

# ASSESSMENT OF SURFACE MORPHOLOGY OF LASER ENGRAVED STAINLESS STEEL



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

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# Faculty of Mechanical and Manufacturing Engineering Technology



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

2022

#### ASSESSMENT OF SURFACE MORPHOLOGY OF LASER ENGRAVED STAINLESS STEEL

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### UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

#### **DECLARATION**

I declare that this Choose an item. entitled "Assessment of Surface Morphology of Laser Engraved 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.

Signature : ..... Supervisor Name Prof. Madya Ir Dr. Mohd Hadzley Bin Abu Bakar Date 22 Februari 2023 TEKNIKAL MALAYSIA MELAKA UNIVERSITI

#### 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. Laser machines are spesifically designed for engraving on different types of materials, cutting, ethcing, and marking. The parameters in this process play a significant role as the parameters changed, the output changes. The current research will be concentrating on analysing the line pattern surface when laser engraving on stainless steel with the goal of finding the best parameter. According to the results of this experiment, the effect of surface 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 line. To begin, the software packages ImagR and EzCad will be utilised to generate a specified line. 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 best parameter on stainless steel for laser engraving line. 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 parameter. Its purpose is to determine how laser parameters influenced the structural and metallurgical characteristics of stainless steel. It is also useful for analysing the microstructure of the heat affected zone, which is where the material has been damaged by laser heat during the engraving process. A high speed combined with the best feasible number for looping count and speed will have a significant influence. In the following step, a microstructure observations of a stainless steel that has been engraved using a Electronic Microscopic digital USB will be performed. Microstructure observations of engraved lines in stainless steel resulting in information about the material's response to the laser engraving process. Graining size, microhardness, heat impacted zone, and phase transitions are among the observations recorded during microstructure study of engraved stainless steel. SIII TEKNIKAL MALAYSIA ME

#### ABSTRAK

Dalam beberapa tahun kebelakangan ini, ukiran laser telah meningkat sebagai salah satu teknologi yang paling menjanjikan untuk ukiran atau penjenamaan objek. Mesin laser direka khusus untuk mengukir pada pelbagai jenis bahan, pemotongan, pengikisan dan penandaan. Parameter dalam proses ini memainkan peranan penting kerana parameter berubah, output berubah. Penyelidikan semasa akan menumpukan pada menganalisis permukaan corak garisan apabila ukiran laser pada keluli tahan karat dengan matlamat mencari parameter terbaik. Mengikut keputusan eksperimen ini, kesan mikrostruktur permukaan akan dinilai menggunakan parameter asas ukiran laser, iaitu kuasa laser, kelajuan laser, frekuensi laser, dan bilangan gelung dalam garisan ukiran. Untuk memulakan, pakej perisian ImagR dan EzCad akan digunakan untuk menjana talian tertentu. Ini dicapai dengan mengukir bahan kerja keluli tahan karat menggunakan Master Oscillator Power Amplifier (MOPA) Fiber Laser menggunakan gabungan tetapan tertentu untuk mencapai parameter terbaik pada keluli tahan karat untuk garis ukiran laser. Siasatan terhadap hubungan antara ukiran laser pada keluli tahan karat dan campuran faktor mendedahkan bahawa gabungan parameter, termasuk kekerapan, kuasa, kelajuan dan kiraan gelung, adalah kritikal dalam mendapatkan parameter terbaik. Tujuannya adalah untuk menentukan bagaimana parameter laser mempengaruhi ciri-ciri struktur dan metalurgi keluli tahan karat. Ia juga berguna untuk menganalisis struktur mikro zon terjejas haba, yang mana bahan telah rosak oleh haba laser semasa proses ukiran. Kelajuan tinggi digabungkan dengan nombor terbaik yang boleh dilaksanakan untuk kiraan dan kelajuan gelung akan mempunyai pengaruh yang ketara. Dalam langkah berikut, pemerhatian struktur mikro keluli tahan karat yang telah diukir menggunakan USB digital Mikroskopik Electonic akan dilakukan. Pemerhatian struktur mikro garis terukir dalam keluli tahan karat boleh menawarkan maklumat tentang tindak balas bahan terhadap proses ukiran laser. Saiz butiran, kekerasan mikro, zon kesan haba, dan peralihan fasa adalah antara pemerhatian yang direkodkan semasa kajian struktur mikro keluli tahan karat terukir.

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# TABLE OF CONTENTS

		PAGE
DEC	CLARATION	
APP	ROVAL	
DED	DICATION	
ABS	TRACT	i
ABS	TRAK	ii
ACK	KNOWLEDGEMENTS	iii
ТАВ	BLE OF CONTENTS	iv
LIST	C OF TABLES	vi
LIST	T OF FIGURES	vii
T ICT	TOF SYMBOLS AND ADDEVIATIONS	VII 
<b>L19</b>	T OF STRIBULS AND ADDREVIATIONS	Х
LIST	T OF APPENDICES	xi
<b>CHA</b> 1.1 1.3 1.4	APTER 1 Background Research Objective Scope of Research TI TEKNIKAL MALAYSIA MELAKA	<b>12</b> 12 15 16
CHA	APTER 2 LITERATURE REVIEW	17
2.1	Introduction	17
2.2	Process of Laser Engraving	19
2.3	Types of Laser Engraving Applications	22
	2.3.1 Awards and Trophes	22
	2.3.2 Decorative or Commemorative Annotations	23
	2.3.5 Decorative of Commentorative Annotations	24
	2.3.4 Weddear and Electronic Components 2.3.5 Signage	25 26
2.4	Type of Laser	26 26
	2.4.1 Fiber Laser	26
	2.4.2 Master Oscillator Power Amplifier (MOPA) Laser	28
	2.4.3 CO2 Laser	30
	2.4.4 Ultraviolet (UV) Laser	31
	2.4.5 Neodymium yttrium-aluminum-garnet (Nd-YAG) Laser	33
2.5	Parameters of Laser Engrave	34
	2.5.1 Laser Power	34
	2.5.2 Laser Frequency	35

