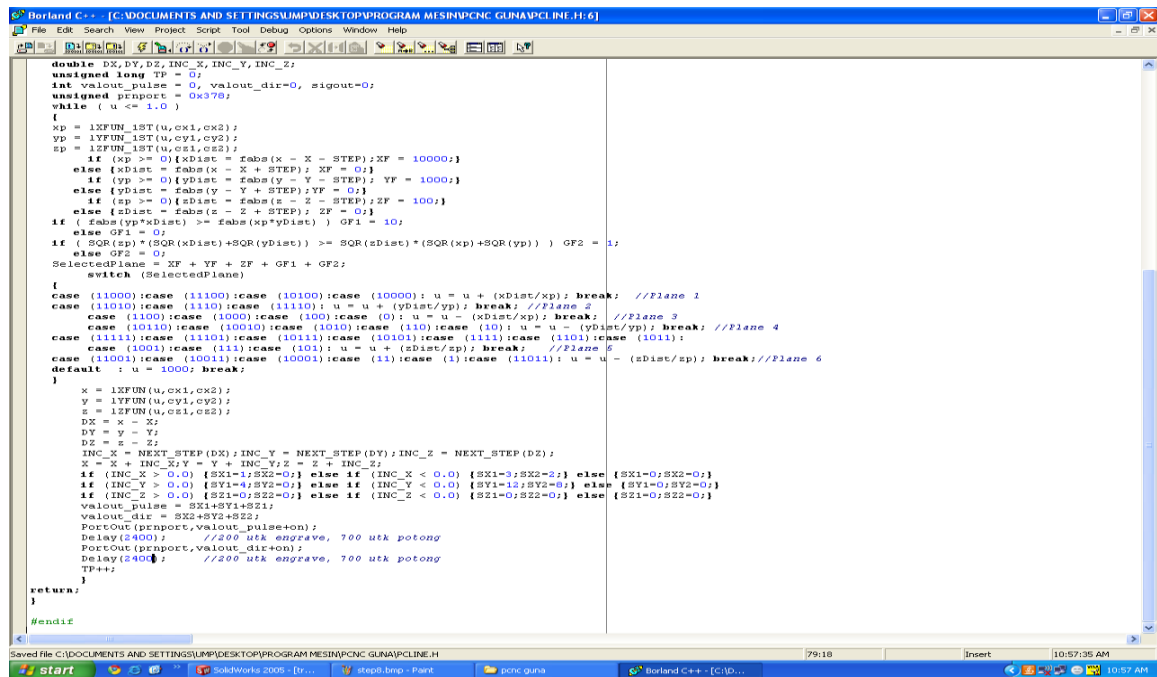


Figure 4.1 (h): Cutting step 8 (Feed rate set-up [in delay])

