CARBON DIOXIDE (CO$_2$) LASER CUT QUALITY OF ACRYLIC WITH DIFFERENT POWER LEVELS

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Report submitted in partial fulfilment 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.

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STUDENT'S DECLARATION

I declared that this dissertation entitled "Carbon Dioxide (CO_2) Laser Cut Quality of Acrylic with Different Power Levels" 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.

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DEDICATION

To my beloved father and mother

Mr. Abdullah Bin Yaacob
Mdm. Wan Zainab Binti Wan Jaffar

To my supervisor

Mdm. Nurul Shahida Binti Mohd Shalahim

ACKNOWLEDGEMENTS

ABSTRACT

Laser is widely applied in today's industry. Laser is widely used in industry for cutting and boring metals and other materials, in medicine for surgery, and in communications, scientific research, and holography. Laser cutting machine is often used in marking or engraving wood, glass, acrylic, rubber, ceramics, coated metals and marble. Laser cutting machine has greater advantages compared to the traditional method for cutting the material. It produces better cut quality of material. The project is to examine the effects of laser cutting of acrylic material with the use of different power levels and constant feed rate. The effects on both parameters, which are striation frequency and the size of HAZ, are analyzed. Manual analysis was used to develop graphs that describe the effects of power on laser cut quality. The suitable desired power level to get the optimum cut quality of acrylic is 22.5 watts at feed rate 1800 μs. For optimum cut quality, striation frequency and size of HAZ parameters are kept at minimum levels. Increasing power leads to the decrease of striation frequency. The size of HAZ increases when there is an increase in power. Power laser produces small effects on the striation frequency and size of HAZ. Study and analyze the other parameters or factors that affect the cut quality of acrylic should be consider for the future research.

ABSTRAK

Hari ini, laser diterapkan secara meluas dalam industri. Laser digunakan secara luas di industri untuk memotong dan membuat lubang pada logam/besi dan bahan lain, dlm bidang perubatan, komunikasi, kajian saintifik, dan holografi. Mesin laser pemotong sering digunakan dalam penandaan atau pengukiran kayu, kaca, acrylic, getah, seramik, lapis metal dan marmar. Mesin laser pemotong mempunyai banyak kelebihan berbanding dengan cara tradisional dalam pemotongan bahan. Mesin laser pemotong boleh menghasilkan kesan pemotongan yang baik terhadap bahan yang dipotong. Projek ini bertujuan untuk mengkaji kesan pemotongan laser terhadap bahan iaitu, acrylic dengan menggunakan kuasa laser yang berlainan serta kadar pemotongan yang tetap. Kesan terhadap kedua-dua parameter iaitu frekuensi pengoresan dan saiz zon kesan pemanasan dianalisis. Analisis manual digunakan untuk membuat graf yang menunjukkan kesan kuasa ke atas kualiti pemotongan laser. Tahap kuasa laser yang sesuai digunakan untuk mendapatkan kualiti pemotongan yang optimum adalah 22.5 watts pada kadar potongan 1800 µs. Untuk mendapat kualiti pemotongan yang optimum, parameter frekuensi pengoresan dan zon kesan pemanasan ditetapkan pada tahap minimum. Peningkatan pada kuasa menjurus kepada penurunan frekuensi pengoresan. Saiz zon kesan pemanasan meningkat apabila kuasa ditambah. Kuasa laser menghasilkan kesan yang kecil pada frekuensi pengoresan dan zon kesan pemanasan dianalisis. Kajian dan analisis parameter atau faktor lain yang mempengaruhi kualiti pemotongan acrylic perlu diambil kira untuk kajian masa akan datang.

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

CHAPTER 1

INTRODUCTION

1.1   INTRODUCTION

Laser, which stands for Light Amplification by Stimulated Emission of Radiation, is an electrical-optical device that produces coherent radiation. Simply put, a laser is a device that creates and amplifies a narrow, intense beam of coherent light. Nowadays, laser is widely applied in today's industry.

Lasers are widely used in industry for cutting and boring metals and other materials, in medicine for surgery, and in communications, scientific research, and holography. They are an integral part of such familiar devices as bar code scanners used in supermarkets, scanners, laser printers, and compact disk players. One of the laser systems that dominate the commercial laser industry is CO_2 laser systems. It has its own strengths in various cutting and marking applications.

The concept used in developing the laser-cutting machine is the concept of stimulated emission which was first suggested by Albert Einstein in 1916 by proving the Planck's Law of Radiation. Laser cutter machine is being used for an increasing number of applications in sheet metal processing and represents a unique quality. The high level of production flexibility and the almost unlimited diversity of materials and shapes explain its worldwide recognition as an indispensable basic technology. High precision of the dimensions and minimum heat distortion of the sheet parts are just two of the

advantages that convince the user of the first class cutting results.Laser cutting machine is often used in marking or engraving wood, glass, acrylic, rubber, ceramics, coated metals and marble. In the higher wattage (25 or greater), material such as acrylic may be completely and accurately cut out to form various shapes.

Acrylic is a versatile material and has been used in a wide range of fields and applications. It is a useful, clear plastic that resembles glass, but has properties that make it superior to glass in many ways. Acrylic also is completely transparent, rigid, and exhibits great resistance to breakage. As for these characteristics, acrylic has become widely used in today's industry. It is used to make various products, such as shower doors, bath enclosures, windows and skylights. It is chosen over glass for many reasons. It is many times stronger than glass, making it much more impact resistant and therefore safer. Falling against an acrylic shower door will not likely break it. Baseballs that crash through glass windows will, in most cases, bounce off acrylic windows. Acrylic also insulates better than glass, potentially saving on heating bills. Another great advantage of acrylic is that it is only half as heavy as glass. This makes working with acrylic much easier. It can also be sawed, whereas glass must be scored. [12]

In the present days, the applications include inspection windows, sight gauges, windshields, meter faces, protective covers, safety shields, tanks, desk tops, displays, trays, and chair pads. Acrylic comes in a wide variety of standard colors (colorless sheet). It is seen in malls, institutions, prisons, hospitals and commercial buildings. The fact that some of them are bullet resistant, it is now in highly demand.

Acrylics come in various shapes. There are many ways of processing them, and the one discussed here is the process done by using laser cutter machines. The process is called laser cutting process. Some parameters need to be made emphasis to determine the laser cut quality. This research is done to evaluate crucial aspects of the laser cutting process.

1.2   PROBLEM STATEMENT

This experiment is conducted to analyze the parameters while cutting the acrylic using different powers of laser cutting machine. So, investigate what happens to that material when we cut it using different powers. In this project, the most important variables to be controlled are the power and feed rate. The difficult part of this project is to set the power of the laser cutting machine.

The experiment is conducted to analyze the effects of power values on cut quality of materials, which are striation frequency and HAZ. The most suitable power value to produce optimum cut quality is still unknown (power value which produces high quality on both parameters).

1.3   OBJECTIVES

The objectives of this study are:

1.3.1   To study and analyze the effects of different power values with a constant feed rate value in laser cut quality of acrylic.

1.3.2   To find the suitable power to get the optimum cut quality on striation frequency and the size of heat-affected zone (HAZ).

1.4   PROJECT SCOPES

The scopes of the study are:

1.4.1   Experiment and analyze the laser cutting quality by using the material of acrylic.

1.4.2   Study the laser cut quality parameter such as striation frequency and HAZ.

1.4.3   Run the experiment using different power values.

1.4.4   Analyze the data by using manual analysis.

1.5   THESIS ORGANIZATION

This thesis is divided into five chapters and each chapter has its own sub-topics. The first chapter, the introduction explains the preface of acrylics and laser cutter machines. The preface includes the characteristics and also the applications of both materials in today's industry. Advantages of both materials are included as well. The objectives are to explain the importance of carrying out the research. As for the problem statements, all problems and limitations faced during the research are pointed out. Scopes of the project are noted in this chapter as well.

In Chapter 2, definitions of terms associated with the research are stated. The terms are acrylic, surface roughness, striation frequency, and heat-affected zone. The definitions are entailed with the application in today's industry. There is also inclusive explanation on basic components of lasers and how they work.

Chapter 3 presents the methodology of the research. Methods or any particular procedures used to complete the experiment are noted in this chapter. It also includes the chronology of the research.

Results of the conducted experiment are stated in chapter 4. The results are gathered and discussed. Elaboration regarding the experiment is provided as well.

This is the final chapter. General indication of the project is explained in this chapter. Suggestions of reducing the effects or problems when cutting the acrylic are pointed out. The optimum power of giving the good cutting quality of acrylic is mentioned as well. Recommendation regarding the project is pointed out for the benefits in future tasks.

CHAPTER 2

LITERATURE REVIEW

2.1   INTRODUCTION

The literature review is a critical look at the existing research that is significant to the project. In the literature review, evaluation what has already been done. It is also to show how it is related to the current project. The literature review refers to any collections of materials on a topic. It is not supposed to be just a summary of other people's work.

This chapter will discuss on the working principles, basic components of laser, definitions of term associated with the research and parameters of cut quality.

2.2   LASER

2.2.1   History and Development

The process which makes lasers possible, Stimulated Emission, was proposed in 1917 by Albert Einstein. No one realized the incredible potential of this concept until the 1950's, when practical research was first performed on applying the theory of stimulated emission to making lasers. It wasn't until 1960 that the first true laser was made by Theodore Maimam, out of synthetic ruby. Many ideas for laser applications quickly followed, including some that never worked, like the laser eraser. Still, the early pioneers of laser technology would be shocked and amazed to see the multitude of ways that lasers are used by everyone, everyday, in today's world. [9, 20]

Since the early period of laser history, laser research has produced a variety of improved and specialized laser types, optimized for different performance goals, including new wavelength bands, maximum average output power, maximum peak output power, minimum output pulse duration, maximum power efficiency, maximum charging and maximum firing, and this research continues to this day. [14]

2.2.2 Components of a Laser
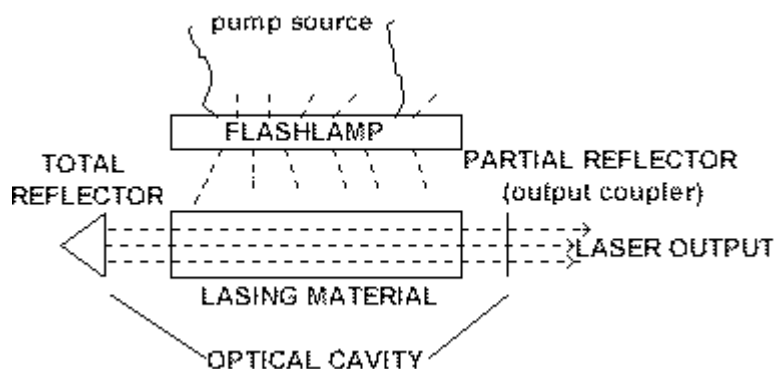
Figure 2.1: Solid State Laser Diagram

Source: Mary Bellis [17]

Figure 2.2 illustrates the basic components of the laser. The components are lasing material, pump source or excitation medium, optical cavity and output coupler. The lasing material can be a solid, liquid, gas or semiconductor, and can emit light in all directions. The pump source is typically electricity from a power supply, lamp or flashtube, but may also be another laser.

