

# PATTERN QUALITY ANALYSIS WHEN LASER ENGRAVING ILLUSTRATION ON STAINLESS STEEL



# BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE TECHNOLOGY) WITH HONOURS

2022



# Faculty of Mechanical and Manufacturing Engineering Technology



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# Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours

#### PATTERN QUALITY ANALYSIS WHEN LASER ENGRAVING ILLUSTRATION ON STAINLESS STEEL

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2022

#### DECLARATION

I declare that this Choose an item. entitled "Pattern Quality Analysis when Laser Engraving Illustration on Stainless Steel " is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



#### APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

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#### DEDICATION

This study is wholeheartedly dedicated to my beloved family especially my parents, who have been my source of inspiration and gave me strength when i thought of giving up, who have never left my side, who never stop provide their moral, spiritual, emotional and

financial support.

I dedicate this study and give special thanks to my supervisor Prof. Madya Ir. Dr. Mohd Hadzley Bin Abu Bakar for all his guidance throughout the process.

I also dedicate this study to my lecturers and friends who always shared their words of

advice and encouragement to finish this study.

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#### ABSTRACT

In recent years, laser engravings have risen as one of the most promising technologies for engraving or branding an object. The current research will be concentrating on analysing the pattern quality when laser engraving illustrations on stainless steel with the goal of improving it. According to the results of this experiment, the effect of surface roughness and microstructure will be evaluated using the basic parameters of laser engraving, which are laser power, laser speed, laser frequency, and the number of loops in the engraving pattern. To begin, the software packages ImagR and EzCad will be utilised to generate a specific illustration. This was accomplished by engraving a stainless steel workpiece using the Master Oscillator Power Amplifier (MOPA) Fiber Laser employing a combination of specified settings to achieve efficiency on stainless steel for laser engraving colour. An investigation into the relationship between laser engraving on stainless steel and a mixture of factors revealed that a combination of parameters, including frequency, power, speed, and loop count, was critical in getting the best colour finish. A low speed combined with the best feasible number for frequency and power will have a significant influence, as no burn scars will occur and a golden-brownish colour will be attained as a result of using these parameters. In the following step, a surface roughness test will be performed to analyse the surface roughness and microstructure of a stainless steel that has been engraved using a stylus profilometer Mitutoyo Surftest SJ-301 and a digital USB microscope will be performed. The measurement of surface roughness was carried out in order to acquire the roughness value (Ra). The optimal Ra value for laser engraving illustrations on stainless steel is 0.093 (µm) at a speed of 4000 mm/s. After that, microstructure observation was carried out with the help of a Nikon Eclipse LV100 Digital Microscope. When there are no burn traces on the surface, it is considered to have a good surface quality.

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#### ABSTRAK

Pada masa kini, ukiran laser telah meningkat sebagai salah satu teknologi yang paling menjanjikan untuk mengukir atau menjenamakan objek. Penyelidikan semasa akan menumpukan pada menganalisis kualiti corak apabila ilustrasi ukiran laser pada keluli tahan karat dengan matlamat untuk memperbaikinya. Menurut keputusan eksperimen ini, kesan kekasaran permukaan dan mikrostruktur akan dinilai menggunakan parameter asas ukiran laser, jaitu kuasa laser, kelajuan laser, kekerapan laser, dan bilangan gelung dalam corak ukiran. Untuk memulakan, pakej perisian ImagR dan EzCad akan digunakan untuk menjana ilustrasi tertentu. Ini dicapai dengan mengukir bahan kerja keluli tahan karat menggunakan Master Oscillator Power Amplifier (MOPA) Fiber Laser menggunakan gabungan tetapan tertentu untuk mencapai keberkesanan pada keluli tahan karat untuk warna ukiran laser. Penyiasatan ke dalam hubungan antara ukiran laser pada keluli tahan karat dan campuran faktor mendedahkan bahawa gabungan parameter, termasuk kekerapan, kuasa, kelajuan, dan kiraan gelung, adalah penting dalam mendapatkan kemasan warna terbaik. Kelajuan rendah digabungkan dengan nombor terbaik yang boleh dilaksanakan untuk kekerapan dan kuasa akan mempunyai pengaruh yang ketara, kerana tiada parut terbakar akan berlaku dan warna keemasan-coklat akan dicapai akibat menggunakan parameter ini. Dalam langkah berikut, ujian kekasaran permukaan akan dilakukan untuk menganalisis kekasaran permukaan dan mikrostruktur keluli tahan karat yang telah terukir menggunakan profilometer stylus Mitutoyo Surftest SJ-301 dan mikroskop USB digital akan dilakukan. Pengukuran kekasaran permukaan telah dijalankan untuk memperoleh nilai kekasaran (Ra). Nilai Ra optimum untuk ilustrasi ukiran laser pada keluli tahan karat adalah 0.093 (um) pada kelajuan 4000 mm/s. Selepas itu, pemerhatian mikrostruktur dijalankan dengan bantuan Mikroskop Digital Nikon Eclipse LV100. Apabila tiada kesan terbakar di permukaan, ia dianggap mempunyai kualiti permukaan yang baik. UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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#### LIST OF SYMBOLS AND ABBREVIATIONS

MOPA	-	Master Oscillator Power Amplifier
CO2	-	Carbon Dioxide
Nd: YAG	-	Neodymium-doped Yttrium Aluminum Garnet
mm	-	millimetre
kHz	-	kilohertz
GPa	-	gigapascal
MPa	-	megapascal
W	-	watt
mm/s	-	millimetre / second
°C	MAL	celcius
μm	5-	micrometre
SiC	<b>a</b> -	silicone carbide SiC
Al2Si2O5(0	H) -	potassium
ZrO2	Tax-	zirconia
	AINO	
	باملاك	اونيۈم,سيتي تيڪنيڪل مليسب
U	NIVER	SITI TEKNIKAL MALAYSIA MELAKA

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#### **CHAPTER 1**

#### **INTRODUCTION**

#### 1.1 Background

Laser has been utilized frequently for cutting and welding activities in recent decades. Recently, this technique was utilized in various industrial processes such as marking, selective removal and processing of diverse materials by introducing laser sources defined by shorter and shorter pulses ranging from nanosecond to femtosecond. Engraving is a process which a product identifying mark was produced such as time stamps, component labels and barcode marking. There are several ways of engraving, such as tin marking, mechanical engraving and electrochemical. Based on (Qi et al., 2003), for comparison with typically marking methods, there are several benefits to laser marking, such as this marking method will not use tool wear because it has a high level of automation and also have a free programming and the choice of characters.

Laser engraving is a subtractive production process using a laser beam to change the surface of an object. This procedure is used mostly to make pictures that are displayed at eye level on the material. The laser generates great heat, which sprays the substance and so reveals the holes that comprise the final picture. The laser is used to mark a metal workpiece surface. Based on (Haron & Romlay, 2019), the operating principle of laser engraving is focused on the vaporization, whereby the interaction from a laser system through a focusing lens (convex lens) between material and laser beam results in the vaporization and melting of the materials used in the work. It is also an excellent example of how a core theoretical notion might remain until a technological application may be rediscovered. The material is therefore removed by an ablation mechanism from the workpiece in layers.

(Mehta et al., 2015), investigated that there are several advantages of laser engraving method compared than commonly used engraving method since that this laser engraving process does not use of any kind of inks and also it does not implied a tool bits. Furthermore, the main advantages of laser engraving method is this process are noncontact working which can minimize the rate of damage to the product, high precision, higher scanning speed, as well as high flexibility and automation.