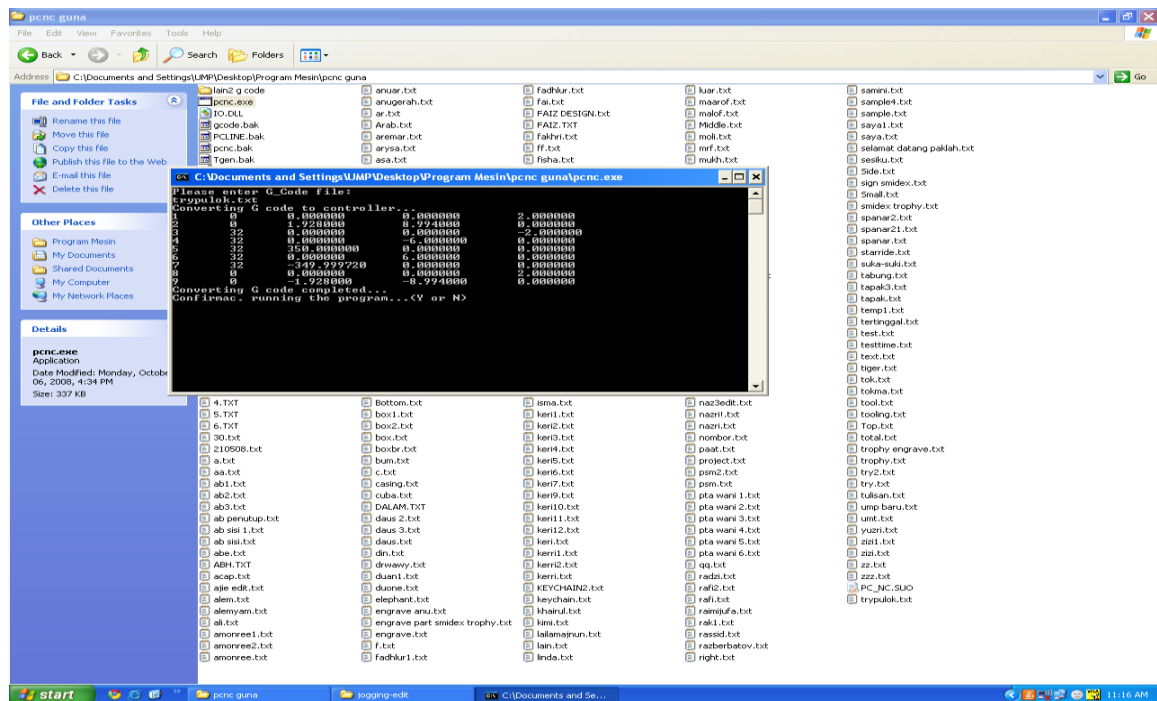


Figure 4.1 (i): Cutting step 9 (run the program and starts the cutting process)

4.3.2 Comparison Between CAD Design and Actual Design

The dimensions of the specimen are not accurate as ideal (design) specimen. This is because, the cutting tool (laser beam) are not sharp enough. It maybe because of the distant between the hose and raw material are not suitable so that it will make the laser beam to diverge and as a result, a better cut cannot be obtained. Figure 4.2 below shows the specimen that already cut.

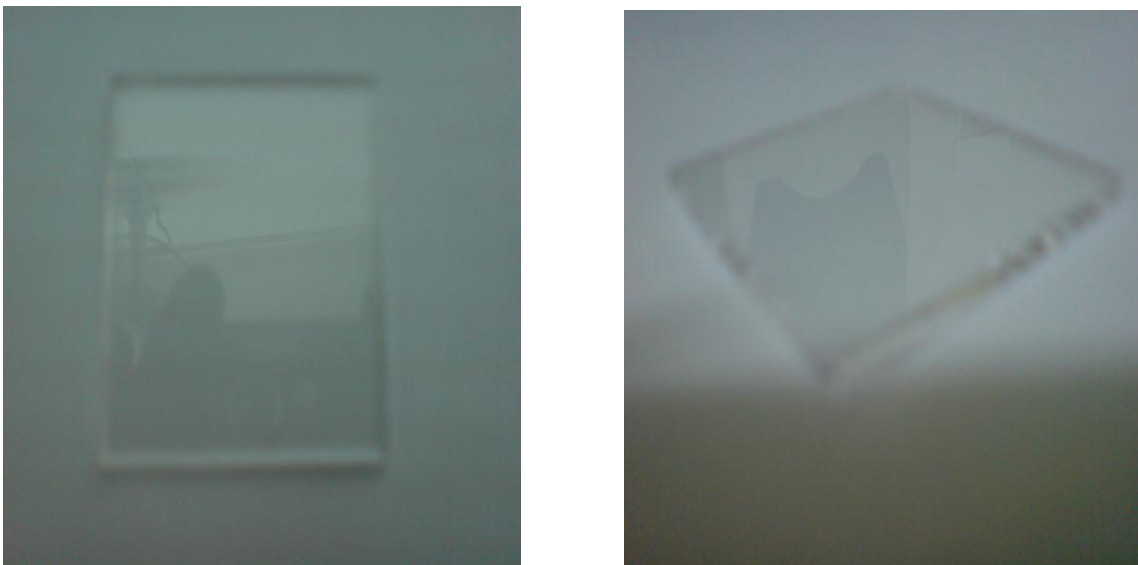


Figure 4.2: The specimen

4.3.3 The Width of Heat Affected Zone (HAZ) Analysis

From the experiment, the data of width of heat-affected zone (HAZ) were collected and keyed into tabular form. Graph that represents the relationship between feed rate and the width of heat-affected zone (HAZ) can be plotted based on the data in the table. Figure 4.3 shows the HAZ image that obtained from the Image Analyzer Machine.