	2.5.3 Laser Speed	36	
	2.5.4 Loop Count	37	
2.6	Material	38	
	2.6.1 Introduction	38	
	2.6.2 Properties of Stainless Steel	38	
	2.6.3 Grade and Applications of Stainless Steel	40	
	2.6.4 Stainless Steel Engraving	41	
СНАЕ	PTER 3 METHODOLOGY	43	
3.1	Introduction	43	
3.2	Project Planning	44	
3.3 Selection of Material. Machine and Software			
	3.3.1 Type of Material	46	
	3.3.2 Type of Machine	47	
	3.3.3 Type of Software	48	
3.4	Identification of Engraving Parameters	50	
3.5	Surface Roughness Test	51	
3.6	Microstructure of Specimen	52	
3.7	Preliminary Findings	52	
	3.7.1 Expected Results	52	
3.8	Summary	55	
CILAT		= /	
		56	
4.1	Trial State	56	
4.2	Inal Study	50	
4.3	4.2.1 Jesus Sneed Test	38 59	
	4.5.1 Laser Speed Test	38 61	
	4.5.2 Laser Loop Could Test	01 62	
1 1	4.5.5 Laser wobble Diameter Test L MALAT 3TA MELAKA	65	
4.4	A 1 Result of Microscopic Observation Laser Speed	0J 66	
	4.4.2 Result of Microscopic Observation Laser Loon Count	70	
	4.4.3 Result of Microscopic Observation Laser Wohlle Diameter	70	
	4 4 4 Microscopic Observation	79 79	
CHAF	PTER 5	80	
5.1	CONCLUSION	80	
5.2	RECOMMENDATION	81	
REFE	RENCES	82	
APPE	NDICES	84	

## LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	Advantages and Disadvantages of Stainless-Steel Laser Engraving	42
Table 3.1	Mechanical Properties of Stainless Steel	46
Table 3.2	Engraving Parameters	50
Table 3.3	Recommended Constant Parameter for Laser Engraving	50
Table 3.4	Surface profile of engraved stainless steel with corresponding surfa	ce
	roughness AYSIA	53
Table 4.1	Laser Speed result	59
Table 4.2	Laser Speed result	62
Table 4.3	Laser Wobble Diameter result	64
	اونيۆم سيتي تيڪنيڪل مليسيا ملاك	
	UNIVERSITI TEKNIKAL MALAYSIA MELAKA	

## LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 1.1	Schematic Laser Engraving System (Deka et al., 2013)	13
Figure 2.1	Laser Engraving Machine	17
Figure 2.2	The Laser Engrave Table in 1981 (History Part 5, n.d.)	18
Figure 2.3	Laser Engraving Illustrations (Laser Engraving Technology)	19
Figure 2.4	Schematic diagram of the Two-dimensional laser engrave system	
	(D. Wang et al, 2015)	20
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.	20
Figure 2.6	Unique laser engraving method on stainless steel marking.	21
Figure 2.7	Laser Engraving on awards and trophies	22
Figure 2.8	Barcode laser engraving IKAL MALAYSIA MELAKA	23
Figure 2.9	QR code laser engraving	23
Figure 2.1	0 Laser Engraving on jewelry	24
Figure 2.11	1 Laser Engraving on Steel wedding ring.	24
Figure 2.12	2 Laser Engraved on Medical equipment.	25
Figure 2.1.	3 Laser Marking Metal for Medical applications.	25
Figure 2.14	4 Stand signage stainless steel with laser engraved	26
Figure 2.1	5 Mechanism of Fiber Laser	27
Figure 2.1	6 Schematic Diagram of MOPA Laser set up (Y. Wang et al., 2018)	28
Figure 2.17	7 Structure of Master Oscillator Power Amplifier (MOPA) Laser	29

Figure 2.18 Marking colour on stainless steel by MOPA	29
Figure 2.19 CO2 Schematic diagram	30
Figure 2.20 Types of UV Laser Marking Machines	32
Figure 2.21 Light absorption rate for metal using UV marking (UV Laser	
Marking   Laser Marking Basics   KEYENCE Malaysia, 2018)	32
Figure 2.22 Mechanism Nd-YAG Laser (Nd:YAG Laser – Definition,	
Construction and Working, n.d.)	33
Figure 2.23 Laser Power vs Depth over time	34
Figure 2.24 Effect of frequency vs speed on laser marking	35
Figure 2.25 Reference chart speed vs power of laser engrave (Gradient	
Reference for the 25-watt laser cutter   Milwaukee Makerspace, n.d.)	36
Figure 2.26 Common types of Stainless-Steel Application	40
Figure 2.27 Example of engraving test on stainless steel	41
Figure 3.1 Flowchart for Bachelor Degree Project PSM1 and PSM 2	45
Figure 3.2 Master Oscillator Power Amplifier (MOPA) Fiber Laser in UTeM.	47
Figure 3.3 ImagR Software	48
Figure 3.4 EzCAD2.76 Software	49
Figure 3.5 Adobe Illustrator Software	49
Figure 3.6 Mitutoyo Surftest SJ-301 Stylus Profilometer Instrument	51
Figure 3.7 Digital Microscope	52
Figure 3.8 Surface roughness of engraved stainless steel	54
Figure 3.9 Laser marking surface appearance with the best parameters on	
stainless steel	55
Figure 4.1 Material Size	57