Figure 1.1 Schematic Laser Engraving System (Deka et al., 2013)

#### **1.2 Problem Statement**

Laser engraving is a typical technology used to engrave practically every material that traditional methods cannot engrave. The heat-up mechanism that vapors the material surface allows the laser engraving process to be done. The laser process is one of the most widely recognized technologies in many years. A Fiber Engraving Laser is commonly been used for various applications such as in electronic industries. Even so, a laser engrave technique using the Master Oscillator Power Amplifier (MOPA) Fiber Laser is still quite rare in Malaysia's market because of the different specialty need and this technology is highly expensive compare than fiber engraving laser.

Stainless steel have been commonly used in industrial applications because of its corrosion resistance, very durable, temperature resistant and high specific strength. In generally known as it is very ductile, traceable, resistant to corrosion, thermal conductivity and electrical conductivity. Hence, the metal material parameter such laser power, speed of the beam and frequency should be measured by refer to the mechanical properties of the material itself, in order to help in the reduction of over burning materials during the engraving process, in the mean time can evaluate the best combination of parameter to produce laser engrave colour when laser engraving illustration.

Laser engraving process is been widely used for multiple type of metals due to its several benefits such as non contact, non cutting force and tiny region of heat effect. However, there are still some downsides during the laser engraving process including very poor ablation surface roughness and certain number of microcrack on the surface that substantially impacts treatment quality. Thus, there is a need to evaluate on the basic parameters laser such as laser power, laser speed and laser frequency values so that it will be suitable to be applied on the stainless steel workpiece to produce a good quality products.

#### **1.3** Research Objective

The general purpose of this research is to analyze the effect of laser engraving parameters on a microstructure and pattern quality on the stainless steel in laser engraving process. In order to accomplish the main objective, below shows the sub-objectives of this study:

- a) To develop a illustration using a Master Oscillator Power Amplifier (MOPA) Fiber Laser on stainless steel.
- b) To evaluate the effect of the process parameter on the surface of the stainless steel.
- c) To analyze the surface roughness and microstructure of stainless steel when undergo laser engraving.

#### 1.4 Scope of Research

The scope of this research is to develop a design using laser engraving on a workpiece metal material. Next, to evaluate the effect of laser engraving parameters on pattern quality on stainless steel, such as speed, frequency and power of the laser engrave machine running during the process. Finally, a research on the effects of laser engraving on stainless steel structural and micro-structure changes. The experiments were conducted Manufacturing Laboratory at the Faculty of Manufacturing Engineering in Universiti Teknikal Malaysia Melaka (UTeM). The research scopes are as follows:

- The testing or measuring of the materials used in this experiment is in the little and low depth.
- Adjust laser engrave machine's differences parameter.
- Study structural and microstructure changing characteristics of the plate at the conclusion of the experiment

#### **CHAPTER 2**

#### LITERATURE REVIEW

This section is focusing on the laser engraving process and the parameter used in this research. It described on the effect of laser parameters in surface morphology on a metal workpiece. In addition, types of a laser engrave, parameters involved, and other additional information were defined. All the information gained from multiple resources which were reference book, journal and online article

#### 2.1 History of Laser

The word "laser" itself stands for "light amplification by stimulated emission of radiation". A laser is a mechanism that induces atoms or molecules to release light at certain wavelengths and then amplifies that light to create a very small beam of radiation. The emission usually spans a very narrow spectrum of visible, infrared, and ultraviolet wavelengths.



Figure 2.1 Laser Engraving Machine

In 1916, Albert Einstein point out a idea involving the laser that under the right conditions, which is atoms could emit excess energy as light, either naturally or when induced by light. Rudolf Walther Ladenburg, a German physicist, discovered stimulated emission in 1928, though it seemed to have little practical use at the time. Laser technology is at the center of the larger scope of nanotechnology that leading to a range of unique properties of laser light. Many different types of lasers have been produced, each with a unique set of characteristics.



Figure 2.2 The Laser Engrave Table in 1981 (*History Part 5*, n.d.)

Lasers proceeded to be able to mark or engrave materials as technology advanced, allowing them to produce barcodes, serial numbers, 2D codes, UDI codes, labels, patterns, and more. In the 1970s, Bill Lawson of LMI started to work with the potential and possibilities of laser engraving in order to develop the then-popular computerized engraving machines. Lawson's system that are include a scanned black and white artwork, information, or designs, engraving either the white or black part, based on user preference, greatly enhanced the end result. Laser Engraving or also known as Laser Etching is a technique that involves changing the surface of an object with a laser beam. This technique is mainly used to produce representations on the content that can be used at eye level. To do this, the laser produces a high heat which vaporizes the matter, thus revealing cavities that will create the final image. It is used to mark the surface of an object with a laser. The CO2 laser, which employs a combination of carbon dioxide and other gases to create long- wave infrared light, is now the most popular laser used for engravers. Lasers for CO2 function effectively in the graving and cutting of heat or electrical conductors like glass and ceramics. The YAG laser is another prevalent type of laser. This gadget employs a Yttrium Aluminium Grenet and tiny amounts of light from a rare element known as neodymium. YAG lasers are suited for graving both metal and non-metal material, and operate well with objects such as very difficult stainless steel grades.



Figure 2.3 Metal Laser Engraving

#### 2.2 **Process of Laser Engraving**

Laser graving is a procedure that uses a high-performance laser to remove the layer of the material physically, creating a hollow that shows an image. Other than that, laser engraving is a method that processes objects into fumes by vaporizing them. The laser beam works as a chisel, incising marks by scraping layers from the material's surface. To produce the high heat needed for vaporization, the laser must reach specific areas with large amounts of energy. While laser engraving melts the surface of the material to modify its roughness, laser graving sublimates the surface of this substance to generate depth gaps. This means that the surface absorbs enough energy quickly, without ever being liquid, to shift from solid to gas. The laser graving system must create sufficient energy to ensure that the surface of the material reaches its vaporizing temperature in milliseconds in order to achieve sublimation. Given the severe sublimation temperatures, laser engravers are formidable instruments. When the temperature reaches for its vaporization temperature optimum value, the materials are evaporated into vapours.



Figure 2.4 Schematic diagram of the two-dimensional laser engrave system

Based on (Patel et al., 2015), laser engraving is the process of engraving or marking an object by using a laser. Laser engraving is the removal to a certain depth of the material from the top surface. Laser engraving is the process of applying laser marking to engrave an item and contrasts from laser marking. On the other hand, laser branding just discolors the surface, without cutting through the surface. It does not require the use of inks or of tool bits that touch and wear out the engraving surface.



Figure 2.5 Laser engraving process (a) Schematic process for laser engraving and (b) engraving depth in the SAE304 stainless steel workpiece of 14 consecutive beam laser beam pulses.



Figure 2.6 Laser Engraving Illustration (Laser Engraving Technology | Matica, n.d.)

Vaporization Temperature of Various Metals		
Material 👔	Vaporization Temperature	
Aluminum	2327°C	
Copper	2595°C	
نیکل ملیسیا ملاک	اونيوم سيتي تيك:	
Magnesium	1110°C	
Zinc	906°C	

Figure 2.7 Vaporization Temperature of Different Type of Metals

#### 2.3 Type of Laser Engrave

#### 2.3.1 Fiber Laser Engrave



Figure 2.8 Mechanism of Fiber Laser (Fibre Laser Marking | Knowledge | Laser Marking Basics | KEYENCE Malaysia, n.d.)