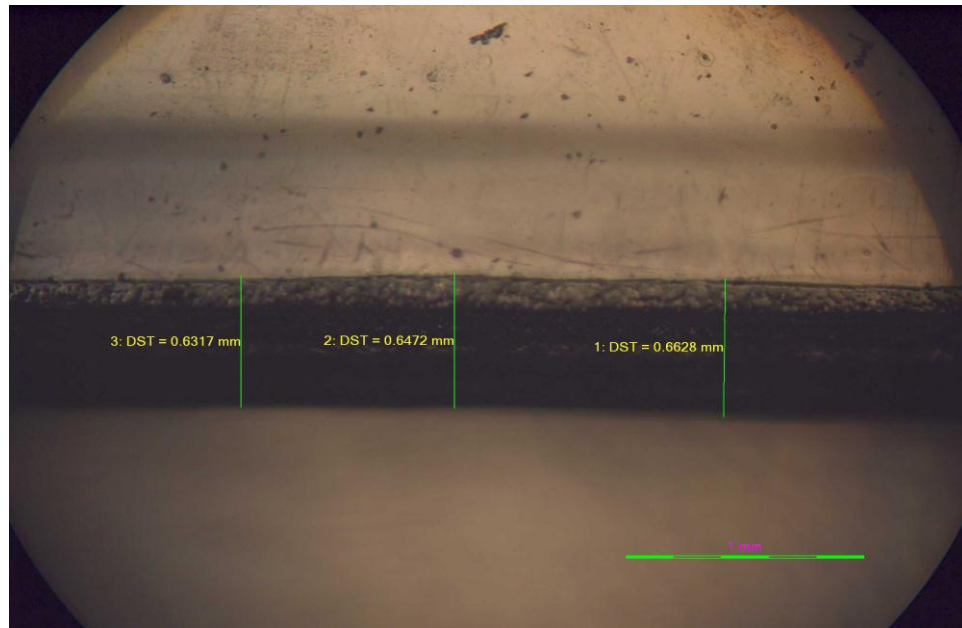


Figure 4.3: Image of Heat Affected Zone (HAZ)

Table 4.3 shows the data for the width of heat-affected zone (HAZ). Three reading were taken during the experiment so that the average of the reading can be taken.

Table 4.2: Table of data for the width of heat-affected zone

Feed rate		The width of Heat-Affected Zone (mm)			
Delay(μ s)	(mm/s)	Reading 1	Reading 2	Reading 3	Average
1900	1.32	1.2560	1.2600	1.2670	1.2600
1800	1.39	0.9883	0.9302	0.9767	0.9650
1700	1.47	0.9573	0.9418	0.9573	0.9553
1600	1.56	0.8372	0.8449	0.8759	0.8527
1500	1.67	0.7906	0.7906	0.7907	0.7906
1400	1.79	0.7636	0.7644	0.7519	0.7609
1300	1.92	0.6938	0.6938	0.7170	0.7015
1200	2.08	0.6317	0.6472	0.6628	0.6772

1100	2.27	0.6744	0.6656	0.6899	0.6766
1000	2.50	0.6628	0.6628	0.6667	0.6641

The effect of different feed rate on the width of HAZ at constant power level is shown in figure 4.4. X-axis represents the value of feed rate from 1.3 to 2.5 mm/s and Y-axis represent the value of average width of HAZ ranged from 0.6 to 1.3 mm.