Figure 4.2 Engraving Test on Stainless Steel	
Figure 4.3 Laser Engraving Result with different speed	58
Figure 4.4 Laser Engraved result with different loop count	61
Figure 4.5 Laser Engraved result with different wobble diameter	63
Figure 4.6 Equipment of Microscopic Observation	65
Figure 4.7 Microscopic Observation on engraved material	65



# LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
MOPA	-	Master Oscillator Power Amplifier
CO2	-	Carbon Dioxide
Nd: YAG	-	Neodymium-doped Yttrium Aluminium Garnet
mm	-	milimitre
kHz	-	kilohertz
GPa	-	gigapascal
MPa	-	Megapascal
W	MAL	watt
mm/s	7-	Milimitre / second
°C	-	celcius 💈
μm	-	micrometre
SiC	3-	silicone carbide SiC
Al2Si2O5(OH)	- In	potassium
ZrO2	ا مالا	اونيومرسيتي تيڪنيڪل zirconia
		18

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# LIST OF APPENDICES

APPENDIX	TITLE	PAGE
APPENDIX A Gantt Chart of PSM1.		84
APPENDIX B Gantt Chart of PSM2.		84



#### **CHAPTER 1**

#### **INTRODUCTION**

#### 1.1 Background

In recent decades, lasers have become increasingly popular for cutting and welding tasks. By introducing laser sources with shorter and shorter pulses ranging from nanosecond to femtosecond, this approach has recently been used in different industrial processes such as marking, selective removal, and processing of various materials. Engraving is a method of creating product identifiers such as time stamps, component labels, and barcode tagging. Tin marking, mechanical engraving, and electrochemical engraving are just a few examples of engraving methods.

Laser engraving is a subtractive manufacturing process that involves changing the surface of an object with a laser beam. This method is mostly used to create images that are **UNVERSITIEKNIKAL MALAYSAMELAKA** displayed at eye level on the material. The laser produces a lot of heat, which causes the substance to spray and show the holes that make up the final image. The laser is used to mark the surface of a metal workpiece. According to (Haron & Romlay, 2019), the working concept of laser engraving is based on vaporisation, in which the contact of a laser system with a material through a focusing lens (convex lens) results in the vaporisation and melting of the materials employed in the operation. It's also a great example of how a fundamental theoretical concept can persist until a technology application is rediscovered. As a result, material is removed from the workpiece in layers by an ablation mechanism.

(Mehta et al., 2015) found that laser engraving has various advantages over other engraving methods because it does not require the use of inks or tool bits. Also, the primary advantages of laser engraving include non-contact working, which reduces the rate of product damage, high precision, faster scanning speed, and great flexibility and automation.



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

#### **1.2 Problem statement**

Laser engraving is a common technology that can engrave almost any material that can't be engraved with older methods. The laser engraving process is enabled by the heat-up mechanism that vaporises the material surface. In recent years, the laser process has become one of the most widely recognised technologies. Fiber Engraving Lasers are extensively employed in a variety of applications, including the electronic industry. Despite this, a laser engrave technique using a Master Oscillator Power Amplifier (MOPA) Fiber Laser is still fairly rare in Malaysia's market due to distinct specific needs, and this technology is much more expensive than fibre engraving laser.

Because of its corrosion resistance, durability, temperature resistance, and high specific strength, stainless steel is widely employed in industrial applications. It is well-known for its ductility, traceability, corrosion resistance, thermal conductivity, and electrical conductivity. As a result, metal material parameters such as laser power, beam speed, and frequency should be measured in relation to the mechanical properties of the material itself, in order to aid in the reduction of overburning materials during the engraving process, while at the same time determining the best combination of parameters to produce laser engrave colour when laser engraving illustration.

Due to various advantages such as non-contact, no cutting force, and a small area of heat effect, laser engraving is commonly utilised for a variety of metals. However, there are several drawbacks to laser engraving, such as very poor ablation surface roughness and a certain number of microcracks on the surface, which have a significant impact on treatment quality. As a result, basic laser parameters such as laser power, laser speed, and laser frequency values must be evaluated so that they can be applied to a stainless-steel workpiece to generate high-quality products.

## **1.3** Research Objective

The general purpose of this research is to analyze the effect of laser engraving parameters on a microscopic 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 straight line engraving using a Master Oscillator Power Amplifier (MOPA) Fiber Laser on stainless steel.
- b) To evaluate the effect of the process laser parameter on the surface of the stainless steel.

c) To analyze the microscopic observations of stainless steel when undergo laser engraving.

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#### **1.4** Scope of Research

The scope of this research is to create a design utilising laser engraving on a metal workpiece. The next step is to assess the impact of laser engraving parameters on stainless steel pattern quality, such as the speed, frequency, and power of the laser engrave equipment used during the procedure. Finally, a study of the impact of laser engraving on structural and microstructural alterations in stainless steel. The experiments were carried out in the Manufacturing Laboratory of Universiti Teknikal Malaysia Melaka's Faculty of Manufacturing Engineering (UTeM). The following are the research areas:

- Testing or measuring of the materials used in this experiment is in the little and low depth.
- Adjust laser engrave machine's differences parameter.

ale

• Study structural and microstructure changing characteristics of the plate at the conclusions of the experiment.