Fiber laser markers have a wavelength of 1090 nm, and may mark a large variety of materials, including the metal and resins, within the typical wavelength range. It is great strength is particularly suitable for marking black-annealed and deep metal graving. Fiber laser markers cannot be employed, instead, as the light passes through transparent things as glass. By using the amplification technology of long-range communication relays for fibre optics, the fiber lasers are high output lasers built. By traversing through the use of the optical fibre, the laser beam is effectively amplified and a high performance laser may be produced. High performance lasers can engrave more deeply in the same marking time and quicker with the same depth, compared with standard laser markers. Laser fibre marking is the solution to shorter time and deeper engravure requirements.

#### 2.3.2 Neodymium yttrium-aluminium-garnet (Nd-YAG) Laser

A Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) laser is a solid-state laser that uses Nd: YAG as a laser medium. These lasers have many uses in the medical and scientific fields, including lasik surgery and laser spectroscopy. The Nd: YAG laser is a fourlevel laser device, which means that laser operation involves all four energy levels. These lasers are capable of operating in both pulsed and continuous modes. Nd: YAG lasers typically produce laser light in the near-infrared region of the spectrum at 1064 nanometers (nm). It also absorbs laser light at various wavelengths such as 1440 nm, 1320 nm, 1120 nm, and 940 nm (Lee et al., 2015).



Figure 2.9 Mechanism Nd-YAG Laser (Nd:YAG Laser - Definition, Construction and Working, n.d.)

#### 2.3.3 Direct Diode Laser

Direct diode lasers are lasers in which the output of laser diodes is used specifically by an operation. It is used extensively in laser material manufacturing, such as laser cutting and laser welding. In comparison, diode-pumped lasers use diode laser radiation to pump another laser, usually a solid-state laser, the power of which is then sent to the application. Typically, the extra laser serves as a light multiplier. About the loss of any optical power, the beam efficiency of its output is so much greater than that of diode lasers that the amplitude, or more specifically the radiance, is still higher.



Figure 2.10 Mechanism of Direct Diode Laser

Direct diode lasers are typically based on gallium arsenide technology, which allows for emission wavelengths ranging about 0.8 to 1 m. Several more direct diode laser technologies probably require high output power. Do seem to be single diode bars, which are ideal for powers of the order of 100 W, but even diode stacks, which contain several diode bars and can produce powers of 1 kW or even several kilowatts, play a factor. It is also possible to combine spectral beams using multiple diode stacks performing at slightly different wavelengths.

#### 2.3.4 CO2 Laser



The carbon dioxide laser (the CO2 laser) was discovered by Kumar Patel in the United States in 1964. The CO2 laser is one of the most powerful and efficient lasers available today, and it is helpful in a wide range of medical, surgical, industrial, and military applications. Based on (Yong Zhang and Tim Killeen, 2016), lasers of carbon dioxide might well supply power rates from milliwatts to tens of kilowatts, making them suitable for instrumentation or brutal cutting. As CO2 lasers are highly spectrally purified, with a radiated line width of less than 1 kHz without any power compromise, conversion efficiencies of 10% are feasible. These characteristic characteristics allow CO2 lasers to deal with new applications in the fields of material treatment, light detection and rangement.

#### 2.3.5 Master Oscillator Power Amplifier (MOPA) Laser



Figure 2.12 Schematic Diagram of MOPA Laser set up (Y. Wang et al., 2018)

Master Oscillator Power Amplifier (MOPA) lasers are ideal for creating black marks on naturally and coloured anodized aluminium without scratching the paint. They are often used to create high-contrast markings on a variety of other metals such as nickel alloys, steels, titanium. A MOPA laser, for example, can produce a wide variety of reproducible annealing colours on stainless steel. Furthermore, MOPA lasers give advantages in terms of label longevity during reprocessing. High-quality markings that are resistant to many passivation and sterilisation processes can be accomplished with the ability to change the laser parameters flexibly. All elements of a fiberlaser source are included inside the MOPA laser. The pulse width, frequency, control waveform and other characteristics of the laser upgrading have been considerably enhanced in MOPA. A defined black, black aluminium oxide surface can be tinted in stainless steel by using the MOPA laser. As a result, the MOPA laser is often used to marking medicinal products.



Figure 2.13 Marking colour on stainless steel by MOPA



Figure 2.14 Structure of Master Oscillator Power Amplifier (MOPA) Laser

#### 2.4 Factor that affected the marking quality of laser engraving

#### 2.4.1 The focal position of the laser engraving machine

The focus position of the laser marker is giving effect on the quality of the engraving. Laser simply focuses on maximum power and effect in order to assess whether the proper, high impact is on process quality and affects the laser if the right role is played by the workpiece to produce the processing effect. By adjusting the lens height in laser operations it allows the laser to achieve its strongest condition. The strongest condition of the laser, accompany by a loud beep-similar sound, is marked by a dazzling blue-white light (Qi et al., 2003).



Figure 2.15 Laser Marking Beam (Laser Marking - Methods, Materials & Applications | Fractory, n.d.)

#### 2.4.2 The performance of laser beam focusing

The performance of the laser beam focusing will effect marking quality directly, the laser beam focuses on extremely small areas, so the energy is concentrated. Without strong focusing performance, the optimal laser location can not be achieved, the high laser energy density cannot be used and the laser marking machine cannot be realized. The beam waist is always between the spot-speech and the target in the ideal concentrating circumstance.



Figure 2.16 Laser Beam Focusing Lens (Laser Marking - Methods, Materials & Applications | Fractory, n.d.)
# 2.4.3 Laser engraving machine cooling method

The approach should not be overlooked for the laser marking cooling machine. The Cooling System is that the whole laser machine can be stable and sustainable, that heat affects the escape of the laser and the circuit system, that it affects the fibre-lasermarking system, that reduces the body's inner temperature and reduces the fault of the machine, improves the stability of the equipment and that has a small volume of fast discharge of heat.

# 2.4.4 The movement speed of the laser beam

Another key component is the movement speed of the laser beam. The process of laser and material contact, laser beam speed and material interaction effects are affected.



Figure 2.17 Laser Beam Scanning Strategy (Nikolidakis et al., 2018)

Material	Thickness	Power (%)	Speed (mm/sec)
Acrylic	15 mm	100	1
	12 mm	100	1.4
	10 mm	100	2
	8 mm	100	2.5
	6 mm	100	5
	4 mm	100	7
	3 mm	100	10
	2 mm	100	25
alsa Wood	2 mm 3 mm 6 mm	15 15 35	25 20 25
lard Plywood	4 mm 9 mm	100 65	6 2
Carboard	2 mm	15	35
Engraving Sp Material Acrylic	eed Chart Pow	er (%)	Speed (mm/sec)
Nood	10 to 20%		200 mm/sec
	Himme and Himme	ed quideline. Adius	t the power and speed

# 2.4.5 Material of Laser Engraving

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By using the same laser engraving machine, several materials have been marked that differ in their tiny lines. Then the marking lines will also have a varied impact if the laser intensity employed is different. In order to pick the optimum laser system, the material qualities and laser qualities are crucial. The interaction between the laser and the substance is determined by the material absorption and its temperature. The wavelength of the laser employed is very dependent on the absorption. It is very important to select a wavelength which is highly absorbed by the material to get an effective laser process. Most of the materials are quite easy to laser. Although not all materials yield the same laser depth or contrast, they typically may be engraved safely.