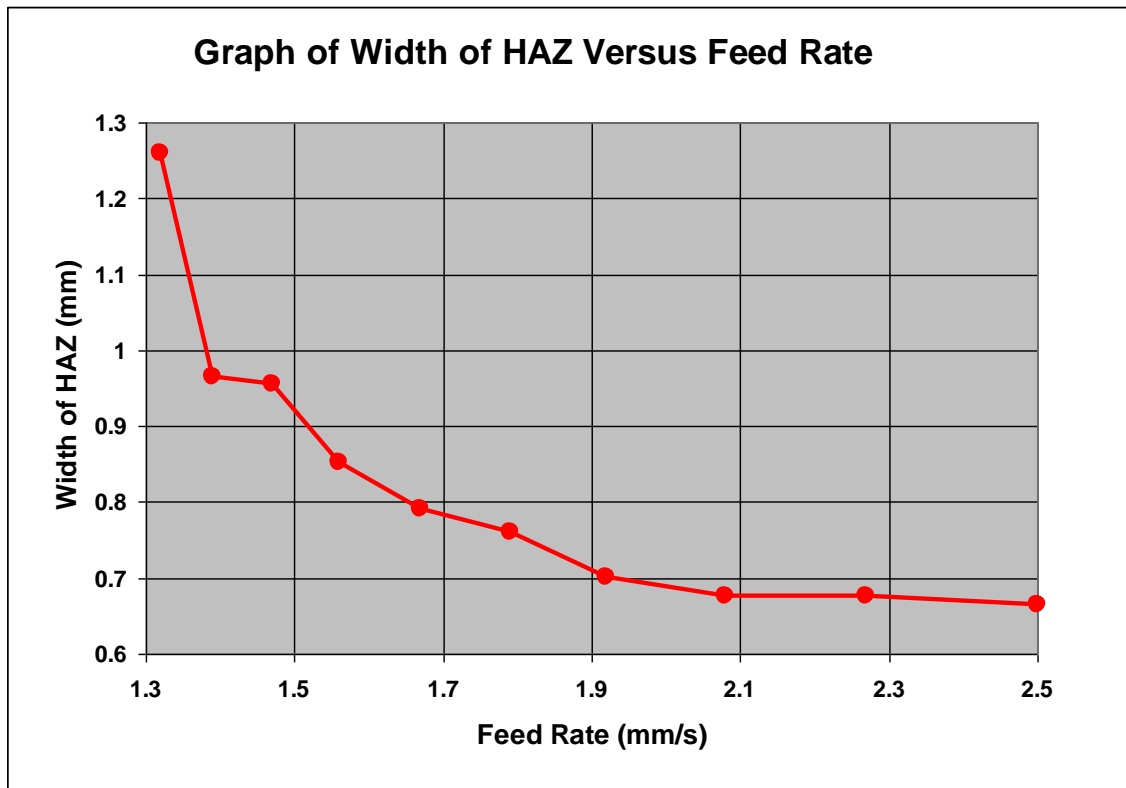


Figure 4.4: Graph of the width of HAZ versus feed rate

Theoretically, the width of HAZ will decrease with an increase of feed rate for the feed rate range from 1.32 to 2.5 mm/s. This result has an agreement with the reference [7]. This can be explained in terms of the material ability to conduct heat. As the feed rate increases, the time for the heat conduction is lowered and the spread of heat damage is reduced.

4.3.4 Striation Frequency Analysis

From the experiment, the length of two striations from any side was taken in three readings and data were keyed into tabular form. From the data taken, the average length of 2 striations can be determined and the value were keyed into another table. Graph that represents the relationship between feed rate and the striation frequency (HAZ) can be plotted based on the data in the second table.

Figure 4.5 shows the image of the striation that obtained from the Image Analyzer Machine.

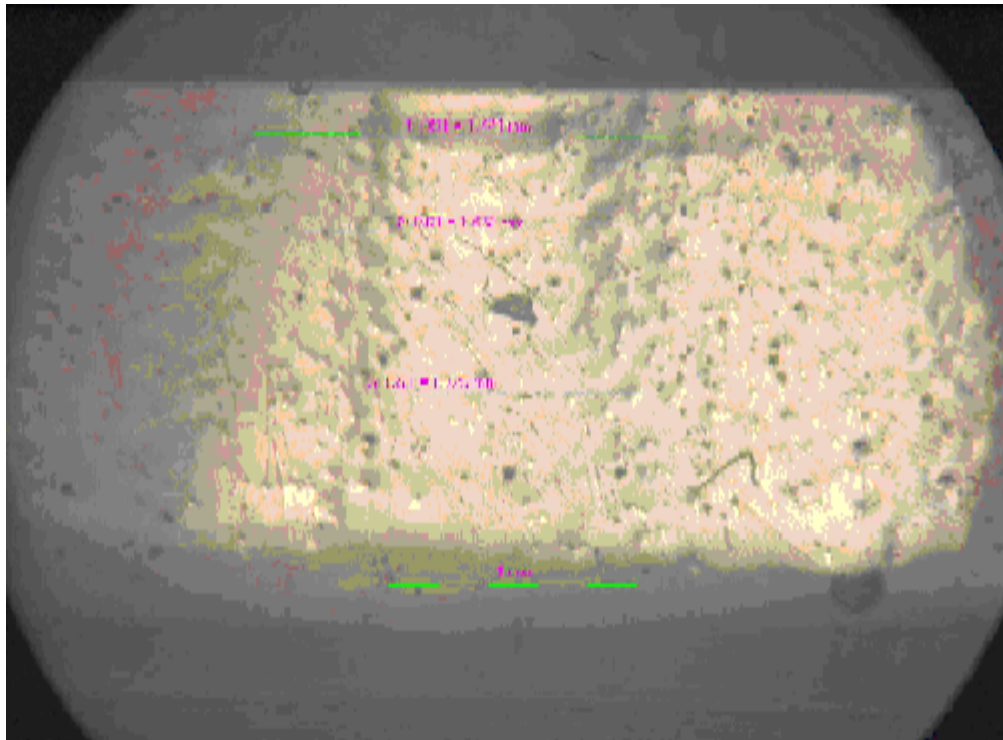


Figure 4.5: Image of the two striations.

From the experiment, three reading of the length of two striation were taken so that, parallax error can be reduced and more accurate reading can be obtained. Table 4.4 shows the results of the experiment.

Table 4.3: Table of data for the length of 2 striations

Feed rate		Length of 10 Striation (mm)			
Delay(μ s)	(mm/s)	Reading 1	Reading 2	Reading 3	Average
1900	1.32	1.632	1.638	1.626	1.632
1800	1.39	1.679	1.683	1.671	1.678
1700	1.47	1.703	1.703	1.711	1.705
1600	1.56	1.753	1.756	1.751	1.753
1500	1.67	1.771	1.774	1.763	1.769
1400	1.79	1.798	1.787	1.794	1.793
1300	1.92	1.806	1.802	1.802	1.803
1200	2.08	1.815	1.806	1.818	1.813
1100	2.27	1.845	1.842	1.837	1.841
1000	2.50	1.852	1.845	1.849	1.849

Figure 4.6 shows the relationship between length of two striations and feed rate. X-axis represent the feed rate value from 1.3 to 2.5 mm/s. The length of two striations was represented by Y-axis which valued from 1.6 to 1.8mm.