The excitation medium is used to excite the lasing material, causing it to emit light. The optical cavity contains mirrors at each end that reflect this light and cause it to bounce between the mirrors. As a result, the energy from the excitation medium is amplified in the form of light. Some of the light passes through the output coupler, usually a semi-transparent mirror at one end of the cavity. The resulting beam is then ready to use for any of hundreds of applications. [14]

2.2.3   Working Principle of Laser
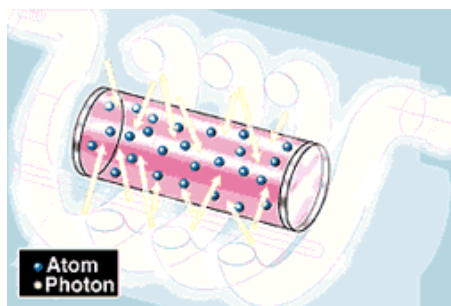
Step 1: Atom Excitation
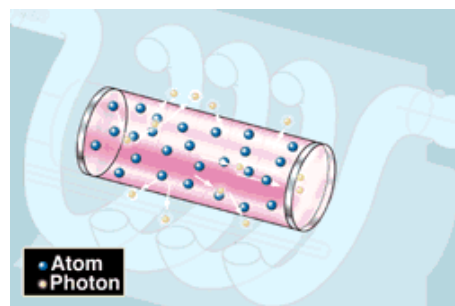
Step 2: Photon Productions
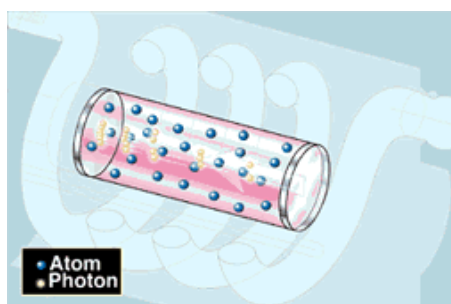
Step 3: Reflection
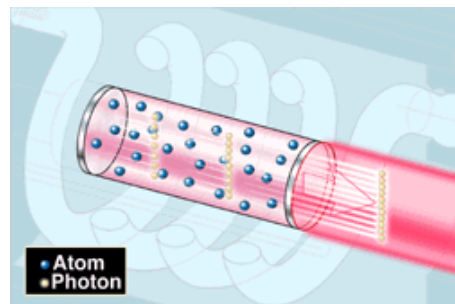
Step 4: Laser Beam Prodction

Figure 2.2: Laser Working Principles

These are the process of generating laser beam. In the first picture, it is illustrated that high-voltage electricity causes the quartz flash tube to emit an intense burst of light, exciting some of the atoms in the ruby crystal to higher energy levels. It is stated in picture 2 that 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. Picture 3 explains that mirrors at each end reflect the photons back and forth, continuing this process of stimulated emission and amplification. And the last process is the photons leave through the partially silvered mirror at one end. This is laser light. [7, 18]

2.3 CO$_2$ LASER CUTTING MACHINE

Laser cutting is a technology that uses a laser to cut materials and is usually used in industrial manufacturing. Laser cutting works by directing the output of a high power laser, by computer, at the material to be cut. The material then melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials. Some 6-axis lasers can perform cutting operations on parts that have been pre-formed by casting or machining.

Laser cutting usually works much like a milling machine would for working a sheet in that the laser (equivalent to the mill) enters through the side of the sheet and cuts it through the axis of the beam. In order to be able to start cutting from somewhere else than the edge, a pierce is done before every cut. Laser cutting machine allows you to create intricate designs and highly detailed inlays with a low-cost, highly profitable tool. Attached to the computer just like a printer, the system will cut designs we create in most graphic software programs. Set up the page size to the size of the piece we are engraving, create our image, and print it to the laser.

The carbon dioxide laser (CO$_2$ laser) was one of the earliest gas lasers to be developed (invented by Kumar Patel of Bell Labs in 1964) and is still one of the most useful materials ever created. Carbon dioxide lasers are the highest-power continuous wave lasers that are currently available. They are also quite efficient: the ratio of output power to pump power can be as large as 20%. This machine can cut through wood, acrylic, plastic, cloth, leather, matte board, melamine, paper, pressboard, rubber, wood veneer, fiberglass, cork and many other materials. The advantages of CO$_2$ laser cutting machine are: [9, 20]

    i. The laser creates a beam of light that is used to cut through the material, so there is no part of the laser system in contact with the material.

ii. For thinner materials, all Epilog laser systems include an Integrated Vacuum Table to hold down papers, fabrics, and thin plastics as you cut through the material.

iii. It is amazingly precise, following the pattern you've drawn on screen.

iv. Cut several patterns from the same piece of material.
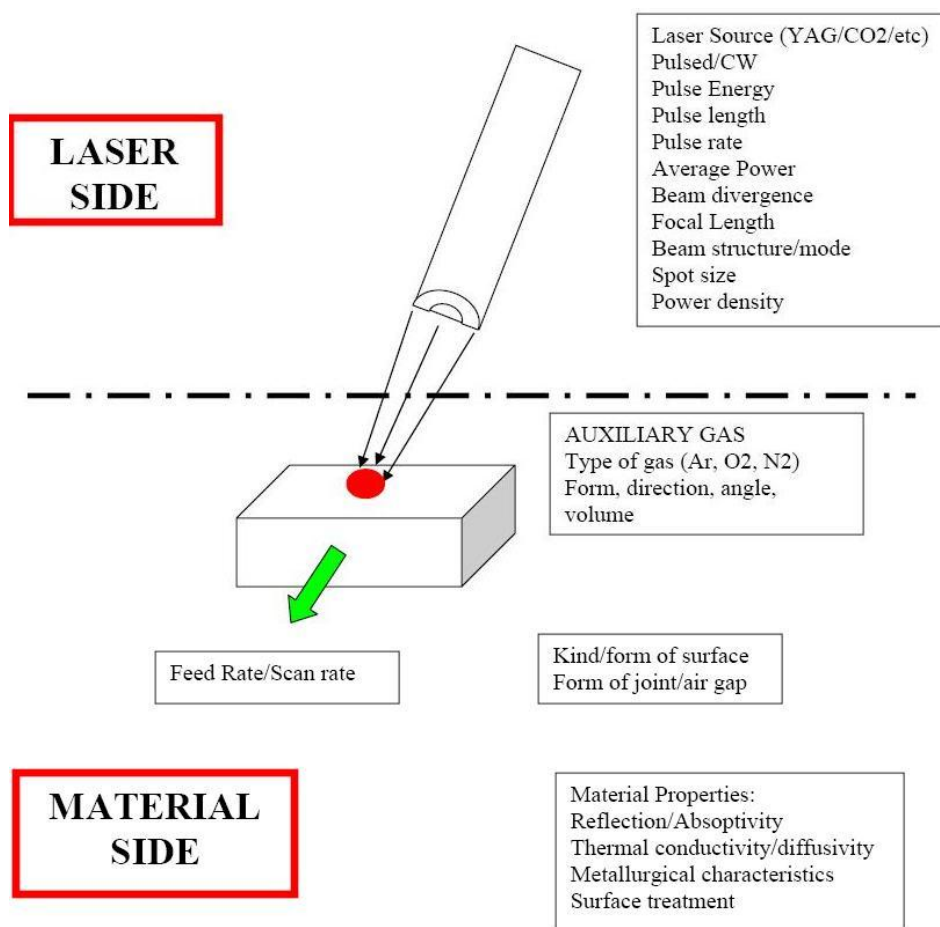
Figure 2.3: Laser Precision Process: Important parameters, which influence material processing

2.4   ACRYLIC

Acrylic is widely known for its importance to the industry. It is used to make various products, such as shower doors, bath enclosures, windows and skylights. It is chosen over glass for many reasons. It is many times stronger than glass, making it much more impact resistant and therefore safer. Falling against an acrylic shower door will not likely break it. Acrylic also insulates better than glass, potentially saving on heating bills. Another great advantage of acrylic is that it is only half as heavy as glass. This makes working with acrylic much easier. It can also be sawed, whereas glass must be scored. [12]
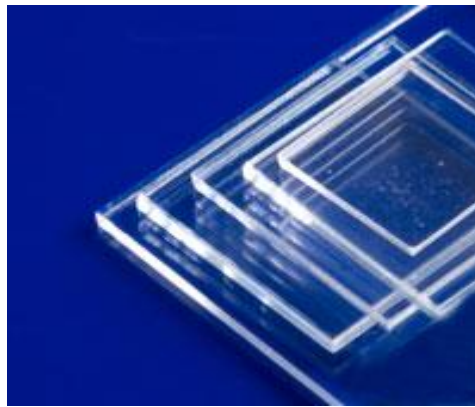
Figure 2.4: Acrylic

In the present days, the applications include inspection windows, sight gauges, windshields, meter faces, protective covers, safety shields, tanks, desk tops, displays, trays, and chair pads. Acrylic comes in a wide variety of standard colors (colorless sheet). The fact that some of them are bullet resistant, it is now in highly demand.

Acrylics come in various shapes. There are many ways of processing them, and the one discussed here is the process done by using laser cutter machines. The process is called laser-cutting process. Some parameters need to be made emphasis to determine

the laser cut quality. This research is done to evaluate crucial aspects of the laser cutting process.

2.4.1   Properties

Acrylic is considered as a versatile material because of its properties. It resembles glass but has properties that make it superior to glass in many ways. Furthermore, the fact that it is transparent, rigid, and exhibits great resistance to breakage has made the demand for the production increases. Table below shows the properties of acrylics.

Table 2.1: Properties of Acrylic

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	$261000 - 39200$ 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 Stability	Good
Cure	Fast

2.5   CUT QUALITY

2.5.1   Striation Frequency

The laser cutting quality is affected by the striation formed at the cutting edge. Its formation is dependent on cutting speed and parameters of the work piece. Slow drift and disturbances on the parameters will affect the striation formation. Any changes in the kerf width will increase the striation size through the cutting process. The factors that can yield this situation are variations in laser power, cutting speed and energy coupling factor. [4, 16]
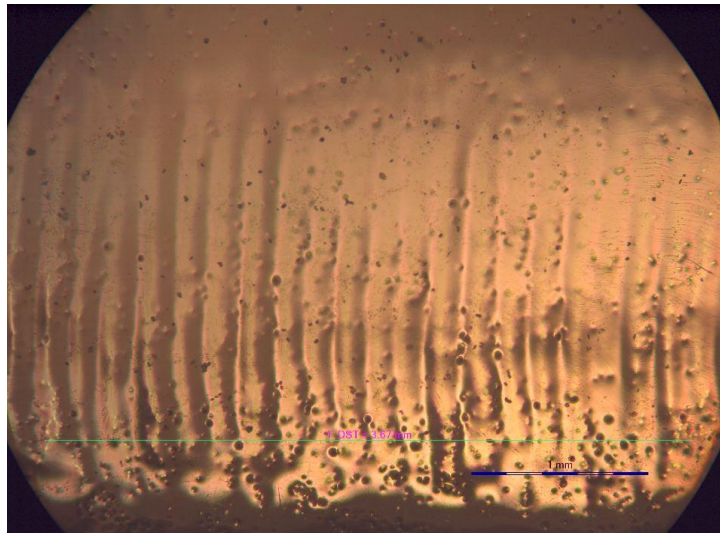
Figure 2.5: Example of striation