# 2.5 Parameter of Laser Engrave

#### 2.5.1 Laser Power

Laser power has to be chosen on the basis of the procedures. For metal laser cutting or engraving, it is advisable to use a laser power of at least 50 watts. For direct laser marking metals, 40 or 50 Watt of fibre laser power can be employed. The direct marking of metals is advised for 25 to 150 watts of CO2 laser power. The strength of the Fiber laser beam may be reduced so that a defined depth may be removed or engraved. Usually many laser gravure passes are necessary. Metal laser engrave has an usual depth of 0.003 to 0.005." (75 to 125 microns). The removal of this large amount of metal might nonetheless cause melting or deformation in one pass. Metal engraving in numerous passes is therefore generally done. The laser engraving procedure allows permanent markings to be produced, which cannot be erased by heat or wear. This sets the percentage power of the laser. Speed and power often often a trade-off. If the mark is too strong at full power attempt to speed up before you decrease power to see if cycle times may be improved.

	Level			
Engraving parameter (factor)	low	medium	high	
Pulse frequency, $f_p$ (kHz)	50	100	150	
Power, $P(W)$	10	12	15	
Scan speed, vt (mm/s)	5	15	30	
Focus, z (mm)	0	1	2	

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#### Figure 2.19 Laser Engraving Parameter

(Lin et al., 2008) describes that the engraved depth values dropped as the feed speed ratio increased. However, as the laser power was raised, the engraving depth values increased as illustrated in Figure 2.20. Higher laser power or a lower feed speed ratio will produced a deeper laser engraving depth. The engraved depth and colour difference were significantly affected by the feed speed ratio by laser power interaction procedures. As a result, as the laser output power is higher, the engraved depth and colour difference values will increased as well, but the feed speed ratio will decreased.



Figure 2.20 Average depth of engrave with different feed speeds (Lin et al., 2008)

## 2.5.2 Loop Count

Loop count is the number of times the material is processed with a parameter combination of laser power, laser speed, and laser frequency (Barrimi et al., 2013). The loop count specifies the number of times the laser will pass over the workpiece's mark. The number of loops will increase the depth of the marking. (Patel et al., 2015), elaborated that the mark depth, width, and contrast have all been measured in relation to the pulse frequency. When the pulse frequency is around 3 kHz, the mark depth reaches its maximum, but the mark width remains nearly constant at varied pulse frequencies. As the pulse frequency rises, material evaporation decreases and oxidation increases, resulting in improved mark contrast. When the laser pulse frequency was around 8 KHz, the maximum mark contrast was obtained.

#### 2.5.3 Laser Speed

The laser parameter speed defines laser head movement. Fast velocities lead to short exposure durations while moderate velocities contribute to long exposures. For instance, large-scale TroLase gravings of materials engraved at high speed between 80% and 100% should not exceed 10% for photographs with much detail on wood. The quality of the laser cut also influences this option. The speed attribute shows that the laser beam is moving by marking the item with a speed of in mm. When the speed is too high, the laser beam does not have any impact on the substance that is marked by it using a slow speed.



Figure 2.21 Reference Chart speed versus power for laser engraving (Gradient Reference for the 25 Watt Laser Cutter | Milwaukee Makerspace, n.d.)

# 2.5.4 Frequency

The frequency (Hz) attribute is used to indicate the laser pulses per second' Q-Switch frequency during marking. This frequency alteration provides various marking effects. This parameter is utilized for adjusting the laser output frequency by using the Qswitch directly. The Q-Switch is an optical electric device that regulates the opacity of lens, allowing the user to modify the frequency of the laser beam. A lower frequency produces "spotted" gravure, whereas a higher frequency allows gravure "line." Frequency is inversely related to the strength of the laser beam, such that the marking process cannot be efficient if the frequency is too high. The Q-switch is related to a shutter sluice that closes and disconnects the laser beam.



Figure 2.22 Effect of frequency versus speed on laser marking

# 2.6 Type of Material Suitable for Laser Engraving

# 2.6.1 Aluminium Alloy

Aluminium alloy plate workpiece is the sampling used to engrave. As in history, engraved metal plates were frequently manufactured from iron and copper, but these days, metals such as bronze, zinc, stainless steel, and aluminium are commonly used for this purpose. These metals are, as previously said, tarnish and corrosion resistant, and are relatively abundant, making them less expensive to use in the production of these metal plates.



Figure 2.23 Engraving on Aluminium Alloy (Engraving Of Aluminium Alloys With Pulsed Fiber Lasers | SPI Lasers, n.d.)



Figure 2.24 The Effect of Laser Parameter on Aluminium Alloy

The benefits of using aluminum alloy in laser engraving are there is no machining force between workpieces, no cutting force and little heat. The great accuracy of the workpiece is therefore guaranteed. Laser alloy marking is very flexible in material, form, size, and the object's processing environment. So the industrial mass production needs may be met. Laser engraving is good, the lines may reach millimetres and microms and can be marked permanently and for the anti-counterfeiting product it is vital. The use of laser marker with computer control technology for the aluminium alloys can provide efficient, automated machinery for processing. In addition, numerous words, symbols and patterns may be produced and current production can enhance significantly. There is no pollutant source and great environmental protection in laser markings for aluminium alloys.

(Zhu et al., 2019), has evaluated and analyzed the effect of laser power and different cleaning speed on the micro-morphology of aluminium alloy as shown in Figure 2.25. The surface of the aluminium alloy seems rougher and shows a fewer annular structures and holes if the cleaning speed was set to 10.4 mm/s. At the same time, the removal of the oxide film turns to be the most efficient which is generally flat with only just few holes, when ever the surface power of the Nd:YAG laser cleaning aluminium alloy was set to 98 W and the cleaning speed is 4.1mm/s as shows on reference sample (c) in Figure 2.25. However, the number of holes increased clearly when the cleaning speed drop to 1.0mm/s.



Figure 2.25 The sample of SEM surface microstructure of aluminium alloy workpiece.

(a) Reference sample, (b) 10.4mm/s, (c) 4.1mm/s, (d) 1.0mm/s



Figure 2.26 SEM microstucture of aluminium alloy using different powers: (a) Reference sample, (b) 50 W, (c) 88 W, (d) 98 W and (f) 110 W

According to (Lichovník et al., 2019), investigated on a experimental marking to an aluminium workpiece using the CO2 Laser. The experimental was performed by following the practical parameters. The parameter for laser power was set to 10 %, 20 %, 40 % and 60 % at a constant feed rate of 150 mm·s-1. As shown in Figure 2.24, that is the optimal practical parameters that were selected which is 60 % for laser power and 150 mm·s-1 feed rate. As the result, the marking product turned out of high quality, it is distinguished by its color saturation, its distinctive contrast and no visible laser cut or other lack. Furthermore, the resistance of aluminium alloy material to mechanical wear is pretty good.



Figure 2.27 The optimal technical parameter for laser engraving on aluminium sample

The difference between the advantages and disadvantages of aluminium alloy are shown in table 2.1. The disadvantages shown give the limitation for the laser engraving on aluminium alloy. However, there are many advantages of aluminium alloy that can give benefit to the laser engravement and the engravement quality.

Advantages of Aluminium	Disadvantages of Aluminium
Alloy	Alloy
It is a light metal, about the third	Softer than other steel
of the density of steel, copper	
and brass.	
Has a good corrosion resistance	Higher cost of raw material
to common atmospheric and	
marine atmospheres.	
High reflectivity and can be used	
for decorative applications.	
کل ملیسیا ملاك	اونىۋىرىسىتى تىكنىچ
Some aluminium alloy can	
match or even exceed the	AL MALAYSIA MELAKA
strength of common construction	
steel.	
Good conductor of heat and	
electricity.	