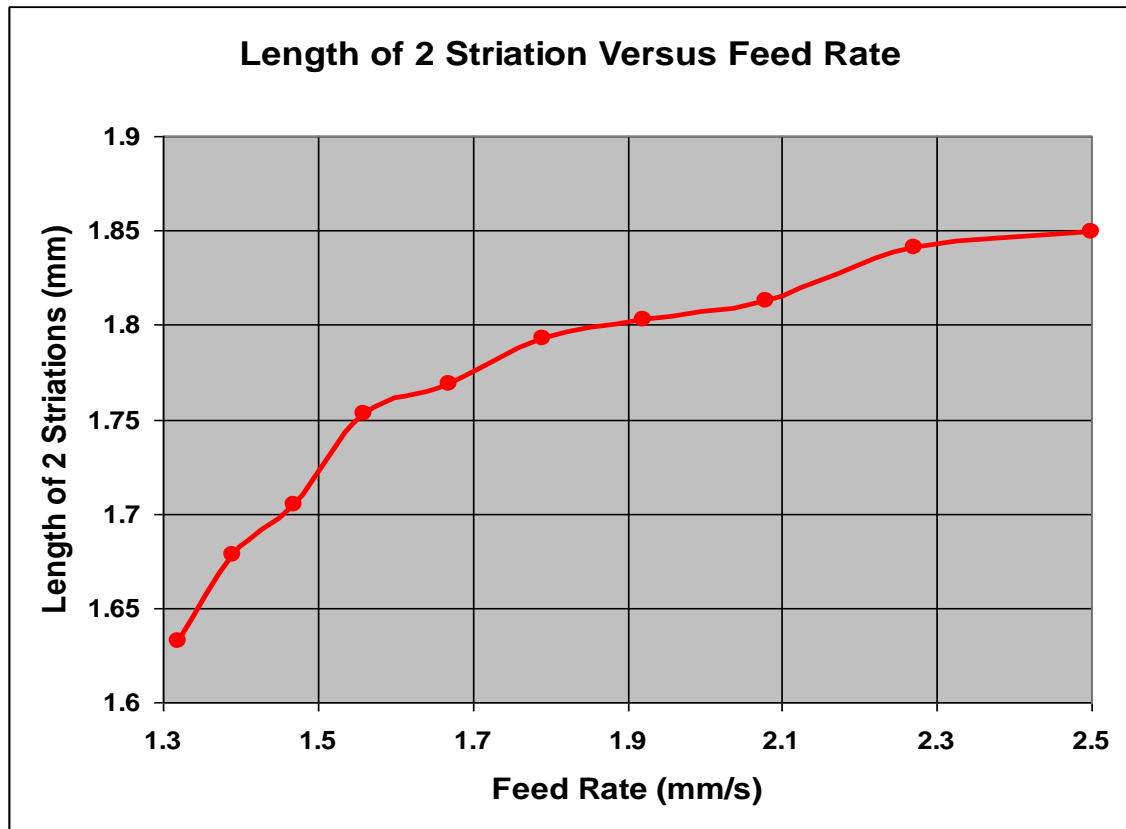


Figure 4.6: Graph of length for 2 striations versus feed rate

From figure 4.6, the relationship between length of two striations and feed rate can be obtained. An increasing in feed rate led to an increase in the length of two striations. Since the lengths of two striations were obtained, the striation frequency can be calculated by using equation 3.1. Below is the sample calculation using equation 3.1.

Sample Calculation

$$\begin{aligned}
 \text{Striation frequency (Hz)} &= \frac{\text{No. of Striations} \times \text{Feed Rate}}{\text{Length of two striations}} \\
 &= \frac{2 \times 2.5 \text{ (mm/s)}}{1.849 \text{ (mm)}} \\
 &= 2.704 \text{ (1/s)} \\
 &= 2.704 \text{ Hz}
 \end{aligned}$$

Table 4.5 below shows the results that obtain from the calculation using equation 3.1.

Table 4.4: Table of data for striation frequency

Feed Rate		Average Length of 2 Striation (mm)	Striation Frequency (Hz)
Delay(μ s)	mm/s		
1900	1.32	1.632	1.618
1800	1.39	1.678	1.657
1700	1.47	1.705	1.724
1600	1.56	1.753	1.764
1500	1.67	1.769	1.888
1400	1.79	1.793	2.000
1300	1.92	1.803	2.130
1200	2.08	1.813	2.295
1100	2.27	1.841	2.466
1000	2.50	1.849	2.704

From the equation 3.1, the striation frequency is directly proportional to the feed rate. From the table 4.5 as well, the striation frequencies were increase as the feed rate increase. This result has an agreement with the reference [7]. The effect of different feed rate on the striation frequency at constant power level was clearly shown in figure 4.7. X-axis represents the value of feed rate from 1.3 to 2.5 mm/s and Y-axis represent the value of striation frequencies ranged from 1.5 to 2.9 Hz.