2.5.2 Heat Affected Zone (HAZ)

Heat affected zone is the region close to the laser irradiated area that obvious temperature change from original area happens, or obvious strain state change happens. 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. [13]
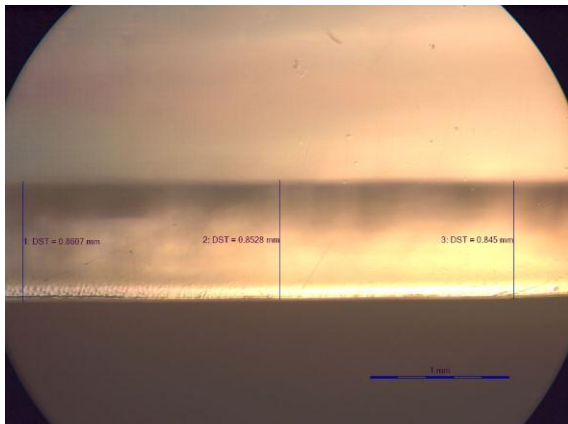
Figure 2.6: Image of HAZ　　　　　　　　**Figure 2.7:** Zoom Image of HAZ
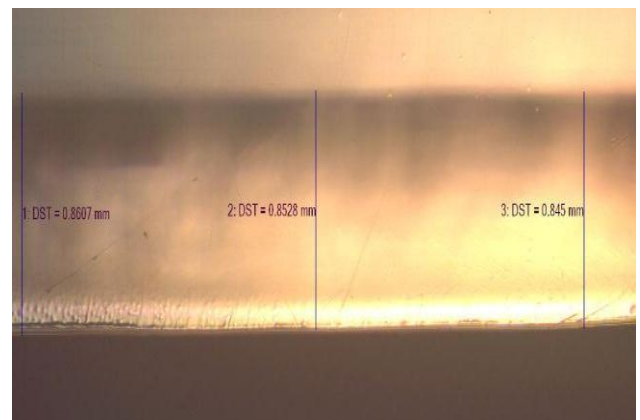
CHAPTER 3

METHODOLOGY

3.1   INTRODUCTION

This chapter focuses on how the experiment will be conducted. Based on the guidelines stated in Chapter 2, this chapter will emphasize on how this project will be carried out from the beginning of the process until the end of the experiment of the project, which is to find the best cutting quality using different power values of laser cutting machine. Next is the analysis of acrylic. Investigate the parameters, which are striation frequency and size of heat-affected zone (HAZ). Figure 3.1 and 3.2 illustrate the flowchart for the overall final year project and the chronology of this experiment.
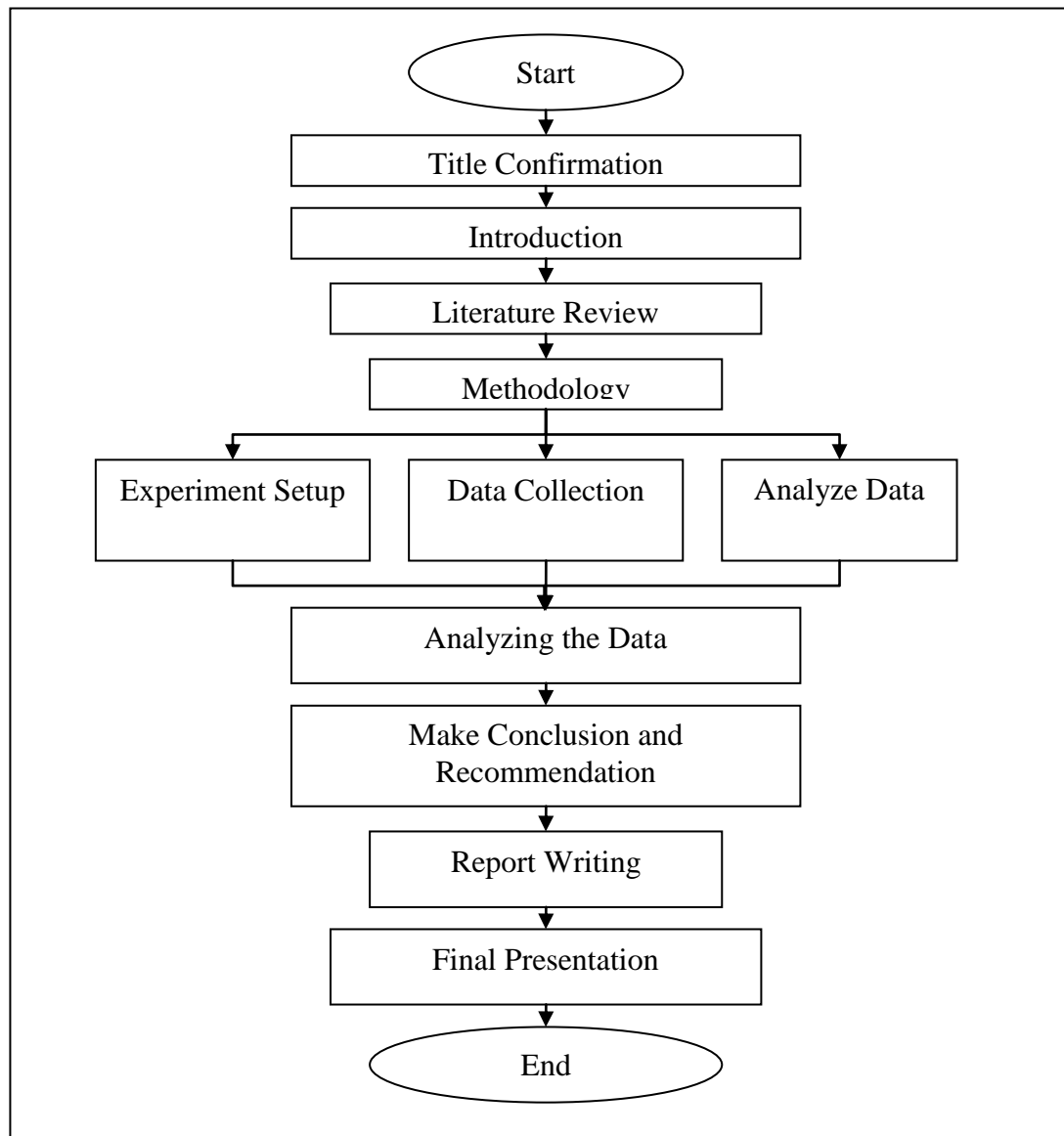
Figure 3.1: Flow chart for overall FYP