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#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1 Introduction

"Laser" is a term for "light amplification by stimulated emission of radiation." A laser is a process that causes atoms or molecules to emit light at specific wavelengths, which is then amplified to produce a very tiny beam of radiation. The emission covers a very narrow wavelength range of visible, infrared, and ultraviolet wavelengths. As technology evolved, lasers were able to mark or engrave materials, allowing them to make barcodes, serial numbers, 2D codes, UDI codes, labels, patterns, and more. In the 1970s, Bill Lawson of LMI began working with the potential and capabilities of laser engraving in order to develop then computerized engraving machines. Lawson's approach, which includes scanned black and white artwork, information, or designs, engraving either the white or black component, depending on user option, significantly improved the finished product. (Lin et al.,2008)



Figure 2.1 Laser Engraving Machine

Laser Engraving, also known as Laser Etching, is a process that includes using a laser beam to change the surface of an object. This approach is mostly used to generate eye-level representations of content. To perform this, the laser generates a high level of heat, which vaporizes the matter, revealing cavities that will be used to create the final image. A laser is used to mark the surface of an object. The CO2 laser, which generates long-wave infrared light by combining carbon dioxide and other gases, is now the most popular laser used among engravers. CO2 lasers are useful for engraving and cutting heat or electrical conductors such as glass and ceramics. Another common type of laser is the YAG laser. The device allows use of a Yttrium Aluminum Grenet and tiny amounts of light from the uncommon element neodymium. YAG lasers are well-suited for graving both metal and nonmetal materials, and they work well with tough stainless-steel grades.



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

#### 2.2 Process of Laser Engraving

Laser engraving is a technique that employs a high-powered laser to physically remove a layer of material, leaving a hollow with an image. Aside from that, laser engraving is a means of converting items into fumes by vaporising them. The laser beam acts as a chisel, incising marks by removing layers from the surface of the material. To generate the high heat required for vaporisation, the laser must deliver massive amounts of energy to particular regions. While laser engraving melts the surface of the material to change its roughness, laser graving sublimates the surface of this substance to create depth gaps. This means that the surface absorbs enough energy quickly to transition from solid to gas without ever becoming liquid. In order to achieve sublimation, the laser graving system must generate enough energy to ensure that the material's surface reaches its vaporising temperature in milliseconds. Laser engravers are formidable tools given the high sublimation temperatures. When the temperature reaches the optimal vaporisation temperature, the materials evaporate into vapours.(Agalianos et al., 2011)



Figure 2.3 Laser Engraving Illustrations (Laser Engraving Technology)



Figure 2.4 Schematic diagram of the Two-dimensional laser engrave system (D. Wang et al, 2015)



**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.

According to (Patel et al., 2015), laser engraving is the process of engraving or marking an object with a laser. Laser engraving is the removal of material from the top surface to a specific depth. In contrast to laser marking, laser engraving is the process of using laser marking to engrave an item. Laser branding, on the other hand, simply discolours the surface without cutting through it. It does not involve the use of inks or tool bits that touch and wear out the engraving surface.



Figure 2.6 Unique laser engraving method on stainless steel marking.

#### 2.3 Types of Laser Engraving Applications

#### 2.3.1 Awards and Trophies



Figure 2.7 Laser Engraving on awards and trophies

Laser engraving is one of the most versatile and easily accessible types of marking available. Laser engraving produces clean, readable engravings straight onto a surface. This property makes engraving preferable to painting, staining, or embossing. Most award and trophy manufactures use laser engraving on a variety of materials, including glass, metal, and wood. Furthermore, other types of laser engraving can cut shapes into durable rubber to make unique stamps. These stamps are ideal for use on award certificates, mass signatures, letterheads, and other decorative markings.

#### **2.3.2 Barcode Creation**

From regular weekly grocery to industrial equipment components, we see a lot of goods with barcodes. The majority of barcodes that we come across are simply printed on paper or straight onto the item. Users may cut barcodes directly into these orders to avoid future problems with adhesive-resistant surfaces, excessively large items, or heavy duty use that would wear down a regular barcode. Other than that, users also can cut QR codes, unique identification markers, or similar markings onto these things in addition to barcodes made up of many lines of varying weights.



UNIVERSFigure 2.8 Barcode laser engraving MELAKA



Figure 2.9 QR code laser engraving

#### 2.3.3 Decorative or Commemorative Annotations

Laser engraving also can make a personalize present with a decorative or commemorative annotation. Users can choose to laser engrave fine jewelry or timepieces, glassware or table settings, and party favors such as keychains or bottle openers. These engravings personalize otherwise mundane gifts.



Figure 2.11 Laser Engraving on Steel wedding ring.

#### 2.3.4 Medical and Electronic Components

Medical and technological parts demand quick and accurate identification, especially in high-stress situations. Many manufacturers choose to label these items with laser engraving to ensure that they remain identifiable. The reasons for marking these components by laser engraving include easy legibility, especially at small sizes, text that will not rub off, and simple mass marking. Laser engraving on medical and technical components, particularly small or sensitive parts, is frequently shallower than on other items.



Figure 2.13 Laser Marking Metal for Medical applications.