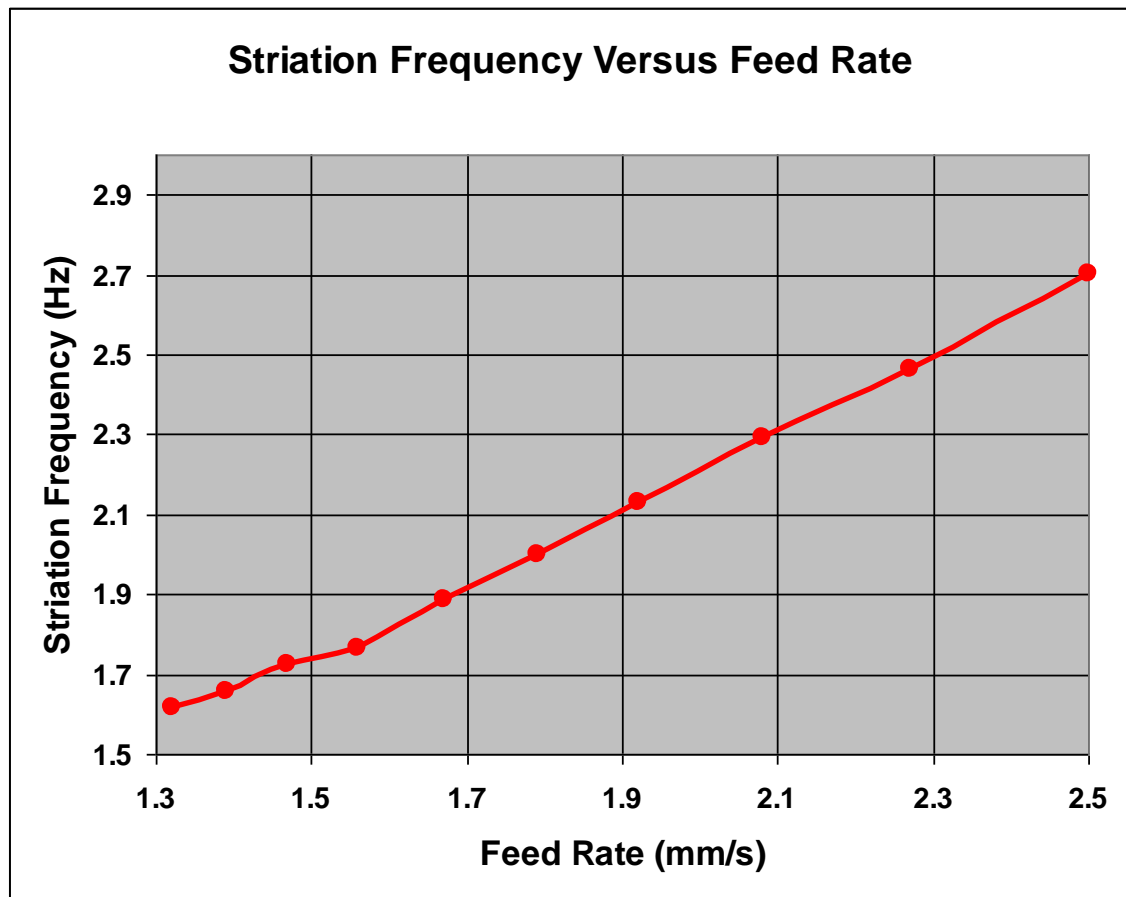


Figure 4.7: Graph of the striation frequency versus feed rate

Formation of striations occurs because of the cyclic variations in the driving factor of oxidation reactions, which are related to the oxygen partial pressure in the cutting zone. Viscosity and surface tension of the molten acrylic also contribute to this cyclic nature.

4.4 DISCUSSION OF ERROR OCCURS

Graph that have been plotted were not very smooth because there was an error occur during the experimental process. The error occurs because of following factors.

- (i) The laser beam produced by the laser machine.
- (ii) Experimental factor such as room temperature, air humidity, air ventilation, vibration caused by the laser machine and lightning condition.

Laser beam from the laser machine were not sharp enough because of the unsuitable standoff height. Standoff height must be control because it represents the distance between the lens inside the laser machine and the material to be cut. The function of the lens is to sharpen the laser beam. In order to get better product (specimen), the standoff height must be control so that the divergence of the laser beam can be reduced and as a result, sharper laser can be produce. The divergence laser beam affects the width of HAZ because the area that hit by the laser beam became larger.