17

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                    ┌─────────┐
                    │  Start  │                    (3.2)
                    └────┬────┘
                         ▼
              ┌──────────────────────┐
              │ Sketching of specimen│            (3.3)
              └──────────┬───────────┘
                         ▼
              ┌──────────────────────┐
              │  Cutting of material │            (3.4)
              └──────────┬───────────┘
                         ▼
              ┌──────────────────────┐
              │Evaluation of cut quality│         (3.5)
              └──────────┬───────────┘
          ┌──────────────┴──────────────┐
          ▼                             ▼
   ┌─────────────┐              ┌──────────────┐
   │Heat affected│              │  Striation   │
   │ zone (HAZ)  │              │  Frequency   │
   └──────┬──────┘              └──────┬───────┘
          └──────────────┬─────────────┘
                         ▼
              ┌──────────────────────┐
              │ Analyze of cut quality│           (3.6)
              └──────────┬───────────┘
                         ▼
                    ┌─────────┐
                    │   End   │
                    └─────────┘
```
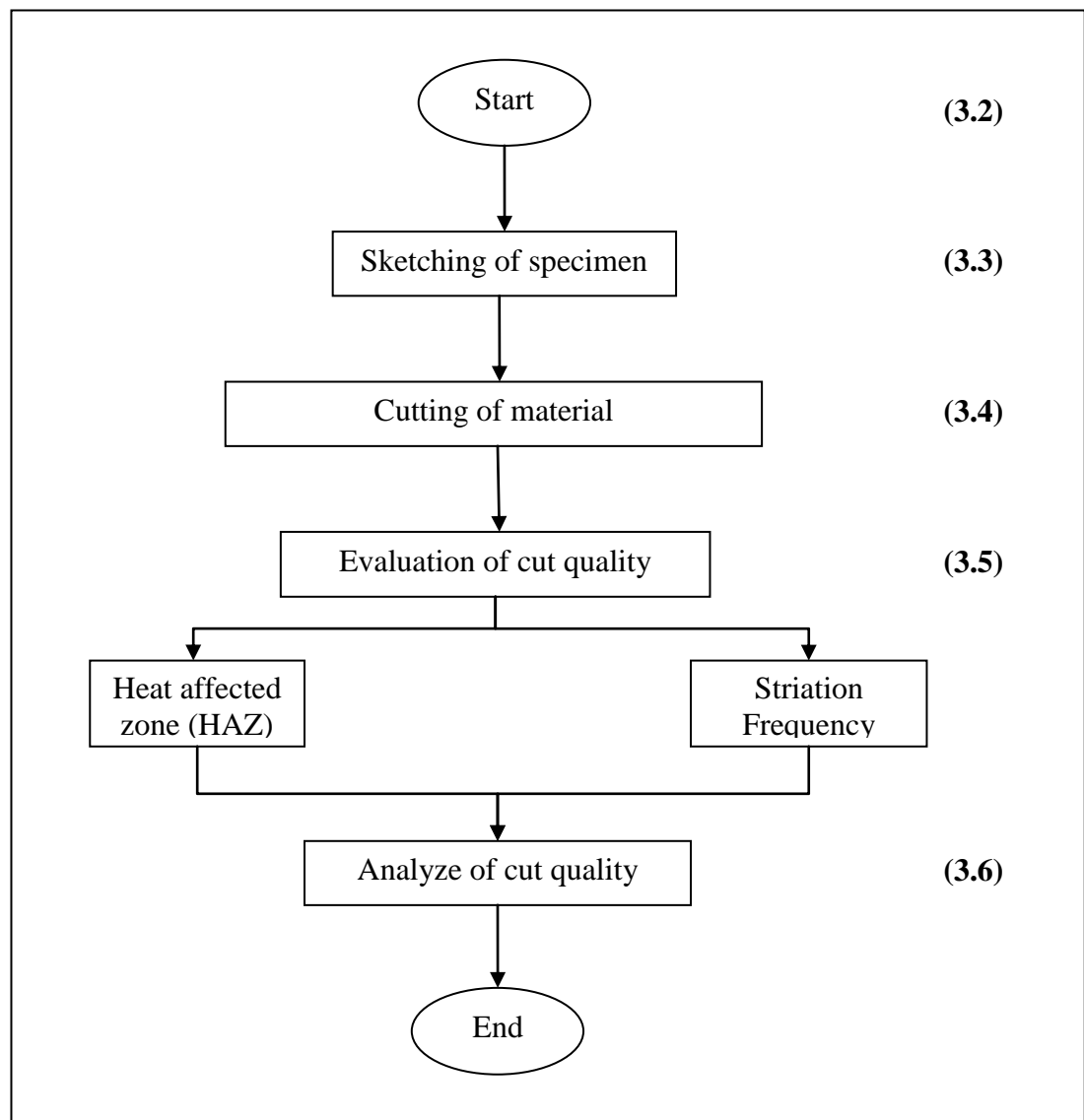
Figure 3.2: Chronology of experiment

3.2   EXPERIMENT

These experiments are carried out to analyze the parameters of cut quality. The power used in the experiments is set as independent variable and the constant variable is the feed rate. Five different powers are used to analyze the parameters of laser cut quality. Three samples are cut to test out each different power. Acrylic with the width 3 mm is use as the material to test the cut quality.

Manual analysis is used to develop models that describe the effect of the independent process parameter on laser cut quality. Different equipments are used to analyze the parameter of cut quality.

Table 3.1: Parameter of the experiment

Parameter	Value
Material and thickness	Acrylic, 3 mm
Delay	1800 µs
Power	55%, 60%, 65%, 70%, 75%, 80%, 85%, 90% and 95% from 30 watt
Feed rate	1.42 mm/s

3.3   SKETCHING OF SAMPLE

Before getting the materials needed, the first thing that needs to be studied is the material, acrylic.

Then design the sample using Solid Work software. Figure 3.3 shows the sample's feature. This part will be saved as a drawing (.dwg). Figure 3.4 shows parts of the drawing. Attached the design to the software using machine's computer. The laser-cutting machine has its software (Art Cam) to read the design.
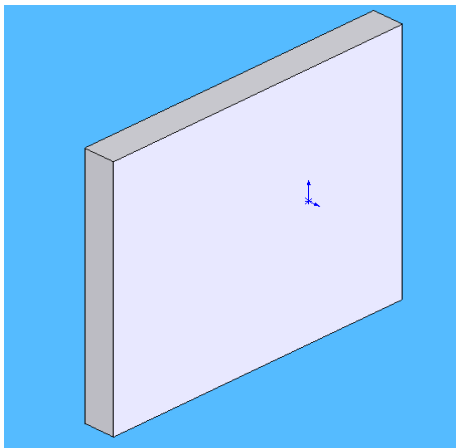
Figure 3.3: Part in SolidWork   **Figure 3.4**: Part in drawing
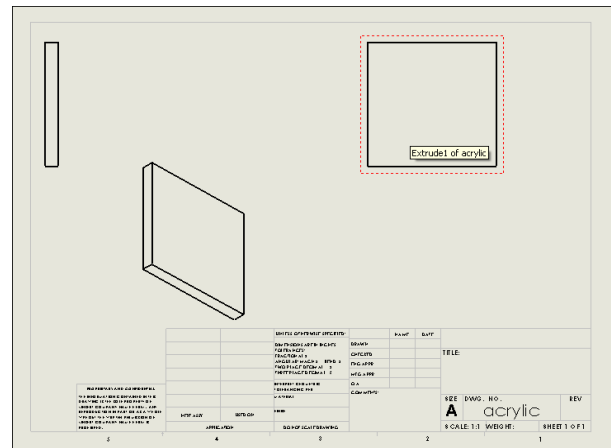
3.4   CUTTING OF MATERIAL

This project then will be carried out by using the laser-cutting machine. The delay set for cutting the material will be 1800 μs and it will remain as constant variable. This is because the best delay for cutting acrylic is 1800 μs and it produces the optimum cut quality. The cutting process will be started with the power of 55% until 95% from 30 watt. Cut three samples for each power.

Before start cutting the material, wear the safety equipments such as eyewear, and mask. This is the precaution for the laser machine. The laser cutting machine may also be hazardous like other machines. The laser machine produces radiation and it can affect human body system. Figure below shows the laser-cutting machine in the UMP's lab.
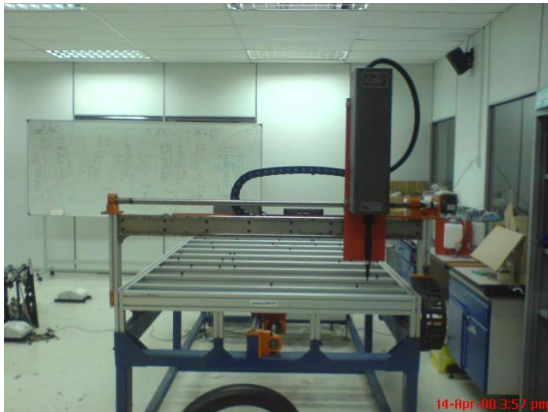
Figure 3.5: Laser Marking Header   **Figure 3.6**: Laser Cutting Machine

These are the examples of acrylic after being cut using laser cutting machine:

Figure 3.7: Samples of Acrylic

Figure 3.8: Samples of Acrylic with Different Power Levels

3.5 EVALUATION OF CUT QUALITY

After cutting the material, proceed these experiments by doing some evaluation of cut quality which is HAZ and striation frequency. To analyze the cut quality, same equipment is used and the sample must be clean up without using any chemical solution or water.

3.5.1 Heat Affected Zone (HAZ)

For the measurement of the size of HAZ, 40 mm long of sample of cut edge is taken at the middle of the cut. Image analyzer is used to analyze the size of HAZ. Three readings are taken for each sample. The tool at image analyzer software is used to get the values of the size of HAZ. Same samples are used to study the striation frequency.

3.5.2 Striation Frequency