#### 2.3.5 Signage

The most typical application of laser engraving is in long-lasting signs. There are numerous advantages to engraving maps, directions, and other sign items rather of painting or printing them. Some places prefer engraving to other techniques of signage because it is more permanent, even in tough circumstances where the sign may become damp or worn. It is also importantly good in increasing legibility due to the depth of the letters and quick manufacture, which is important in temporary construction regions and other comparable places.



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA Figure 2.14** Stand signage stainless steel with laser engraved

#### 2.4 Type of Laser

#### 2.4.1 Fiber Laser

Fiber laser marking machines are among the most advanced and commonly used laser marking systems available today. It is very versatile, requires little maintenance, and produces no consumables. The fibre laser marker is widely used for accurate and efficient marking, notably in the metal and plastic processing industries. A fibre laser marking machine is a type of laser marker that is used to mark letters, numbers, and designs on various materials. A fibre laser marking machine is often referred to as a fibre laser marker. Laser marking is the method of permanently marking the surface of various materials with laser beams. (Genna et al., 2015)

The idea behind laser marking is to expose the deep material by evaporating the surface material, engrave traces by modifying the chemical and physical properties of the surface material with light energy, or burn away part of the material with light energy to reveal the desired marks. Fiber laser marking equipment are typically employed when greater precision and accuracy are required.(Haron & Romlay, 2019)



Figure 2.15 Mechanism of Fiber Laser

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

Master Oscillator Power Amplifier (MOPA) lasers are good for making black lines on naturally and coloured anodized aluminium without harming the paint. They are frequently used to make high-contrast marks on other metals such as nickel alloys, steels, and titanium. For example, a MOPA laser may produce a wide range of reproducible annealing colours on stainless steel. MOPA lasers also provide advantages in terms of label lifetime during reprocessing. With the flexibility to adjust the laser parameters flexibly, highquality markings that are resistant to several passivation and sterilising processes can be achieved. The MOPA laser contains all of the components of a fiberlaser source. MOPA has significantly improved the pulse width, frequency, control waveform, and other laser upgrade properties. The MOPA laser can colour a specified black, black aluminium oxide surface in stainless steel. As a result, the MOPA laser is frequently used to brand pharmaceutical items.



Figure 2.16 Schematic Diagram of MOPA Laser set up (Y. Wang et al., 2018)



Figure 2.18 Marking colour on stainless steel by MOPA



Figure 2.19 CO2 Schematic diagram

Kumar Patel discovered the carbon dioxide laser (the CO2 laser) in the United States in 1964. The CO2 laser is one of the most powerful and efficient lasers on the market today, and it may be used in a variety of medical, surgical, industrial, and military applications. According to (Yong Zhang and Tim Killeen, 2016), carbon dioxide lasers might provide power rates ranging from milliwatts to tens of kilowatts, making them suited for instrumentation or severe cutting. Because CO2 lasers are extremely spectrally pure and have a radiated line width of less than 1 kHz without sacrificing power, conversion efficiencies of 10% are possible. These defining characteristics enable CO2 lasers to address additional applications in the fields of material treatment, light sensing, and rangement.
#### 2.4.4 Ultraviolet (UV) Laser

The ultraviolet spectrum has wavelengths ranging from 10 nm to 400 nm. They have a shorter wavelength than visible light but a greater wavelength than X-rays. Longwavelength UV light is not considered ionising since its particles lack the energy to ionise atoms. It may, however, cause chemical reactions that yield bright or fluorescent substances. As a result, UV's chemical and biological effects go far beyond simple heating, and its interactions with organic molecules allow for a wide range of practical applications. Gas lasers, solid state lasers, and diodes can be used to construct tools that generate ultraviolet photons, as well as lasers that cover the entire UV spectrum, which are now accessible (Penide et al, 2015)

UV lasers have a 355 nm shorter wavelength than standard lasers (1064 nm). Because of their high absorption rate, these lasers are referred to as "UV laser markers" because of their ultraviolet wavelength. "Cold Marking" refers to how these lasers can mark and treat materials with minimal thermal damage. UV laser marking is appropriate for high-contrast, low-product-damage applications. UV lasers are third-harmonic generation (THG) lasers, with a wavelength one-third that of normal lasers. When a 1064-nm laser is sent through a non-linear crystal, its wavelength is reduced to 532 nm. The wavelength is reduced to 355nm by another crystal.

When marking with UV lasers, high absorption rates can be obtained even with highly reflecting materials such as gold, silver, and copper. This helps to guarantee that only minor heat damage occurs. This not only minimises the amount of soot and burrs on the surface, but it also avoids any surface damage, allowing you to label and process the material in a corrosion-resistant manner.



Figure 2.20 Types of UV Laser Marking Machines



**Figure 2.21** Light absorption rate for metal using UV marking (UV Laser Marking | Laser Marking Basics | KEYENCE Malaysia, 2018)

#### 2.4.5 Neodymium yttrium-aluminum-garnet (Nd-YAG) Laser

A solid-state laser that uses Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) as a laser medium is known as a Nd: YAG laser. These lasers have numerous applications in medicine and science, including lasik surgery and laser spectroscopy. The Nd: YAG laser is a four-level laser, which implies that it operates at all four energy levels. These lasers can operate in both pulsed and continuous modes. Nd: YAG lasers typically emit laser light at 1064 nanometers in the near-infrared part of the spectrum (nm). It also absorbs laser light with several wavelengths, including 1440 nm, 1320 nm, 1120 nm, and 940 nm (Lee et al., 2015).