Table 2.1 The Advantages and Disadvantages of Aluminium Alloy

#### 2.6.2 Stainless Steel

Stainless steel is an iron alloy with a minimum of 10.5% chromium content of carbon. The chromium generates an oxide coating that prevents corrosion of the iron. Corrosion resistant steel is the alternative name for stainless steel. Either a CO2 laser or a fibre laser can be used for the steel surface. The laser beam intensity makes the oxide darken and creates a strong laser mark in each case. Fiber laser markings are darker than CO2 laser markings as the stainless steel more effectively absorbs fibre laser wavelength. A laser fibre may also cut thin stainless steel (up to about 0.005 inches or 125 microns).



Figure 2.28 Engrave on Stainless Steel Metal



Figure 2.29 Removal material graph

According to (Nikolidakis et al., 2018), on an SAE304 stainless steel plate, a set of 126 experimental samples with varied combinations of process parameters was made. As shown in Figure 2.29, by increasing the average output power P and decreasing the scanning speed V, the removed material layer thickness Dz is increased. Additionally, raising the average output power P, scanning speed V, and repetition rate F results in an increase in the material removal rate DV.



Figure 2.30 Example of engraving test on stainless steel



Figure 2.31 Example of Screening of stainless steel test specimens



Figure 2.32 Sample of Microstructure Observation on Stainless Steel

Stainless Steel							
Roughness	Ra [µm]			Rz [µm]			
Marking of the field	0 3 7			0	3	7	
A	9,77	3,64	5,65	33,2	15,88	25,84	
В	1,35	2,81	3,48	6,77	12,47	14,82	
с	0,99	3	3,54	5,46	14,98	17,93	
D	0,81	1,94	4,14	4,57	8,78	17,55	
E	0,68	2,02	2,78	3,57	10,3	12,04	
F	0,82	2,27	3,91	4,27	11,86	16,59	

Figure 2.33 Sample of Surface Roughness Ra Value on Stainless Steel

#### 2.6.3 Ceramic

Ceramics are both hard and broken inorganic materials. Ceramics offer good isolation qualities for heat and electricity. Examples include alumina (Al2O3), potassium (Al2Si2O5(OH)), zirconia (ZrO2), barrier, silicone carbide (SiC) and ceramic tiles for typical ceramics. Laser processing of ceramics is usually carried out using a laser of 10.6 to 9.3 microns CO2 and some ceramics absorb a laser laser wavelength of 1.06 microns. A CO2 laser is also available to cut thin-film ceramic, creating a crisp edge with minimum colouring. A CO2 laser is used for the laser graving of ceramics. This procedure results in a shallow depth of texture that allows complex patterns and detailed pictures to be created. Laser marks on some ceramics such as alumina, tungsten carbide (WC) and zirconia may be performed using a 1.06 micron fibre laser to generate a black, homogeneous surface mark. A thick, liquid blend of crystalline oxides, nitrides or carbides forms the shape of ceramics. The mixture is moulded and fired to make a solid ceramic item at high temperatures. Timing clay to create vessels and tiles make the oldest ceramics. Most state-of-the-art ceramics like alumina (aluminium oxide) and tungsten carbide provide features such as electrical isolation and wear resistance. Marking and graving are the most frequent laser method process for ceramic materials.



Figure 2.34 Example of deep engraving on ceramic tile

#### **CHAPTER 3**

#### METHODOLOGY

#### **3.1** Introduction

This chapter focuses on proposed research techniques for the qualitative and quantitative of the effect of laser engraving parameters on surface morphology and quality on stainless steel in the mixed method theoretical study. This methodology enabled a detailed knowledge of the influence on the material of stainless steel by the laser engraving parameters which are speed, power and frequency. This chapter is on the significance and a constructivist approach of based theory for this topic.

Based on Sachin Patel (2015), laser engraving is the process of engraving or marking an object by using a laser. Laser engraving is the removal to a certain depth of the material from the top surface. Laser engraving is the process of applying laser marking to grave an item and contrasts from laser marking. On the other hand, laser branding just discolors the surface, without cutting through the surface. It does not require the use of inks or of tool bits that touch and wear out the engraving surface.

Laser engraving technology will be implemented in this study to produce an laser engraved metal workpiece. By using ImagR and EzCad Software, a specific pattern design will be generated. This result is then used as the main input for the laser engraving process.

#### 3.2 Planning Process

Planning must be carried out in the correct method in order to identify all information and requirements such as hardware and software. Data gathering and the uses of hardware and software needs are two major factors in the planning stage. In order to ensure the project is operating smoothly and easily, the most significant part of the planning process should be created before the process is conducted. This planning method plays a very important role in project management to complete the project in due time. The process planning can also be led to ensure that the process is progressively followed.

In this study, the first part of the project mainly focuses on the three chapters which are introduction, literature review and methodology. Multiple perspectives at this step were collected such as the problem statement, the benchmarks, the scope and projectrelated information. After that, all the method are used for the second phase of the project that consist of other three stages interphase which is conduct the experiment using the Laser Engraving Machine, data collection and analyzing the data.

This experimental process was performed at Manufacturing Laboratory at Faculty of Manufacturing Engineering in Universiti Teknikal Malaysia Melaka (UTeM) to seek for more knowledge and documentation about stainless steel laser engraving using MOPA fiber laser engrave machine. The parameter of the speed, power, and loop count of the laser machine was observed in this research to get good 2D models on the workpiece for stainless steel.

A flowchart has been created for this overall project, as illustrated in Figure 3.1, in order to conduct this study. This flow chart shows the overview of the laser engraved process from the literature review to the experiment and till the results have been analyzed and reported.



Figure 3.1 Flowchart for Bachelor Degree Project

#### **3.3** Selection of Material, Machine and Software

This chapter discusses the materials and properties to carry out this project. The machines that were used throughout the experimentation phase to obtain the required results in this research were discussed in this chapter. Other than that, the software that is used for the experiment also was discussed in this section.

#### **3.3.1** Type of Material

Stainless Steel was selected as the material for the workpiece or specimen that is used to analyze an entire laser engraving process. The thickness of the material is 1.0mm, 180mm width and 127mm long. Mechanical properties of stainless steel were listed in Table 3.1.

Table 3.1 Mechanical Prop	perties of Stainless Steel
Properties	Value
Modulus of elasticity	193 GPa
Density	8.03 [g/cm <sup>3</sup> ]
Tensile strength	515MPa and
Yield strength 🥌	205 MPa
UNIV Bulk modulus EKNIKAL	MALAY 68-70 GPaLAKA
Melting Point (°C)	1664 (°C)
Boiling point (°C)	1672 (°C)

There are many advantages of using stainless steel in the laser engraving process, this material is more resistant to wear and abrasion than aluminium or other materials. The surface can be cared for regular without any harsh chemical needed so it is suitable for advertising and signs, since it has aesthetic apperarance which result will turn out a good quality product. Moreover, laser engraving or etching cannot easily give damage to stainless steel because the material is heat resistance and is also used for high reflectivity therefore stainless steel material will be used to be applied for the laser engraving process as a metal workpiece.

#### **3.3.2** Type of Machine

This project was using Master Oscillator Power Amplifier (MOPA) Fiber Laser that is available in the Manufacturing Laboratory at the Faculty of Manufacturing Engineering in Universiti Teknikal Malaysia Melaka (UTeM). The Master Oscillator Power Amplifier (MOPA) Fiber Laser was shown in Figure 3.2 below.

The laser may provide a power source with an alternative approach using the Master Oscillator Power Amplifier (MOPA) and this provides a pulse frequency with a greater fiber range than 1- 4000 kHz. This allows MOPA laser to provide different engraving outcomes in comparison with other fiber engrave laser technology in various polymers and metal materials. Moreover, laser MOPA may give multiple engrave colors on stainless steel, titanium, and a dark color effect on aluminum, and a superior finish better than fiber laser.