Besides that, environmental effect such as room temperature, air humidity and air ventilation also must be considered. Those factors were affected the cooling rate and the flow of the molten material so that, the striation formation will also be affected. The vibration of the laser machine also gives an effect to the specimen especially on it striation.

In measurement process, lightning condition must be control so that better image can be display by the Image Analyzer Machine and as a result, better measurement can be determined.

4.5 CONCLUSION

From this chapter, all the data has been shown and the results were clearly discussed. The result gather from this experiment has an agreement with the previous study and theory. The result were affected by an error occurs during the experiment but the result shows that the error did not affect the result too much. To gather the better result, procedure of the experiment must follows properly and the factor which affects the result must be control. Overall conclusion and recommendation about this study will be explained in chapter 5.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter will conclude the overall project and recommendation for future study will also be explained in this chapter.

5.2 CONCLUSION

The effects of different value of feed rate and constant power value on the width of HAZ and striation frequencies were studied in this project. Based on the result of the experiment, the objectives of this project were successfully achieved.

According to the result obtained, feed rate had gives effect on the both the width of HAZ and striation frequencies. An increasing in feed rate led to an increase in the width of HAZ. From the experiment, the result shows that at higher value of feed rate, the width of HAZ became smaller. But for the best feed rate according this experiment project is 1.136mm/s at power 25.5W to get good on surface roughness.

From the experiment also, the feed rate value also affect the striation frequencies. The higher the feed rate value, the laser machine will travel faster and as a result, the striation frequencies become larger.

5.3 RECOMMENDATION

From the discussion overviewed, there were some adjustment has to be done before and during the experiment so that, better result can be obtained.

The factor that caused the error has been studied before running the experiment. Standoff height, nozzle cleanliness and usage of assist gas also have to be considered so that, better cutting product can be produce. The environmental effect should be considered because it will affect the result of the experiment especially in striation frequency.

It is better to use other method to analyze the data obtained. ANOVA and regression analysis method are the best example. This is because, wider range of data has to be used and more parameter can be analyzed together. Besides, it is better if the laser machine used has a wider range of power and feed rate value.

To get clearer image, other machine can be used such as Scanning Electron Microscope (SEM). The striation formation was hard to see by the image analyzer because of the limited level of magnifier.