**Figure 2.22** Mechanism Nd-YAG Laser (Nd:YAG Laser – Definition, Construction and Working, n.d.)

#### 2.5 Parameters of Laser Engrave

#### 2.5.1 Laser Power

The laser power must be chosen based on the procedures. A laser output of at least 50 watts is recommended for metal laser cutting or engraving. For direct laser marking metals, fibre laser power of 40 or 50 Watt can be used. Metals should be marked directly with 25 to 150 watts of CO2 laser power. The power of the Fiber laser beam can be lowered so that a specific depth can be erased or etched. Several laser gravure passes are usually happened when operating. Metal laser engraving typically has a depth of 0.003 to 0.005." (75 to 125 microns). The removal of this huge amount of metal may result in melting or distortion in a single pass. Metal engraving is typically done in multiple passes. The laser engraving method produces permanent engravings that cannot be removed by heat or wear. This determines the laser's power percentage. Speed and power are frequently a trade-off. If the mark is too strong at full power, start raising speed before decreasing power to see if cycle times may be improved.



Figure 2.23 Laser Power vs Depth over time

#### 2.5.2 Laser Frequency

The frequency (Hz) characteristic is used to identify the laser pulses per second' Q-Switch frequency during marking. This frequency trend produces a variety of marking effects. This parameter is used to directly modify the laser output frequency via the Q-switch. The Q-Switch is an optical electric device that controls the opacity of the lens and allows the user to change the frequency of the laser beam. A lower frequency results in "spotted" gravure, whereas a higher frequency allows for "line" gravure. Frequency is inversely proportional to laser beam power, therefore if the frequency is too high, the marking process will be inefficient. A Q-switch is connected to a shutter sluice, which closes and disconnects the laser beam.



Figure 2.24 Effect of frequency vs speed on laser marking

#### 2.5.3 Laser Speed

The laser head's movement is determined by the laser parameter speed. Slower speeds result in longer exposure durations, while faster speeds result in shorter exposure times. For example, large-scale engravings of materials etched at high speed between 50 and 100 percent should not exceed 10 percent for pictures with intricate wood grain. This decision is also influenced by the quality of the laser cut. By designating the object with a speed in millimeters per second, the speed attribute indicates that the laser beam is moving. When the speed is too high, the laser beam has no effect on the material that it marks; when the speed is too low, the laser beam has no effect on the material that it marks. While marking an object, the Speed attribute specifies the vector speed of the laser beam in millimeters per second. A slow pace results in a deep, well-defined mark, yet a fast speed renders the laser beam ineffectual on the material being marked.



Figure 2.25 Reference chart speed vs power of laser engrave (Gradient Reference for the 25-watt laser cutter | Milwaukee Makerspace, n.d.)

#### 2.5.4 Loop Count

The number of times a material is processed using a parameter combination of laser power, laser speed, and laser frequency is referred to as the loop count (Barrimi et al., 2013). The loop count defines how many times the laser will pass over the mark on the workpiece. The depth of the marking will increase as the number of loops increases. According to (Patel et al., 2015), the mark depth, width, and contrast were all measured in proportion to the pulse frequency. The mark depth reaches its maximum at roughly 3 kHz, whereas the mark depth remains virtually constant at different pulse frequencies. As the pulse frequency increases, material evaporation and oxidation decrease, resulting in better mark contrast. Maximum mark contrast was observed when the laser pulse frequency was around 8 KHz.



#### 2.6 Material

#### 2.6.1 Introduction

Stainless steels contain at least 10.5 percent chromium. A thin, tenacious surface layer of chromium oxide provides corrosion resistance. If the oxide layer is physically damaged, the layer regenerates quickly, sustaining corrosion resistance. However, a chemical environment that disrupts this layer might cause corrosion. As a result, while stainless steel is highly resistant to atmospheric corrosion, it is not impervious to corrosion in all situations. Stainless steels are classified into five types: austenitic, ferritic, martensitic, duplex, and precipitation hardened. The primary difference between each class is determined by the predominant phase present in the stainless steel as defined by the key alloying elements.

#### 2.6.2 Properties of Stainless Steel

Chromium and nickel are the most common alloying components in stainless steels. Chromium is generally used to offer corrosion resistance and strength. Nickel adds strength as well as some corrosion resistance. Manganese, carbon, and molybdenum are minor alloying elements. Manganese is found in minor amounts in steels, but at larger concentrations it stabilizes austenite and partially replaces nickel in 200-series steels. Carbon is primarily an impurity in austenitic steel, but it also serves as a strengthening ingredient in ferritic and martensitic steel, as it does in carbon and low-alloy steel. Molybdenum increases strength and resistance to chloride pitting. Different elements, like as titanium or niobium, fulfil other functions particular to the alloy's application.(Kučera et al., 2014)

#### 2.6.2.1 Austenitic Steel

Austenitic steel includes 16 to 26% chromium and up to 35% nickel, have the best corrosion resistance. They are nonmagnetic and cannot be hardened by heat treatment. The most popular is the 18/8, or 304, grade, which is composed of 18% chromium and 8% nickel. Aircraft, dairy, and food-processing sectors are examples of typical applications.

#### 2.6.2.2 Ferritic Steel

Standard ferritic steels are nickel-free and contain 10.5 to 27 percent chromium; due to their low carbon content (less than 0.2 percent), they are not heat harden able and have less significant anticorrosion uses, such as architectural and auto trim.