Lastly, study the striation frequency by using image analyzer. One reading for each sample is taken. The distance for 2 striations is measured using image analyzer and the striation frequency is calculated by dividing the number of striations per unit length by the feed rate. To find 2 striations, manual measurement is used by the tool in image analyzer software, exactly like the one done to find the size of HAZ.

Figure 3.9: 4 Parts of Image Analyzer

3.6 ANALYZE OF CUT QUALITY

After the material is analyzed, manual analysis method is used to analyze the data. By using all the data gained from the analysis, the average of each striation frequency and size of HAZ are calculated.

Only one sample of average for each power is taken. It is the best sample gotten from the experiment. From the data, two graphs are developed. The graphs are:

 i. Heat Affected Zone Versus Power
 ii. Striation Frequency Versus Power

Based on the graphs, the suitable power to get the optimum cut quality of all parameters can be identify.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the results of the experiment and analysis are discussed. The research is about the laser cut quality of acrylic and it is carried out using experimental analysis.

Lower striation frequency is seen to have better cut quality. As for the HAZ, smaller size shows good quality.

In this chapter, the most suitable power level to produce the optimum cut quality can be identifying. The optimum cut quality is determined by both parameters which are striation frequency and the size of HAZ. It must not be too big or too small in value. It also can identify whether or not the results of the experiment are equal to the theory.

4.2   RESULTS OF THE EXPERIMENTAL ANALYSIS

The experiment is carried out according to the condition as mentioned in Table A to get the results that will be used to develop the graphs in manual analysis. Start cutting the acrylic using 16.5 Watts (55%) of power level, as the value enables us to cut the acrylic 3 mm using other constant parameters.

4.2.1   Experimental Setup

Before cutting the material, the equipment needs to be set up. Knowing the type of laser used in this analysis. It uses pulse and delay as the parameters. Table 4.1 shows the general laser specifications:

Figure 4.1: Ilios CO_2 Laser Marking Machine 30 Watts

Table 4.1: General Specification of 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)

After studying the specifications of the laser cutting machine, the parameters to be analyzed are decided. Below shows the parameters used in the experiment:

Table 4.2: Parameters of the experiment

Parameter	Values
Delay	1800 μs
Feed rate	1.42 mm/s
Power analyzes	16.5, 18.0, 19.5, 21.0, 22.5, 24.0, 25.5, 27.0 & 28.5 watt

Before calculating the results, the feed rate for this experiment was converted. These are the steps to find the feed rate:

$$Feedrate = frequecy \times \frac{dis\tan ce}{pulse}$$

$$Feedrate = \frac{1}{2delay} \times \frac{dis\tan ce}{pulse}$$

$$Feedrate = \frac{1}{2 \times 1800\mu s} \times \frac{51mm}{10000\,pulse}$$

$$Feedrate = 277.778\frac{pulse}{\sec} \times (5.1 \times 10^{-3})\frac{mm}{pulse}$$

$$Feedrate = 1.42\frac{mm}{s}$$

4.2.2 Effects of power on the striation frequency

The effects of various power levels on striation frequency are shown in Figure 4.2. It shows that striation frequency is almost independent of power, but a slight increase in striation frequency occurs with an increase in feed rate up to a critical feed rate.
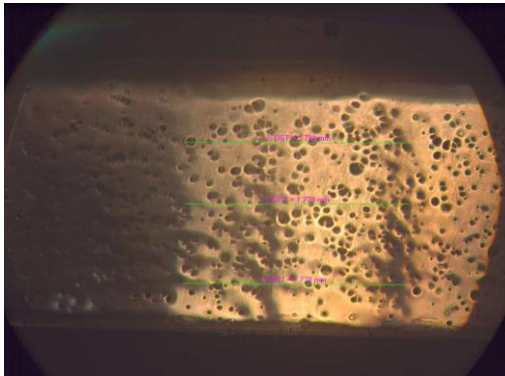
Figure 4.2 (a): 27.0 Watts   **Figure 4.2 (a):** 28.5 Watts
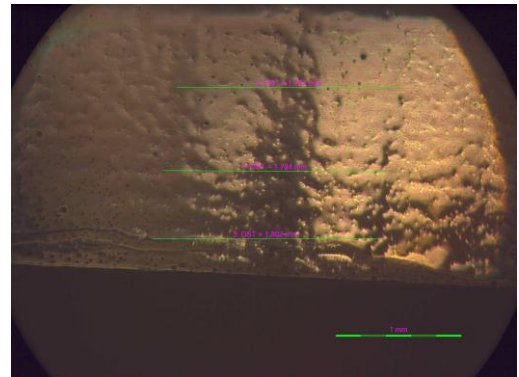
Figure 4.2: Examples Image No. of Striation

Table 4.3: Result of length for 2 striations

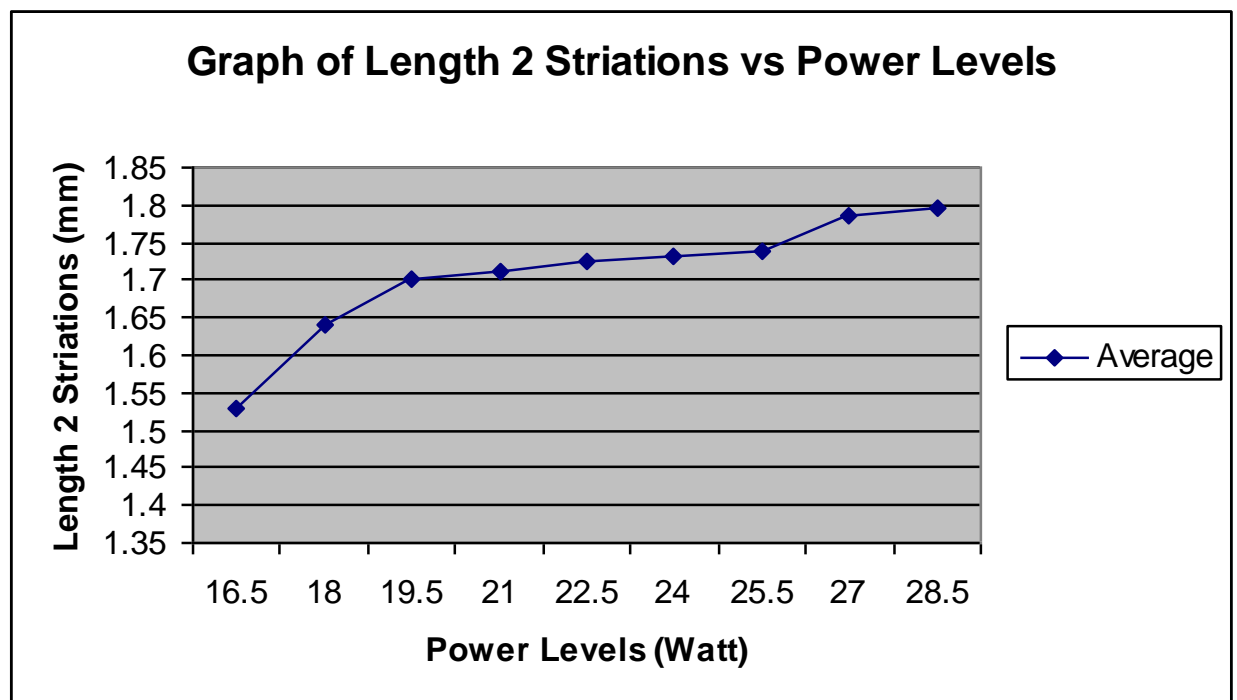| Sample (Watts)	Reading (mm)			Average (mm)
	1	**2**	**3**	
16.5	1.531	1.518	1.535	1.528
18.0	1.651	1.643	1.628	1.641
19.5	1.705	1.682	1.713	1.700
21.0	1.721	1.682	1.729	1.711
22.5	1.736	1.694	1.748	1.726
24.0	1.729	1.721	1.744	1.731
25.5	1.736	1.740	1.744	1.740
27.0	1.798	1.779	1.779	1.785
28.5	1.787	1.794	1.802	1.794

Figure 4.3: Graph of Average Length of Striation versus Power Levels

4.2.2.1   Manual Calculation

To find the striation frequency, use manual calculation. The formula used is:

$$\text{Striation Frequency} = \frac{\text{No. of striations}}{\text{Length}} \times \text{Feed Rate}$$

$$\text{Striation Frequency} = \frac{2}{1.528mm} \times 1.42\frac{mm}{s}$$

$\text{Striation Frequency} = 1.859Hz$

Table 4.4: Results for manual calculations to find striation frequency

Sample (Watts)	Length of 2 striations (mm)	Striation Frequency (Hz)
16.5	1.528	1.859
18.0	1.641	1.731
19.5	1.700	1.671
21.0	1.711	1.660
22.5	1.726	1.645
24.0	1.731	1.641
25.5	1.740	1.632
27.0	1.785	1.591