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APPENDIX C

Laser Cutting Machine



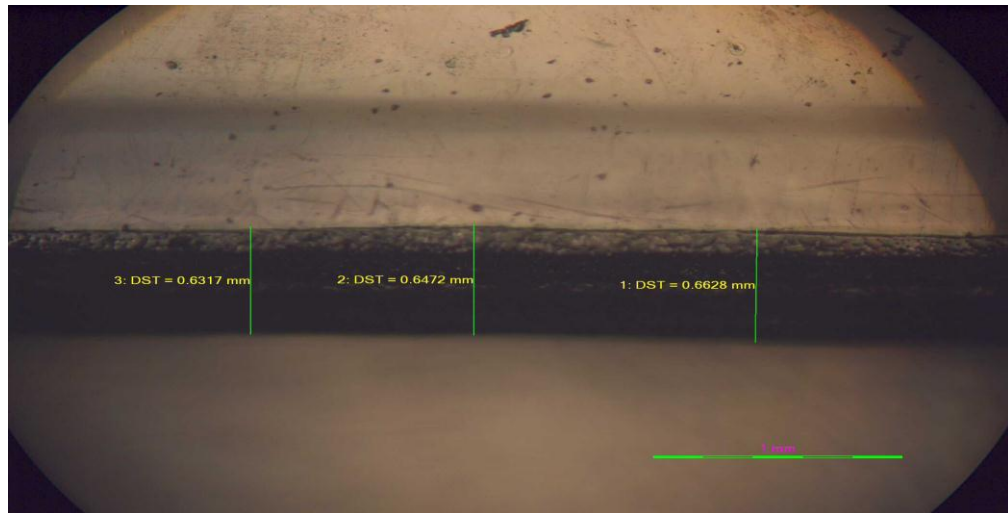
APPENDIX D

Image Analyzer

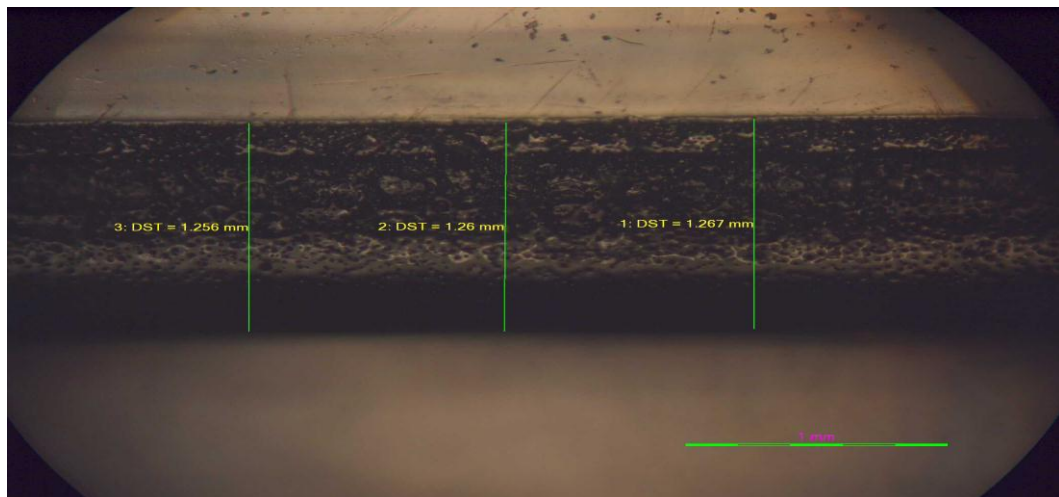


APPENDIX E

Image of HAZ



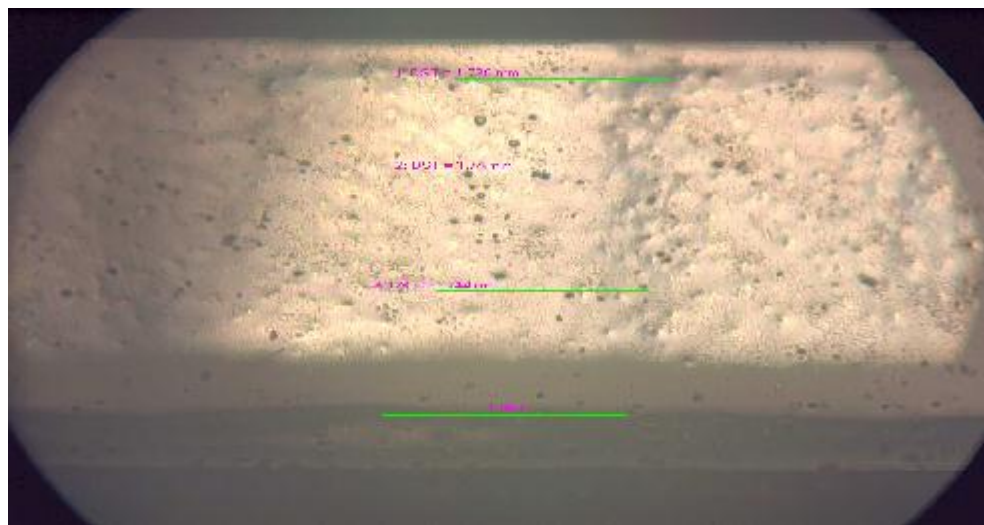
Feed Rate = 1200 μ s (2.08mm/s)



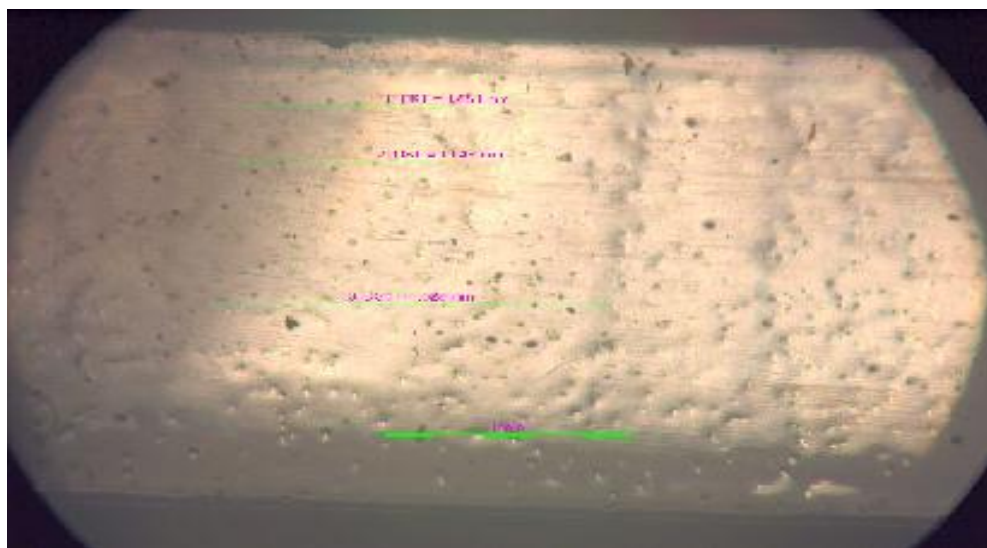
Feed Rate = 1900 μ s (1.32mm/s)

APPENDIX F

Image of Striation



Feed Rate = 1600 μ s (1.56mm/s)



Feed Rate = 1900 μ s (1.32mm/s)