#### 2.6.2.3 Martensitic Steel

Martensitic steels typically include 11.5 to 18% chromium and up to 1.2 percent carbon, with nickel added occasionally. They are heat harden able, have a low corrosion resistance, and are used in cutlery, surgical tools, wrenches, and turbines.

## 2.6.2.4 Duplex Steel

Duplex stainless steels are an equal mix of austenitic and ferritic stainless steels, they contain 21 to 27 percent chromium, 1.35 to 8% nickel, 0.05 to 3% copper, and 0.05 to 5% molybdenum. Duplex stainless steels are stronger and more corrosion resistant than austenitic and ferritic stainless steels, making them helpful in storage tank construction, chemical processing, and chemical transport containers.

#### 2.6.2.5 Precipitation Hardened Steel

The strength of precipitation-hardening stainless steel is due to the addition of aluminum, copper, and niobium to the alloy in amounts less than 0.5 percent of the alloy's total mass. It has corrosion resistance comparable to austenitic stainless steel and contains 15 to 17.5 percent chromium, 3 to 5 percent nickel, and 3 to 5 percent copper. Long shafts are built with precipitation-hardening stainless steel.

#### 2.6.3 Grade and Applications of Stainless Steel

There are numerous optimization grading systems for stainless steel, which are classified based on their composition, physical qualities, and applications. Each type of stainless steel is allocated a numerical grade after being categorized by its series number. 200, 300, 400, 600, and 2000 are the most popular series numbers. The most popular grades are 304 and 316, which are austenitic chromium-nickel alloys. The 400 Series, which is formed from ferritic and martensitic chromium alloys, contains cutlery grade stainless steels. Surgical steel is known as type 420, and razor blade steel is known as type 440.

		Common Stainless Steel Applications
Stainless Steel Alloy	Classification	Typical Applications
430	Ferritic	Used for moderately corrosive applications involving vegetables, fruits, and dry foods. Ideal for table surfaces, equipment trim, and places with little welding or forming.
420	Martensitic	Very durable; excellent corrosion resistance. Used for knife blades, spatulas, and other utensils.
316	Austenitic	Superior durability; ideal for food processing equipment and components. Can withstand corrosive foods and frequent cleaning and sanitizing.
304	Austenitic	Excellent corrosion resistance; often used for items requiring welding and forming, such as vats, bowls, and piping.
303	Austenitic	Less weldable but more machinable than 304. Good corrosion resistance; widely used in trim and other applications not intended for direct contact with food.
1.4539	Austenitic	Suitable for hot or cold corrosive foods that sit for long periods, such as brines and other salty liquids.
1.4462	Duplex	Stronger than 1.4539; ideal for same applications.
6% Molybdenum	Austenitic	Well suited for corrosive foods and high temperatures such as steam heating and hot work areas.

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Figure 2.26 Common types of Stainless-Steel Application

#### 2.6.4 Stainless Steel Engraving

Stainless steel is a metal that is widely used in a variety of sectors. Stainless steel has become indispensable in the composition of parts for medical, tooling, aeronautics, automotive, consumer goods, cutlery, jewelry, signage, and so on due to its anti-corrosive qualities. In addition to resistance to corrosion, stainless steel is also resistant to acid attack and can tolerate most cleaning and sterilization processes. It is a brilliant, long-lasting, and versatile substance. Stainless steel engraving is a procedure with a significant added value for identification and traceability applications, as well as personalization applications.



Figure 2.27 Example of engraving test on stainless steel

The black marking method locally warms the material to just below its melting point. This results in oxide layers on the workpiece's surface, which are connected with metallic annealing colors. It is also the recommended procedure when a precise fit is required or material bulging has to be avoided. Only metals that change color when exposed to heat and oxygen can be annealed, such as steels and titanium, but not aluminum or nonferrous metals. The oxide layer is typically black, although it can also be other annealing colors. Black marking is a marking technique that generates black, high-contrast markings. This structured surface reduces the amount of light reflected, resulting in a deep, matt blackening of the marking that appears the same from every angle. As a result, the marking is non-abrasive.

The parameterization of the laser is critical for obtaining a deep and high-contrast marking. Stainless steel laser engraving is typically done with a higher laser power, slower marking speeds, and multiple passes. Multiple laser beam passes will eliminate more material and result in cleaner engraving and edges. The increased number of laser passes enables deeper marking.

Advantages	Disadvantages
Laser marking methods produce a permanent on the stainless steel's surface	The surface of stainless-steel material may be removed. As a result, the
يىكل مليسىيا ملاك UNIVERSITI TEKNIKAL	anti-rust and anti-corrosive qualities will deteriorate.
Does not require application and cleanup like the marking compound	It has higher cost
Laser marking methods are precise and produce marking of high contrast.	

**Table 2.1** Advantages and Disadvantages of Stainless-Steel Laser Engraving

#### **CHAPTER 3**

#### METHODOLOGY

#### 3.1 Introduction

This chapter focuses on the proposed research approaches for the qualitative and quantitative effects of laser engraving parameters on surface microstructure and quality on stainless steel in a mixed method theoretical study. This methodology allowed for a thorough understanding of how the laser engraving characteristics of speed, power, and frequency affect the stainless-steel material. This chapter discusses the significance of grounded theory and a constructivist approach to it.

According to Sachin Patel (2015), laser engraving is the process of utilizing a laser to engrave or mark an object. Laser engraving is the process of removing material from the top surface to a specific depth. In contrast to laser marking, laser engraving is the process of using lasers to engrave an object. Laser branding, on the other hand, simply discolors the surface without cutting through it. It does not involve the use of inks or tool bits that touch and wear out the engraving surface.