28.5	1.794	1.583
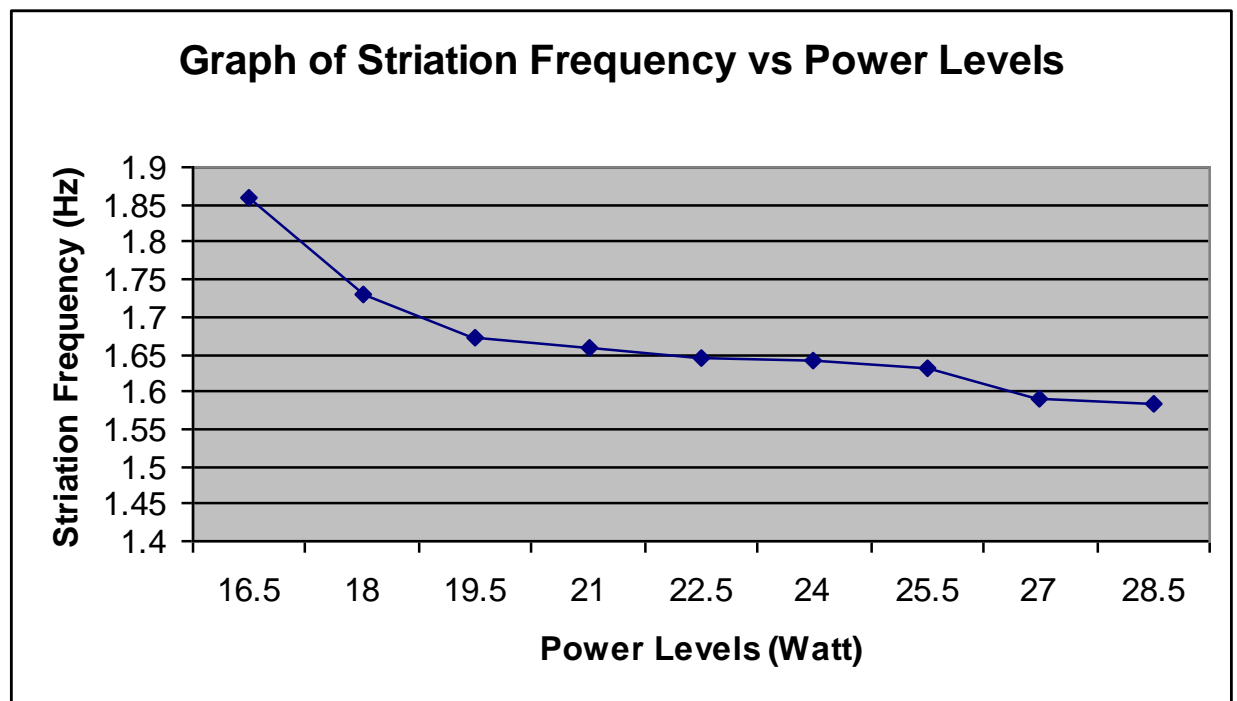
Figure 4.4: Graph of Striation Frequency versus Power Levels
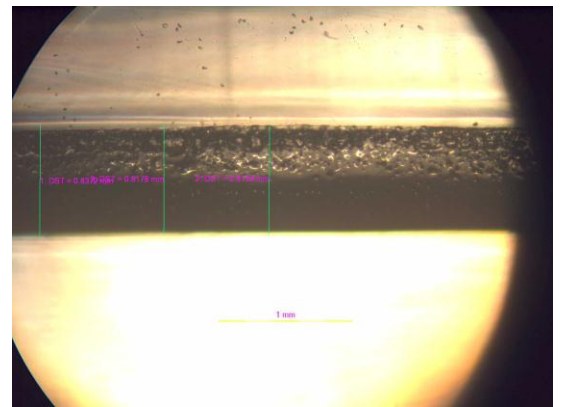
Lower striation frequency shows better quality compared to higher striation frequency. It means that larger length of two striations is better than smaller length. According to the graph analysis, we can see that the power of 28.5 watts demonstrates the best cut quality on striation frequency. For the power of 16.5 watts, it produces unsatisfying cut quality on striation frequency.

4.2.3 Effects of power on the size of heat-affected zone (HAZ)

Generally, power produces small effects on the formation of the size of HAZ. Figure 4.5 shows the effects of various power levels on the size of HAZ. When the continuous power output laser increases, the size of HAZ also increases. It means that power does influence the size of HAZ.
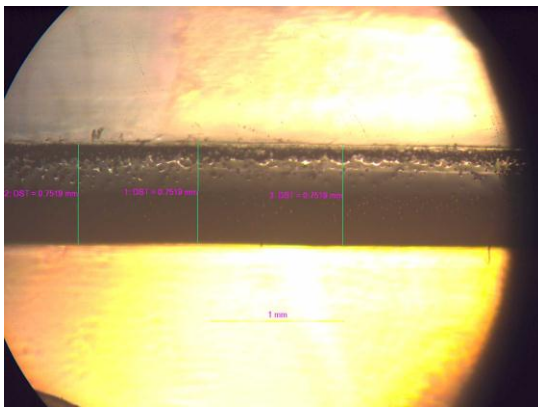
Figure 4.3 (a): 16.5 Watts   **Figure 4.3 (b):**   28.5 Watts

Figure 4.3: Examples Image of the size of HAZ

Table 4.5: Result of the size of HAZ

Sample (Watts)	Reading (mm)			Average (mm)
	1	2	3	
16.5	0.7519	0.7519	0.7519	0.7519
18.0	0.7596	0.7596	0.7519	0.7570
19.5	0.7752	0.7558	0.7558	0.7623
21.0	0.8023	0.7906	0.7868	0.7932
22.5	0.8256	0.7906	0.7907	0.8023
24.0	0.8023	0.8062	0.8062	0.8049
25.5	0.8178	0.8100	0.8139	0.8139
27.0	0.8178	0.8023	0.8178	0.8126
28.5	0.8372	0.8178	0.8139	0.8230
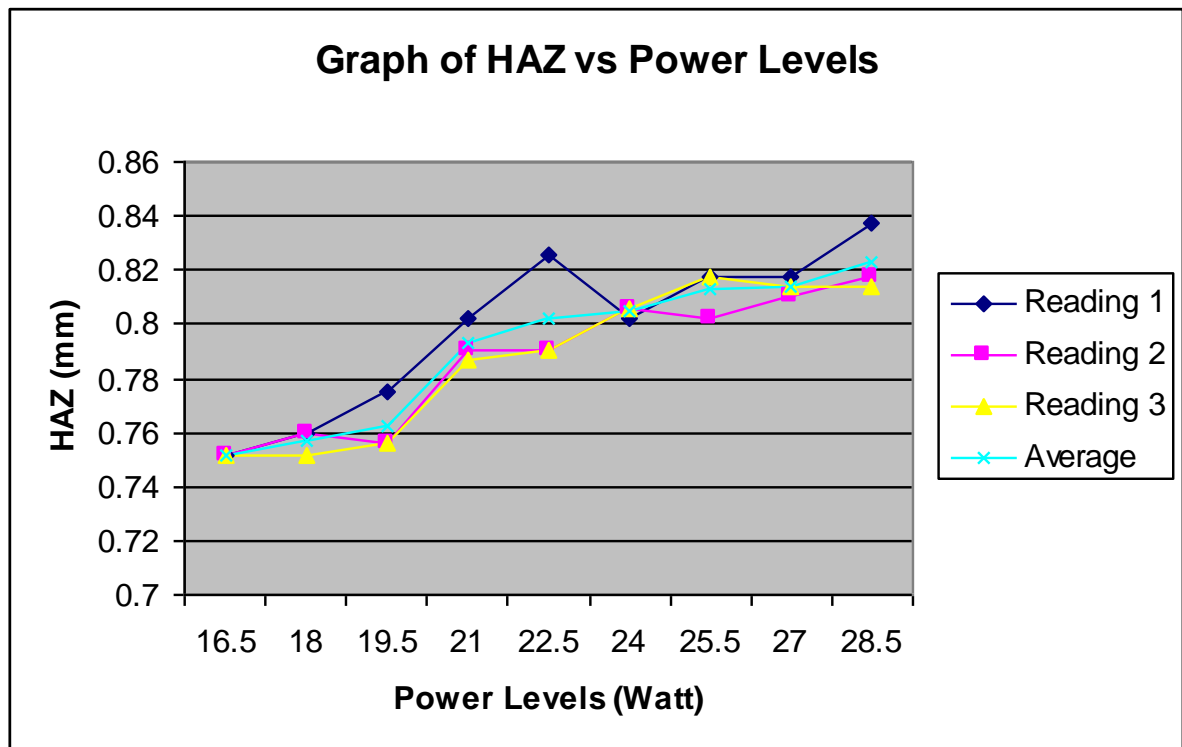
Figure 4.6: Graph of HAZ versus Power Levels
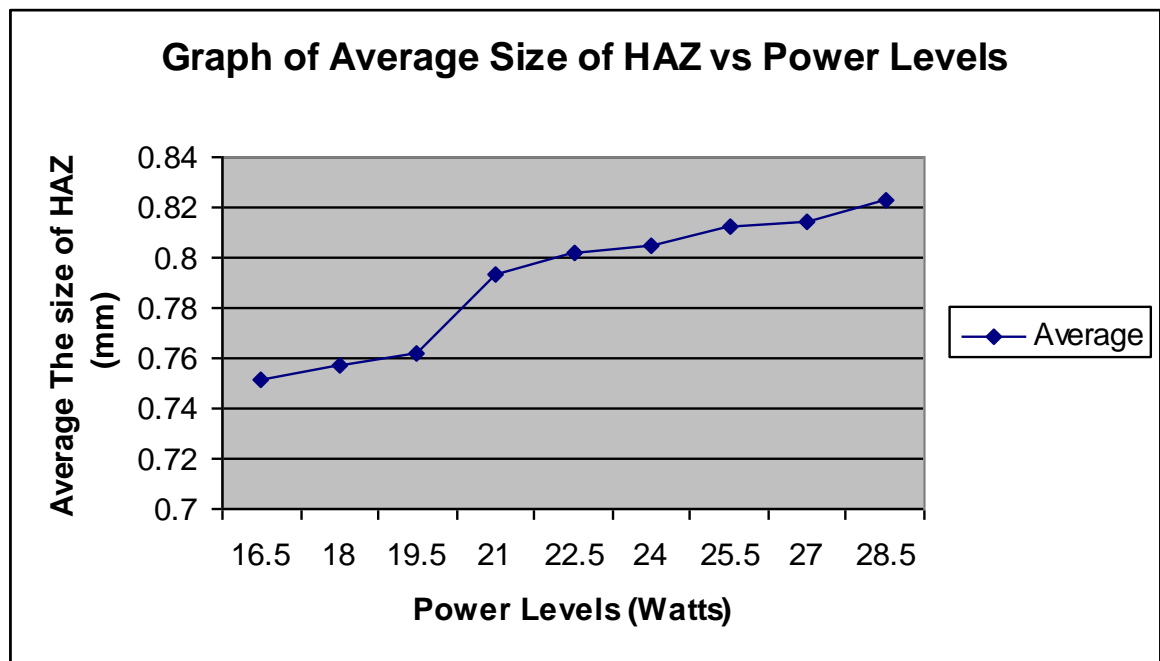
Figure 4.7: Graph of Average size of HAZ versus Power Levels

In the experiment, ranges of power levels from 16.5 to 19.5 Watts and 21.0 until 28.5 Watts have produced small effects on the size of HAZ. However, for the 19.5 to 21.0 Watts, it increases drastically. It means that it has a big formation of the size HAZ for 21.0 Watts. This concludes that the power of 16.5 Watts produces better cut quality on HAZ.

4.2.4   The Optimum Cut Quality

After analyzing all the parameters, we need to decide the suitable power level to get the optimum cut quality on striation frequency and the size of HAZ. This can be done by analyzing the data to get the optimum cut quality.

To analyze the optimum cut quality, we take the length of striation and the size of HAZ into the table. Then, the graph was developed. From the experiment, the distances of two striations were taking. In order to find the optimum cut quality, divide the length of two striations with number of striations beforehand. It shows the length of one striation. The length of striation is stated according to the striation frequency. The larger length of striation shows lower striation frequency. Below states the formula used to find the length of one striation:

$$striation = \frac{length}{No.\,of\ striations}$$

$$striation = \frac{length}{2}$$

$$striation = \frac{1.528}{2}$$

$$striation = 0.7640$$

Table 4.4: Length of striation and size of HAZ

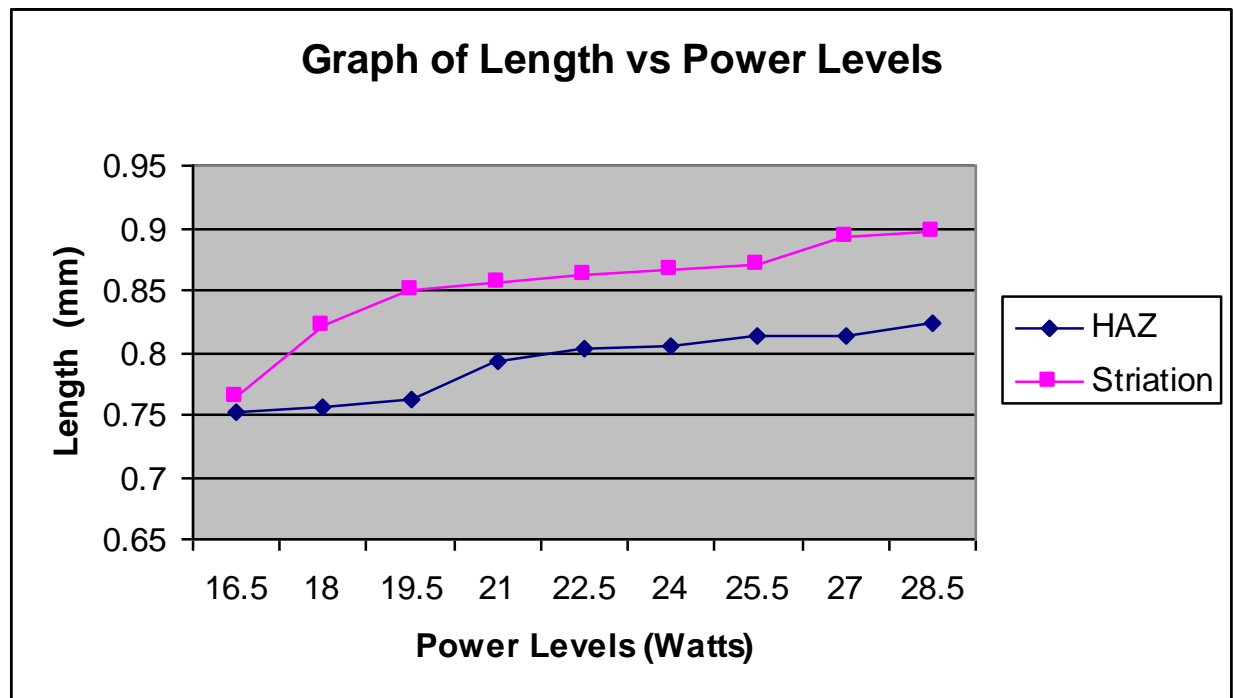| Sample (Watts)	Length of 2 striations (mm)	Length of striation (mm)	Size of HAZ(mm)
16.5	1.528	0.7640	0.7519
18.0	1.641	0.8205	0.7570
19.5	1.700	0.8500	0.7623
21.0	1.711	0.8555	0.7932
22.5	1.726	0.8630	0.8023
24.0	1.731	0.8655	0.8049
25.5	1.740	0.8700	0.8139
27.0	1.785	0.8925	0.8126
28.5	1.794	0.8970	0.8230

Figure 4.8: Graph of Length of striation and size of HAZ versus Power Levels

Figure 4.8 shows the difference between length of striation and the size of HAZ. This graph only illustrates how to get the optimum cut quality on striation frequency and the size of HAZ. Length of striation influences striation frequency. The larger the length of striation frequency, the lower the striation frequency will be. For the HAZ, when the size of HAZ is smaller, it shows that power level is more suitable to get the best cut quality on the size HAZ.

Both optimums cut quality of acrylic need to be found. The power level is chosen by considering both criteria. Then only it is considered the best power level to get the optimum cut quality. Now, the suitable power level was decided to get the optimum cut quality of acrylic 3 mm. The optimum cut quality on striation frequency and the size of HAZ is 22.5 watts (75%). It is because the striation frequency for this power level is intermediate (average). It also produces smaller size of HAZ. The percentage between both lines in the graph for 22.5 watts also is also seen to be lower compared to other power levels. At this power level, striation frequency and the size of HAZ are optimum. Both show average values, not too large or smaller value.

4.4   DISCUSSION