Figure 3.2 Master Oscillator Power Amplifier (MOPA) Fiber Laser in UteM

#### 3.3.3 Type of Software

To design the desired pattern that will be engrave by the Master Oscillator Power Amplifier (MOPA) Fiber Laser, ImagR was used in this experiment. It is possible to process images online with ImagR, which is software for laser engraving. It is equipped with an auto-adjust feature. When a user initially uploads an image to the website, it automatically converts to greyscale. From there, the user can crop the image and resize it to the desired dimensions, all while maintaining a DPI of 254. Once the image has been resized, may either manually modify the brightness, contrast, sharpening, and other settings, or use the auto button. In the Figure 3.3 shows the example of ImagR interface. ImagR was easier to use as the MOPA laser machine is compatible with the graphical programme format selected. The intended picture or design is already a basic 2D model that was afterwards imported to EzCAD2.76 as shown in Figure 3.3.



Figure 3.3 Imag-R software



Figure 3.4 Adobe Illustrator Software



Figure 3.5 EzCAD2.76 Software

# **3.4 Identification of Engraving Parameters**

In this engraving method study, there are four parameters which are laser power, engrave speed, pulse frequency and laser loop counts. The laser frequency and the laser speed were set to fixed parameters and the variable parameters were laser power and laser loop count as shown in Table 3.2. Meanwhile in Table 3.3 showed the suggested constant settings that implemented for the whole experiment.

Designation	Engraving	Recommended	Unit	
	Parameter	Data		
Stainless	Laser loop count	1,2,3	-	
Steel	E -			
N. A.	Engraving speed	500, 1000, 1500,	Mm/s	
II.		2000		
VI SUSAN	Laser power	20,40,60,80	Watt	
	Laser frequency	20	kHz	
ملاك	Lundo Si	بوته است. ت	100	
	0 .	. G. V.		

Table 3.2 Engraving Parameter

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Table 3.3 Recommended Constant Parameter for Laser Engraving

Constant		Units			
Parameter					
Laser Speed	2000	1500	1000	500	Mm/s
Laser Power	80	60	40	20	Watt

#### **3.5** Surface Roughness Test

Surface roughness has been analyzed using the stylus profilometer Mitutoyo Surftest SJ-301 for every test run. The roughness of the surface of the material is effortlessly and accurately tested with the Mitutoyo Surftest SJ-301 style profilometer. The surface roughness of the workpiece material has been inspected by using an image technique and by using a surface profilometer before and after the laser engraving process. The stylus profilometer Mitutoyo Surftest SJ-301 shows the expected depth of roughness (rz) in microns and microns (µm), and the average roughness value (Ra). The Ra values were measured with a field size of 5mm for all the samples. Three measurements were collected for each engraved section in order to eliminate the consequence of measuring mistakes. The mean value of the final Ra value was recorded.



Figure 3.6 Mitutoyo Surftest SJ-301 Stylus Profilometer Instrument

#### 3.6 Microstructure of Specimen

A digital microscope such as in Figure 3.7 shown, it is useful to inspect and analyze the grain measurements of the micro-structure on the engraved material. The sample microstructures were examined to observe the engraving area and base-metal workpiece micrographs.



3.7 Preliminary Finding TEKNIKAL MALAYSIA MELAKA

# 3.7.1 Expected Result

Table 3.4 shows the expected outcome of laser engraving on stainless steel. The outcome enables the characterization of surface after being lasered at specific parameters. In addition, the appearance of the surface on stainless steel workpiece demonstrated the selection of which best surface for product marking.

		Surface become darker as the irradiation power					
		increased					
		4W	8W	12W	16W		
First Irradiation	Cycle						
		(a) 1.46 µm	(b) 1.91 μm	(c) 2.00 μm	(d) 2.24 μm	Surf	
Second Irradiation	VI TER VICE	AVSIA				ace become darker as t	
	00	(e) 2.78 μm	(f) 1.98 μm	(g) 1.52 μm	(h) 1.51 μm	che ir	
Third Irradiation	Cycle	ليبتيا مار VERSITI T	نيكل EKNIKAL	بتي تيك المما معا	وينونرس MELAKA	radiation cycle increas	
		(i) 1.86 µm	(j) 1.24 μm	(k) 1.49 μm	(l) 1.22 μm	sed	
Forth Irradiation	Cycle					Ļ	
		(m) 1.99 µm	(n) 1.25 μm	(o) 1.17 μm	(p) 1.28 μm		

Table 3.4 Surface profile of engraved stainless steel with corresponding surface roughness

Another expected outcome from this study shown in Figure 3.8. Figure 3.8 presents the distribution of surface roughness for stainless steel. Such surface roughness graphs enable the prediction of surface quality when the laser parameters manipulated. Determining the roughness of a surface is critical from a practical engineering standpoint. Surface roughness allows designers to evaluate the accuracy of processed components by predicting variables such as the amount of friction or vibration produced between two contact surfaces. Furthermore, the surface roughness value enables engineering to predict the capability of a component to provide lubrication and estimate the component life of a part.



Figure 3.8 Surface roughness of engraved stainless steel

Futhermore, this study aim to present the result of laser engraving of selected metal with the best parameters. Figure 3.9 shows the example of laser marking product when best parameter used during the laser engraving process.



Figure 3.9 Surface appearance for best selection of parameter

#### 3.8 Summary

This chapter begins with an introduction to the research design used throughout the study. The methodology section covered the type of material, graving settings and machine type utilized during the experiment. The sample utilized was stainless steel and the Master Oscillator Power Amplifier (MOPA) Fiber Laser was utilized for the engraving process. In addition, a surface roughness test was performed using the style profilometer Mitutoyo Surftest SJ-301 while the digital USD microscope was used for the microstructure of the specimen.

### **CHAPTER 4**

#### **RESULTS AND DISCUSSION**

#### 4.1 Introduction

This chapter presents the results and analysis on the pattern quality when laser engraving illustration on stainless steel. The parameters involved in this experiment were laser frequency, laser power, engraving speed, and loop count. The loop count is specified to remain constant through out experiment. The tests performed in this research are surface roughness tests and microstructure observations..

# 4.2 Trial Study

Prior to performing colour laser engraving on stainless steel plate, extra image editing is required. It is required to raise its brightness and contrast in order to enhance the freshness of the visual edges. The illustration that has been selected for engraved is shown in Figure 4.1.



Figure 4.1 Zahir Mosque

The stainless steel plate shown in Figure 4.2 is being used to test the laser engraving process using the Master Oscillator Power Amplifier (MOPA) Fiber Laser. Constant parameters were used to evaluate the illustration design in four different sizes that fit on a single plate, involving laser power, laser speed, frequency, and loop count. The laser was set to a speed of 800 mm/s, with a power of 30 watts, a frequency of 80 kHz, and two loop counts. Stainless steel plates produce a range of results depending on the size of the illustration. The colour of the area that being engraved on plate will differ from its origin.



Figure 4.2 Engraving Test on Stainless Steel

As shown in Figure 4.3, it appeared to have gold-colored engraved parts for sizes (A) and (B) while using 800 mm/s speed and two loop counts at 30W power. As the illustration's size was enhanced, the engraved parts produced a greyish white colour and decreased in colour saturation, as shown in Figure 4.3, size (C) and (D). Through this test, the best size with significant effect has been selected, which is size B (4.5cm x 3.0cm), as this engraving colour for this size (B) created gold-colored in real life based on the angle of viewing.