Based on the experiment done, the results for the striation frequency and the size of HAZ were come out. Firstly, the effects of power on the striation frequency. The results from the experiment are different from the theory. The theory explains that power has no effect at all on striation frequency. However in the experiment it shows that power does affect the striation frequency. This different is due to other factors such as surrounding condition, room temperature, laser machine quality and so on.

As for the effect of power on the size of HAZ, it does not differ much from the theory. The graph shows that at 19.5 and 21.0 Watts the results are a bit different. It is due to unsuitability of power levels used on other parameters at laser machine.

The laser machine in Ump's lab was designed to engrave materials. It uses a small frequency which is suitable for engraving. However, this machine can also cut low melting point materials such as acrylic. Since that the machine is always used to cut acrylic, the laser light happens to diverge. Therefore, in order to get good cutting quality, use the suitable power level and feed rate.

CHAPTER 5

CONCLUSION

5.1   CONCLUSION

The aim of this research is to analyze the effects of different power values with a constant feed rate and to find the best power to get the optimum cut quality on striation frequency and the size of HAZ.

According to the analysis done, it is found that power produces small effects on the formation on the size of heat-affected zone (HAZ). This is because the size of HAZ is affected by the feed rate of laser cutting machine.

The second analysis is done to study the striation frequency. The theory says that, striation frequency is not affected by power. However, from the analysis done, it shows that power produces a small effect to the striation frequency.

Throughout the analysis, it is found that the most optimum power value to cut acrylic 3mm is 22.5 Watts. This value is the most suitable power to get the optimum cut quality on striation frequency and the size of HAZ. This power value has an intermediate value of striation frequency, which is 1.645 Hz. This power also produces small size of HAZ, which is 0.8023 mm. It is decided that the power level of 22.5 and Watts is the best power to cut acrylic 3 mm with constant feed rate.

However, this experiment was also affected by other factors such as surrounding temperature, quality of laser and the conductor's competence as well. These factors are not included in the scope of study. The factors considered in the experiment are only different power values and the constant feed rate.

Factually, every material has different results of cut quality. Thickness of materials also affects cut quality. Acrylic 3 mm and 6 mm have different cut quality. It is proved theoretically and experimentally. However, this project is only to study cut quality of acrylic 3 mm.

As a conclusion, it is found that power laser produces a small effect on the size of HAZ and striation frequency. Therefore, the theory is obey that the power has no effect on striation frequency.

5.2   RECOMMENDATION

For future research, there will be few improvements which need to be done. In order to get optimum cut quality by using the optimum parameter of laser cutting machine, some recommendations are suggested. The improvements can be done by:

i.   Increasing the sharpness of the eye of the laser.

ii.   Modifying the laser machine so that it can also work on other materials besides acrylic.

iii.   Increasing the power and frequency of laser machine to produce better cuts.

iv.   Using intermediate power to get lesser effects of HAZ and striation frequency.

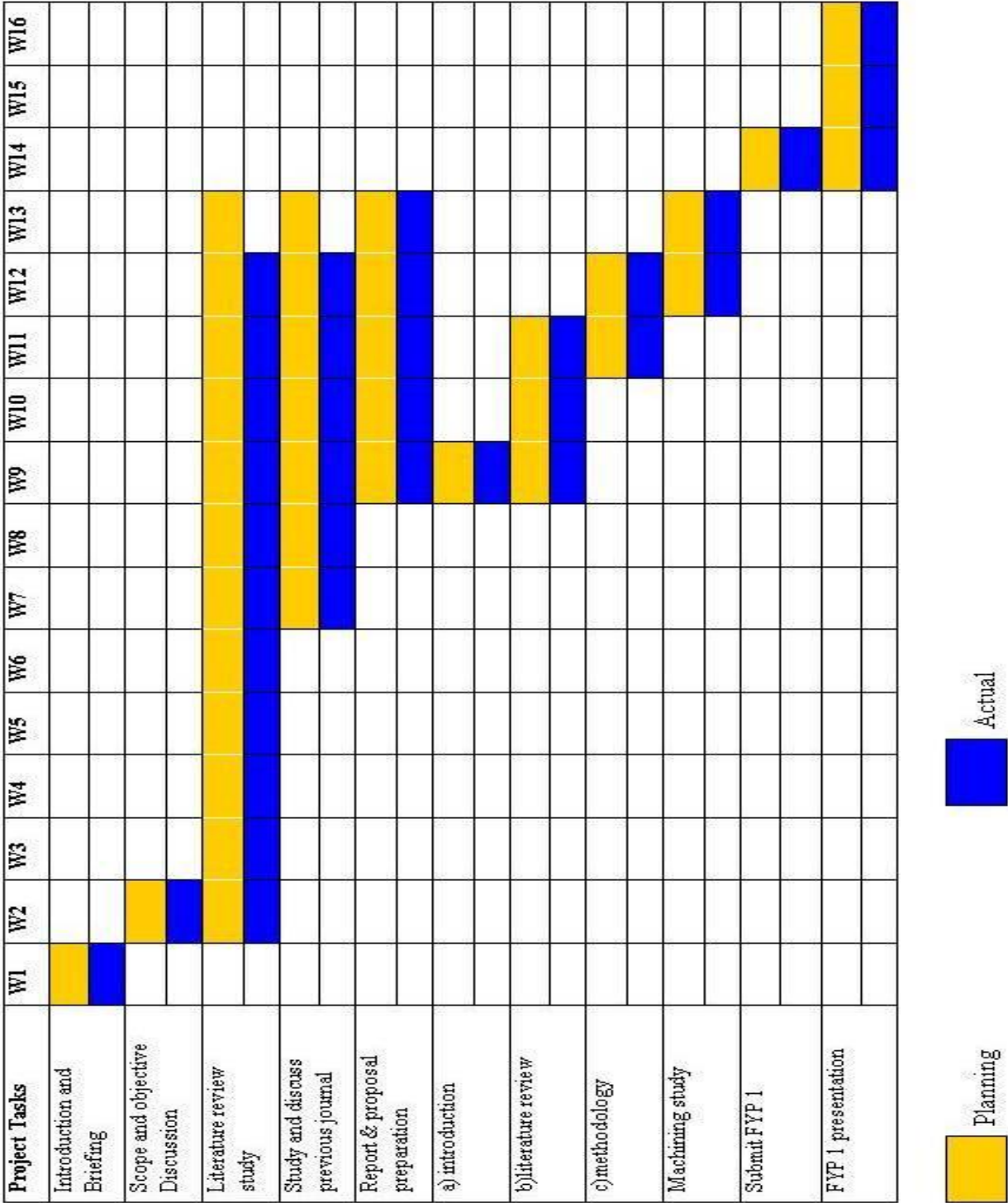v.   Studying environmental factors whether or not it can affect the laser cutting process.

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APPENDIX A1

Gantt chart for FYP 1

| Project Tasks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
Introduction and Briefing	P/A															
Scope and objective Discussion		P/A														
Literature review study		A	P	P	P	P	P	P	P	P	P	P	P			
Study and discuss previous journal							P	P	P	P	P	A	P			
Report & proposal preparation							A	A	P	P	P	P	P/A			
a) introduction									P	A						
b)literature review									A	A	P	A				
c)methodology											A	P				
Machining study												A	P/A			
Submit FYP 1														P/A		
FYP 1 presentation														A		P/A

Legend: Planning (yellow), Actual (blue)

APPENDIX A2

Gantt chart for FYP 2
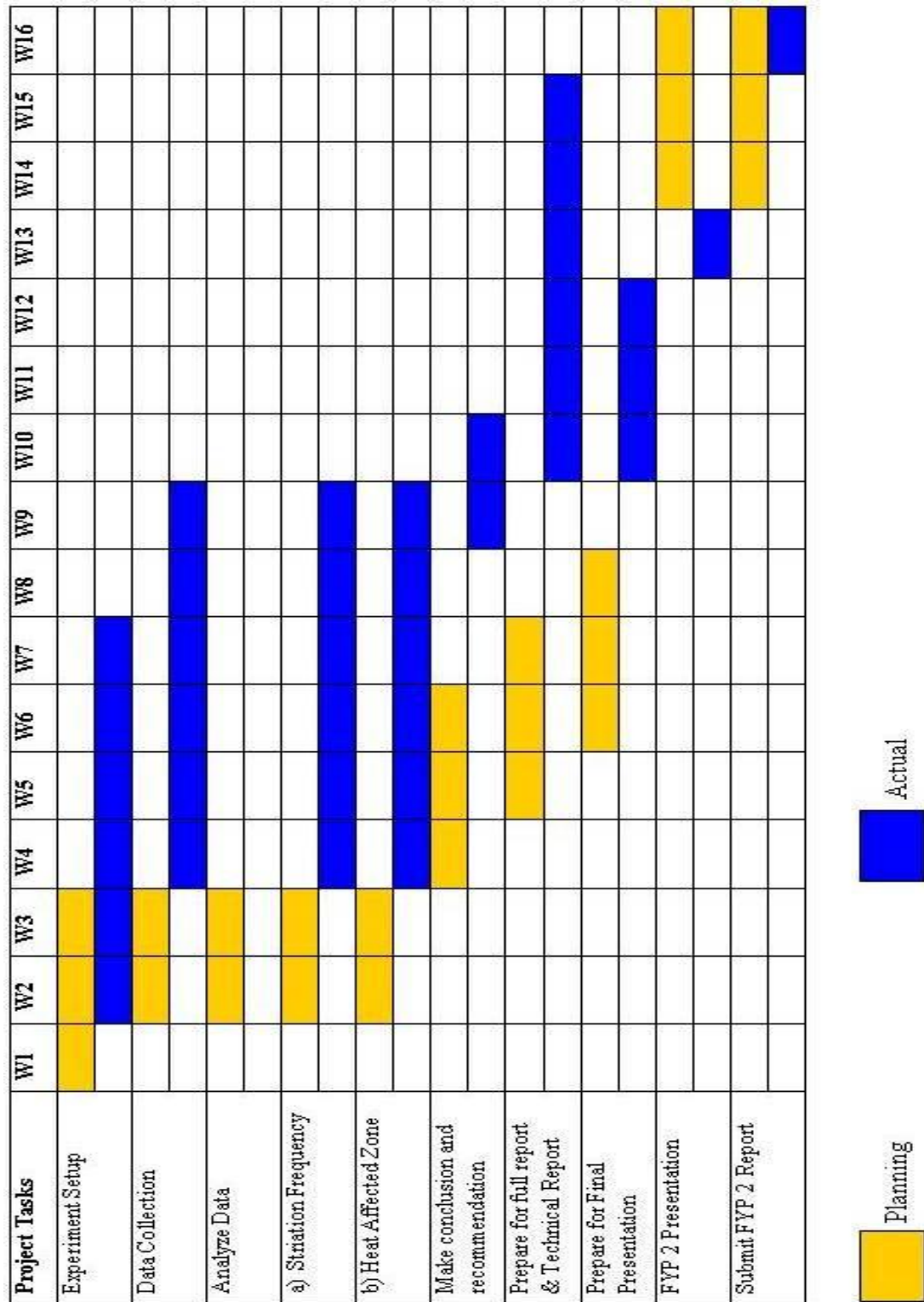
APPENDIX A3

Flow Chart for Overall Project