Figure 4.3 Trial test size of illustration

# 4.3 Result of the experiment

A Power Amplifier with a Master Oscillator (MOPA) Stainless steel is engraved using a fibre laser. There are three samples sampling and analysis. Only one illustrations size of 4.5 cm × 3 cm is used for each sample. Each sample has six different areas of the picture that be engraved using a different combination of laser power, speed, and frequency parameters. The laser power value is determined by increasing the value from the lower range to the upper range, seeing that as the frequency and laser speed values are. It also were chosen by increasing the range value by a greater range value to a lower value. The experimental part is followed by two tests: microstructure observations and surface roughness measurements. Surface roughness observations is conducted using stylus Mitutoyo Surftest SJ-301 profilometer. The Nikon Eclipse LV100 Digital Microscope is used to observe the microstructure of the plate after engraving process.



Figure 4.5 Laser engraving colour outcome (speed)

Figure 4.4 shows the result of laser engraving on stainless steel with different speed, meanwhile other parameter are remained fixed 30W power, 80 kHz frequency, and two loop count. As shown in Figure 4.5, the engraved parts that applied low range speed such as 500 and 800 mm/s showed golden-brownish colour. But as the speed were increased, the engraved parts produced greyish-white to white colour. This means that the higher the laser value parameter, the brighter the colour laser engraving produced on stainless steel.



Figure 4.6 Laser Engraving Result with different parameter of power (W)



Figure 4.6 represents the results of laser engraving on stainless steel with variety of different laser power, while the other parameters remained constant at 500 mm/s speed, 80 kHz frequency, and two loop count. As shown in Figure 4.6, the engraved parts that used a low laser power at 15W had a poor appearance with enhanced brightness due to the laser power burning too low. However, when the power was increased to 30 W, the engraved parts produced a significant effect of golden-brownish colour. Figure 4.7 shows that engraved parts at 100W created a dark brown colour that was slightly burnt due to the excessive use of laser power. This explains that the lower the laser power parameter, the brighter the colour laser engraving produced on stainless steel.



Figure 4.8 Laser Engraving Result with different parameter of frequency (kHz)



Figure 4.8 presents the result of laser engraving on stainless steel at various frequencies, while the other parameters are constant 30W power, 500 mm/s, and two loop count. The engraved parts that used a low range frequency of 30 kHz showed a grey-to-white colour, as shown in Figure 4.8. Meanwhile, as the frequency was increased to 60-70 kHz, the engraved parts turned into a dark brown colour. However, as the frequency reached 80 kHz, the laser engraving colour produced a significant golden brownish colour. It clearly shows that a combination of parameter at 80 kHz frequency, 30 Watt power, and 500 mm/s speed created the ideal colour outcome for laser engraving on stainless steel.

# 4.4 Result of Surface Roughness Test

A surface roughness tester was used to detect the surface texture or roughness of a stainless steel plate immediately and precisely. A roughness tester displays both the measured roughness depth (Rz) and the mean roughness value (Ra) in micrometers (µm).



Figure 4.10 Equipment of Surface Roughness Test



Figure 4.11 Surface Roughness Test on engraved material



Figure 4.12 Example the result of a Surface Roughness Test

The results have been categorized into three graphs, one for each parameter. There are three samples, each with a different parameter combination. The first sample mainly focuses on speed (parameter). The laser speed value was determined by adjusting the range from low to high, while the other parameters remained fixed at 30W power, 80 kHz frequency, and two loop count. Figure 4.8 shows the graph of Surface Roughness (µm) vs Speed (mm/s).


Figure 4.13 Graph Surface Roughness (µm) vs Speed (mm/s)

Parameter	Ro	ughness value (R	ta) in micrometer	rs (µm)
(Speed)	First Reading	Second Reading	Third Reading	Average
500	0.186	0.186	0.186	0.186
800	0.135	0.133	0.135	0.135
1000	0.106	0.108	~ Q.110	0.108
2000INIVE	RS <sup>0105</sup> EK	NIK 4105MAL	AYS A MIELA	KA 0.105
3000	0.100	0.102	0.104	0.102
4000	0.093	0.093	0.093	0.093

Table 4.1 Roughness value (µm) for speed

Figure 4.8 shows the graph of Surface Roughness ( $\mu$ m) vs Speed (mm/s) for Laser Engraving Testing. According to Figure 4.1, the Ra value decreases as the speed increases. Ra value has a maximum average value of 0.186  $\mu$ m at 500mm/s, meanwhile a minimum average value for Ra is 0.093  $\mu$ m at 4000mm/s.



Figure 4.14 Graph of Surface Roughness (µm) vs Power (Watt)

Parameter	Roughness value (Ra) in micrometers (µm)										
(Power)	First Reading	Second Reading	Third Reading	Average							
15	0.091	0.089	0.092	0.091							
20 Jul	0.103	0.105	. 0.105 	0.104							
30	· 0.114 U	0.116	0.119	0.116							
60 UNIVE	RS0.453 EK	NIK/0.453/AL/	AYSI.0.453ELA	KA 0.453							
80	0.725	0.728	0.731	0.728							
100	1.226	1.222	1.227	1.225							

Table 4.2 Roughness value ( $\mu m$ ) for power

Following that, the second sample is primarily focused with power (parameter). Similar with the first sample, the laser power was determined by increasing the range from low to high, while the remaining parameters stayed constant at 500mm/s speed, 80 kHz frequency, and two loop count. Figure 4.9 represents the relationship between Surface Roughness ( $\mu$ m) and Power (Watt). According to Figure 4.9, the Ra value increases as the laser power increases. The average value of Ra is 1.225 ( $\mu$ m) at 80 watts, while the average value of Ra is 0.091 ( $\mu$ m) at 15 watts.



Figure 4.15 Graph for Surface Roughness (µm) vs Frequency (kHz)

Parameter (Frequency)	Roughness value (Ra) in micrometers (µm)										
(Tropiconey)	First Reading	Second Reading	Third Reading	Average							
30 94/MIN	0.157	0.160	0.159	0.159							
40 Ja	0.369	0.369	0.370	0.369							
50	0.234	0.234	0.234	0.234							
U60IVER	SIT0.267-KI	NK 0.268/AL	AY 0.266 MEI	AK0.267							
70	0.234	0.232	0.231	0.232							
80	0.146	0.146	0.146	0.146							

Table 4.3 Roughness value ( $\mu$ m) for frequency

The third sample focuses on frequency (parameter). As in the previous samples, the frequency was set by increasing the range from low to high, while the remaining parameters remained constant at 500mm/s speed, 30 watts of power, and two loop counts. Figure 4.3 illustrates the relationship between Surface Roughness ( $\mu$ m) and Frequency (kHz). According to Figure 4.3, as the frequency increased from 30 kHz to 60 kHz, the Ra value fluctuated, and then decreased trend over frequency. The maximum average value of Ra is 0.369 ( $\mu$ m) at 40 kHz, while the minimum average value of Ra is 0.146 ( $\mu$ m) at 80 kHz.

#### 4.5 **Analysis Result of Surface Roughness Test**

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With the combination of laser strength, laser speed, frequency, and loop count, the surface roughness of each material was entirely relevant. As the laser speed rose, the surface roughness of the engraved materials reduced significantly. If the speed was maintained at the maximum range value, the determined surface roughness value for each material would be low. However, as the laser power is increased, the surface roughness of the engraved materials increases. If the laser power remained at the maximum range value, the surface roughness Ra would also be at the maximum range value. Following that, when the value frequency increased, the Ra value of the engraved materials decreased. The comparison of the Minimum and Maximum Ra Values of Engraved Stainless Steel is shown in Table 4.4.

Table 4.4 Comparison of the Minimum and Maximum Ra Values of Engraved

- Lessanno		Stainless Steel	<b>eiv</b>	
يا ملاك	Minimum Rot	ighness j	Maximum <b>ج</b> و	ughness
Parameter	SITI TEKNIK Parameter Setting	AL MALAY Ra Value	SIA MELA Parameter Setting	KA Ra Value
	Value		Value	
Laser Speed	4000 mm/s	0.093	500 mm/s	0.186
Laser Power	15 Watt	0.091	100 Watt	1.225
Frequency	80 kHz	0.146	40 kHz	0.369

Based on (Pawar, 2015) the effect of laser engraving operating parameters on the surface quality of mild steel was studied and it was discovered that the surface quality is improved at high speeds. According to Table 4.4, the highest parameter setting value of the laser speed and frequency results in a low surface roughness Ra value of a material. This represents that the laser speed and frequency have a significant effect on the roughness of the material. In comparison to lower laser speeds and frequencies, higher laser speeds and frequencies may result in a better surface roughness.

The highest power at 100 W, with a Ra value of 1.225(µm), affects a stainless steel surface at maximum roughness. The power value that must be optimal is determined by the coating material's characteristics. An optimal power value combined with a higher loop count will result in a superior surface finish, whereas an excessive and inappropriate power value combined with a lower loop count will result in an increase in surface roughness. Oxidation may also contribute to a higher value in surface roughness. The Ra value is high because to the oxidation-induced rusting look.

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#### 4.6 **Result of Microstructure Observation**

The Nikon Eclipse LV100 Digital Microscope is used to observe the microstructure of the plate after engraving process. Microstructural evaluation goes from the simple determination of specific parameters such as grain size or coating thickness through permeability and pore structure to the complete characterization of multi-component systems.



Figure 4.16 Equipment of Microstructure Observation



Figure 4.17 Microstructure Observation on engraved material



Figure 4.18 The microstructure on engraving material with different speed



Figure 4.19 The microstructure on engraving material with different power

According to 4.18, it shows that there are not seen a significant changes in microstructure despite of increasing of laser speed. Meanwhile, Figure 4.19 shows the microstructure of stainless steel etched fields using 15W, 20W, 30W, 60W, 80W, and 100W of power. With 30W to 100W power, parallel lines were clearly visible. Because of the lower laser power and optimal frequency and laser speed, grain spots appeared on the engraved portion with 15W power. Due to the higher power, 80W produced a lot of black patches. Because of the increase in laser power, the colour of the engraved fields darkened and turned golden-brownish.



Figure 4.20 The microstructure on engraving material with different frequency

As shown in Figure 4.20, at 40 kHz, 50 kHz, 60 kHz, 70 kHz and 80 kHz speed, the engraved fields showed parallel lines, meanwhile engraved part at 30 kHz frequency appeared only some grains. But there is a bit dark spot was detected in engraved fields with 50 kHz and 80 kHz frequency due to higher laser power and higher loop counts. The colour was yellowish as the frequency were increased.

The microstructures of the engraved parts that produce the most noticeable colours are seen. When the samples were observed under the microscope, it was discovered that the microstructure was changed as a result of technological parameters such as the pulse rate, engraving speed, number of repeats, and engraving power, among others. The impact of rising the structure's pulse frequency is more easily translated into a laser beam as the frequency of the structure's pulses increases. The structure of the engraving did not affect much as the engraving speed was increased. But when the number of laser power is increased, the thermal effect induced by the re-melting of the structure by the laser beam becomes more visible and noticeable. However, for the same laser energy density, a change in laser power has a greater impact on pore defect than a change in laser speed. Increased laser scanning speed enhances the change of planar crystals to dendrites while also refining the grains. According to (Kang, 2019), laser power has a greater impact on mechanical properties, which corresponds to its greater impact on pore defect. Thus, it is preferable to increase laser power and scanning speed in order to get a lower pore defect count, a larger melt pool, and improved mechanical characteristics and efficiency.

#### **CHAPTER 5**

#### **CONCLUSION AND RECOMMENDATION**

This chapter summarised the findings and conclusions of this research, and recommendations for further study. This research examined the pattern quality produced by the laser engraving procedure on stainless steel. The engraving parameters of laser power, laser speed, and frequency were varied to determine their effect on the surface roughness and microstructure responses. The experimentation on stainless steel proved successful. The section on conclusion includes an overview of the research and a summary of the findings. The recommendation section contains suggestions for future research and development of this project.

#### 5.1 Conclusion

The purpose of this project is to analyse pattern quality when laser engraving illustration on stainless steel. According to the objectives stated earlier in the introduction section, the purpose of this research is to develop a illustration using a Master Oscillator Power Amplifier (MOPA) Fiber Laser on stainless steel. ImagR was used in this experiment. It is so much easier to use the website to editing the illustration. This website possible to process images online with ImagR, which is software for laser engraving. It is equipped with an auto-adjust feature. When a user initially uploads an image to the website, it automatically converts to greyscale. From there, the user can crop the image and resize it to the desired dimensions, all while maintaining a DPI of 254. Once the image has been resized, may either manually modify the brightness, contrast, sharpening, and other settings, or use the auto button.

Next, objective in this research is to evaluate the effect of laser engraving parameters, such as the speed, frequency and power used to run the laser engrave machine during the process, on the pattern quality of stainless steel patterns. A combination of parameters such as frequency, power, speed and loop count were found to be important in achieving the greatest colour outcome for laser engraving on stainless steel, as demonstrated by this experiment. A low speed combined with the best possible number for frequency and power will have a major impact since no burn marks will appear and a golden-brownish colour will be achieved.

The following purpose is to investigate the influence of laser engraving on the structural and microstructural changes in stainless steel for each material portion that has been engraved with a different parameter. Increased laser speed and frequency, as well as the use of the highest possible laser power, have a substantial impact on the roughness of the material. Higher laser speeds and frequencies, when compared to lesser laser speeds and frequencies, may result in a smoother surface roughness on the specimen surface. The use of optimal laser power combined with greater speed and frequency results in improved surface roughness since the burning does not leave burn marks or corrosion.

#### 5.2 Recommendation

Recommended recommendations for future research include the following:

1) For further research, consider adjusting other engraving parameters such as laser frequency, engraving speed, laser power and loop count to another range of value.

2) Consider using materials in the experiment as samples, such as galvanized steel, and titanium.

3) Carrying out additional tests to assess burn mark accuracy, such as engraving depth measurement, corrosion observation, and hardness testing.



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# APPENDICES

ACTIVITIES		Degree project - PSM 1														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Selecting a topic and	Ρ															
research planning	Α															
Understanding Topic	Р															
- Background																
- Problem Statement																
- Objectives	Α															
- Scopes																
Literature Review	Ρ															
Literature neview	Α															
Research	P Y S / ,															
wiethodology	Α	1														
Panart cubricsian	Ρ		7													
Report submission	Α		A.						-							
P. I.I.F.	Ρ								-							
Presentation	Α											1				
P=Planning						-										

# APPENDIX A Gantt Chart.

A=Actual

1.1.1		1		1			1									
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		Degree project - PSM 2														
	er	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Conducting the	Р			214	ITU		1417	1.		o De			.Au	54		
experiment	Α															
Data collection	Р															
	A															
Analysing Data and	Р															
Result	Α															
Report Writing	Р															
	Α															
Report submission	Ρ															
Report submission	Α															
Presentation	Ρ															
Presentation	Α															

P=Planning

A=Actual



# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

# TAJUK: PATTERN QUALITY ANALYSIS WHEN LASER ENGRAVING ILLUSTRATION ON STAINLESS STEEL

SESI PENGAJIAN: 2020/21 Semester 1

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