```
                    ┌─────────────┐
                    │    Start    │
                    └──────┬──────┘
                           ▼
              ┌─────────────────────────┐
              │    Title Confirmation   │
              └────────────┬────────────┘
                           ▼
              ┌─────────────────────────┐
              │       Introduction      │
              └────────────┬────────────┘
                           ▼
                ┌───────────────────────┐
                │    Literature Review  │
                └───────────┬───────────┘
                            ▼
                  ┌─────────────────┐
                  │   Methodology   │
                  └────────┬────────┘

   ┌──────────────────┐ ┌──────────────────┐ ┌──────────────────┐
   │ Experiment Setup │ │ Data Collection  │ │   Analyze Data   │
   └──────────────────┘ └──────────────────┘ └──────────────────┘

              ┌─────────────────────────┐
              │    Analyzing the Data   │
              └────────────┬────────────┘
                           ▼
              ┌─────────────────────────┐
              │   Make Conclusion and   │
              │     Recommendation      │
              └────────────┬────────────┘
                           ▼
                ┌───────────────────────┐
                │     Report Writing    │
                └───────────┬───────────┘
                            ▼
                ┌───────────────────────┐
                │   Final Presentation  │
                └───────────┬───────────┘
                            ▼
                    ┌─────────────┐
                    │     End     │
                    └─────────────┘
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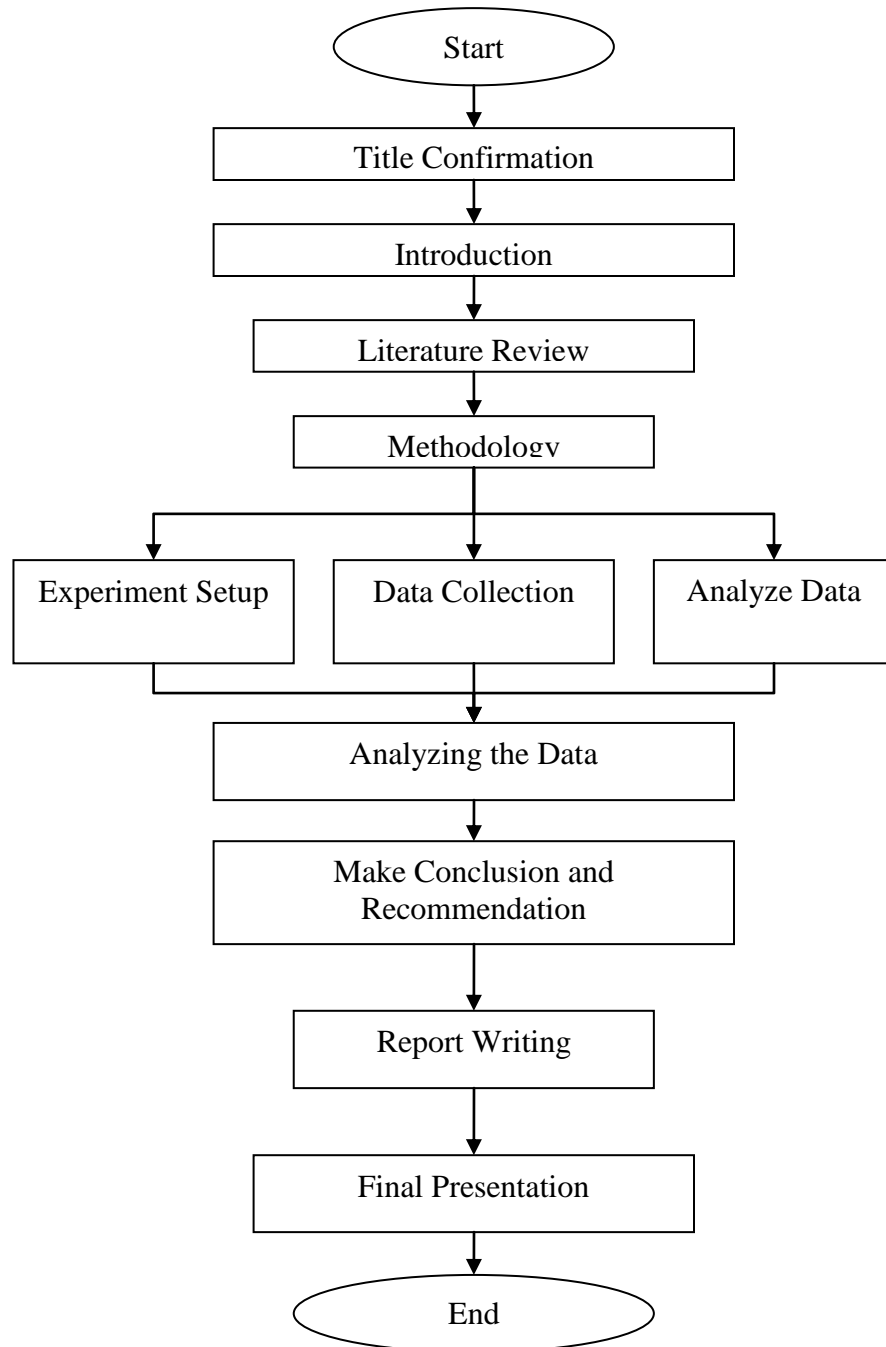
APPENDIX A4
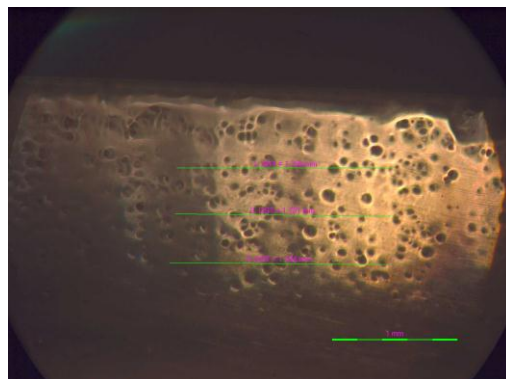
Image of Striations
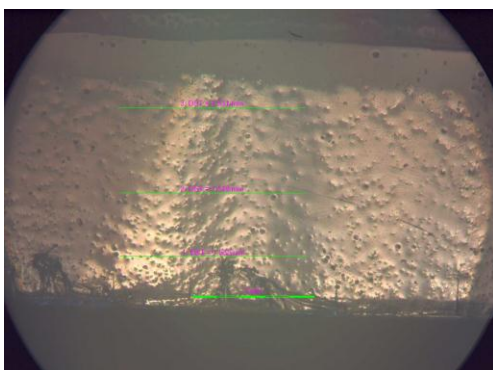
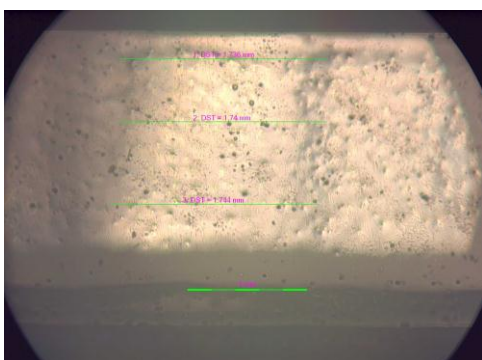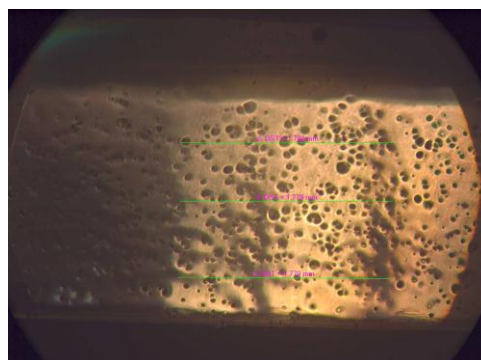16.5 watt
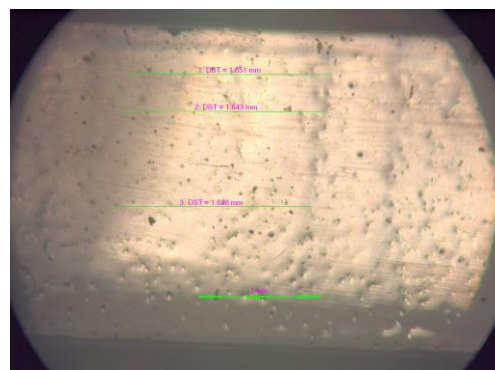
18.0 watt
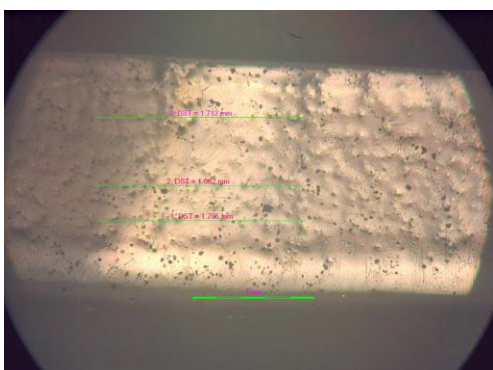
19.5 watt
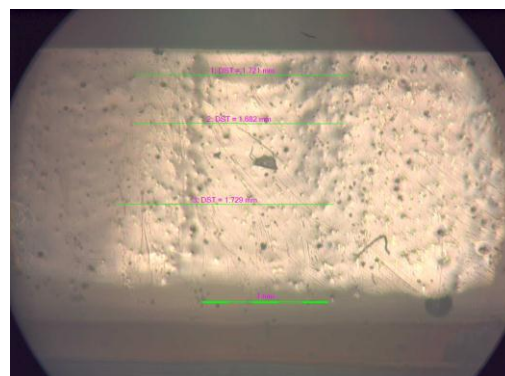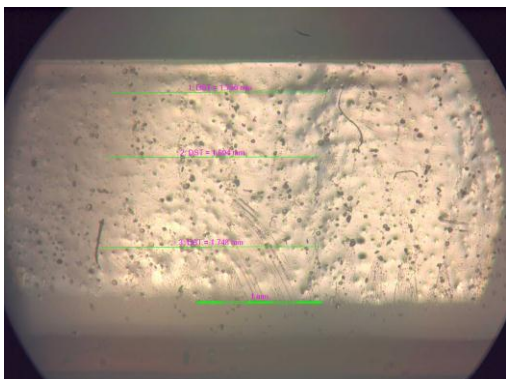
21.0 watt

22.5 watt
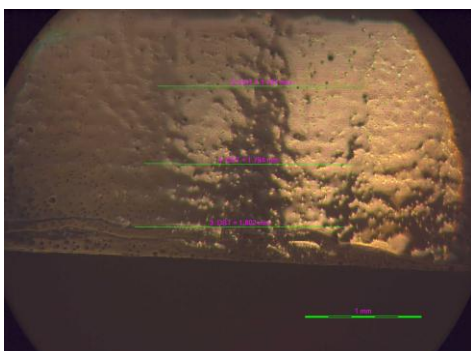

24.0 watt

25.5 watt

27.0 watt

28.5 watt

APPENDIX A5

Image of Heat Affected Zone (HAZ)

16.5 watt

18.0 watt

19.5 watt

21.0 watt

22.5 watt

24.0 watt

25.5 watt

27.0 watt

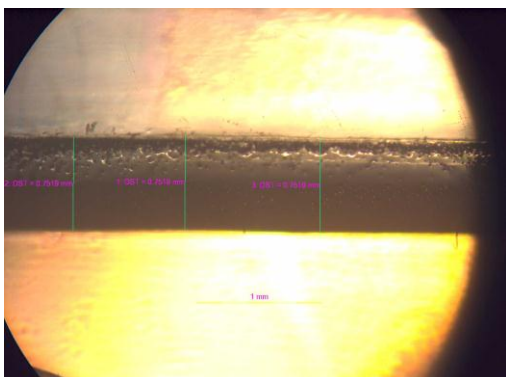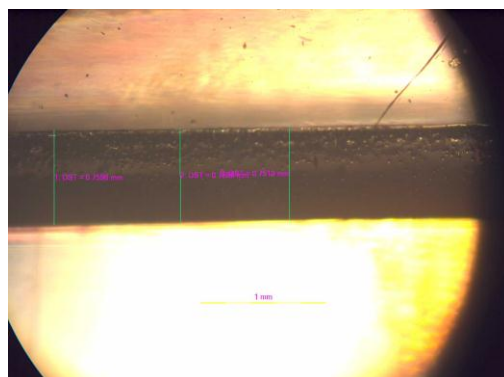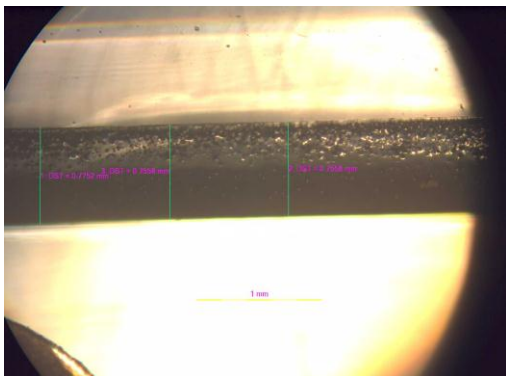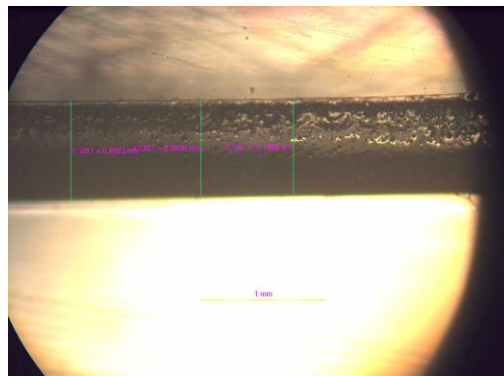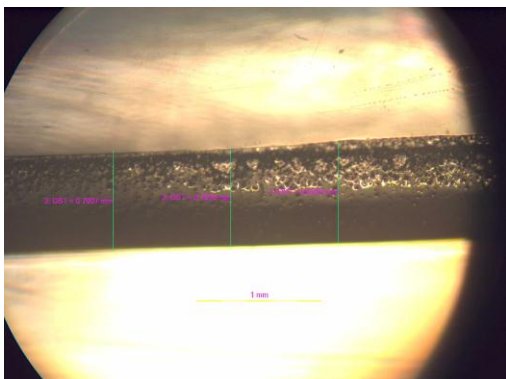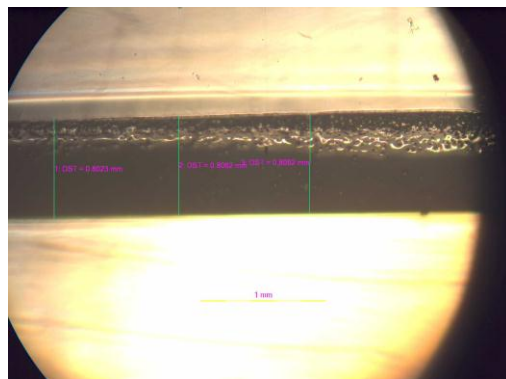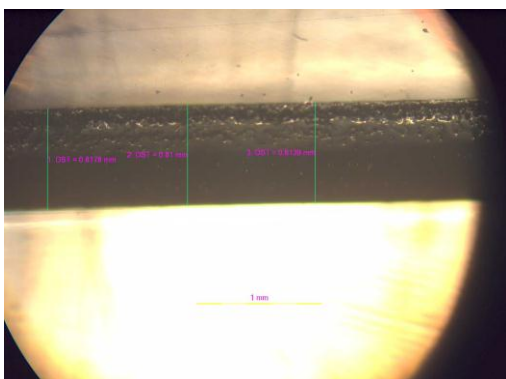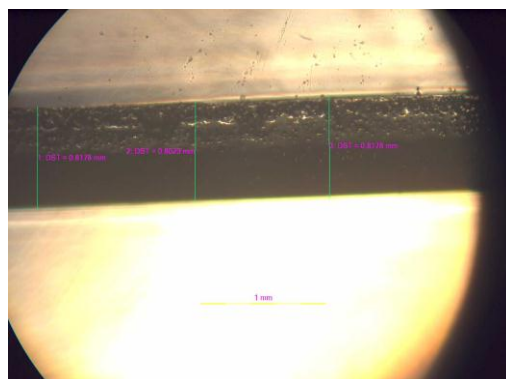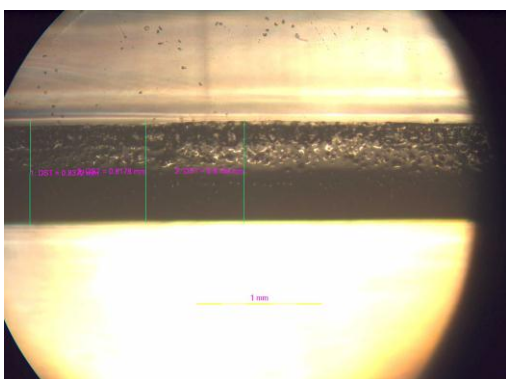

28.5 watt