In this study, laser engraving technology will be used to create a laser engraved metal workpiece. A specific pattern line will be generated using ImagR and EzCad Software. This product is then used as the primary input for the laser engraving process.

#### 3.2 **Project Planning**

Planning must be done correctly in order to identify all information and requirements such as hardware and software. Data collection and the application of hardware and software requirements are two significant components in the planning stage. The most important part of the planning process should be created before the procedure is completed in order to ensure that the project runs smoothly and easily. This planning strategy is critical in project management since it ensures that the project is completed on schedule. Process planning can also be conducted to ensure that the process is followed in a systematic manner.

The introduction, literature review, and methodology chapters are the focus of the first phase of the project in this study. At this stage, multiple viewpoints were gathered, including the issue description, benchmarks, scope, and project-related information. After that, all of the methods are applied to the project's second phase, which consists of three stages: doing the experiment with the Laser Engraving Machine, collecting data, and interpreting the data.

#### UNIVERSITI TEKNIKAL MALAYSIA MELAKA

This experiment was carried out in the Manufacturing Laboratory of the Faculty of Manufacturing Engineering at Universiti Teknologi Malaysia Melaka (UTeM) in order to gain more knowledge and documentation about stainless steel laser engraving using a MOPA fibre laser engrave equipment. In this study, the speed, power, and loop count of the laser machine were examined in order to obtain good 2D models on stainless steel workpieces.

In order to conduct this study, a flowchart was designed for the overall project, as shown in Figure 3.1. This flow diagram illustrates the laser engraving procedure from the literature review through the experiment and finally to the analysis and reporting of the results.



Figure 3.1 Flowchart for Bachelor Degree Project PSM1 and PSM 2

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

This chapter discusses the materials and qualities needed to complete this project. This chapter discusses the machines that were employed during the experimentation phase to achieve the desired outcomes in this research. Aside from that, the software involved in the experiment was also covered in this section.

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

Stainless steel was chosen as the material for the workpiece or specimen used to analyse the entire laser engraving process. Stainless steel has a number of advantages in the laser engraving process, including being more resistant to wear and abrasion than aluminium or other materials. The surface can be maintained on a regular basis without the use of harsh chemicals, making it perfect for advertising and signs. It also has a smooth finish, resulting in a high-quality product. Furthermore, because stainless steel is resistant to heat and has a high reflectivity, it will be used as a metal workpiece for laser engraving. The material is 1.0mm thick, 180mm wide, and 127mm long. Table 3.1 lists the mechanical properties of stainless steel.

Properties	Value
Modulus of elasticity	193 GPa
Density	8.03 [g/cm <sup>3</sup> ]
Tensile strength	515MPa
Yield strength	205 MPa
Bulk modulus	68-70 GPa
Melting Point (°C)	1664 (°C)
Boiling point (°C)	1672 (°C)

**Table 3.1** Mechanical Properties of Stainless Steel

#### 3.3.2 Type of Machine

The Master Oscillator Power Amplifier (MOPA) Fiber Laser was used in this study, which is available in the Manufacturing Laboratory at Universiti Teknikal Malaysia Melaka's Faculty of Manufacturing Engineering (UTeM). Figure 3.2 shows the Master Oscillator Power Amplifier (MOPA) Fiber Laser.

The Master Oscillator Power Amplifier (MOPA), which generates a pulse frequency with a broader fibre range than 1- 4000 kHz, can be used to supply a power source for the laser. This enables MOPA laser to provide distinct engraving results in diverse polymers and metal materials when compared to other fibre engrave laser technology. Furthermore, laser MOPA can engrave several colours on stainless steel, titanium, and aluminium, as well as produce a darker colour effect and a better gloss than fibre laser.



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

#### **3.3.3** Type of Software

In this experiment, ImagR was utilised to design the desired pattern that will be engraved by the Master Oscillator Power Amplifier (MOPA) Fiber Laser. Images can be processed online using ImagR, which is laser engraving software. It has a built-in auto-adjust capability. When a user first uploads an image to the website, it is converted to greyscale automatically. The user can then crop and resize the image to the appropriate dimensions while maintaining a DPI of 254.

After resizing the image, users may either tweak the brightness, contrast, sharpening, and other parameters manually or use the auto button. Figure 3.3 shows an example of the ImagR interface. ImagR was simpler to use because the MOPA laser equipment supports the graphical programme format chosen. The intended image or design is already a simple 2D model, as seen in Figure 3.3, which was then imported into EzCAD2.76.



Figure 3.3 ImagR Software

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Object list × Name Type		Marking parameter	*
		Pen Color	On/O
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		* 2	On
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		* 5	On
		+ 7	On
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	e I e	I Use default par	ram
		Current pen	0
		Loop Count	1
Object property ×		Speed[MM/Second	<b>d</b> 500
Position Size[		Power(%)	50
×		Frequency(KHz)	20
Y		Wave	0
z	N 9-	Start TC[US]	300
A		Laser Off TC[US]	100
_		End TC(US)	300
	8-	Polygon TC(US)	100
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	Hed[F1] Mark[F2] [S]Mark Select Total n 0 Param(F3] 00:00:00	Baram asmul Data	
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Figure 3.4 EzCAD2.76 Software



Figure 3.5 Adobe Illustrator Software

#### **3.4 Identification of Engraving Parameters**

There are four parameters in this engraving process study: laser power, engrave speed, pulse frequency, and laser loop counts. The laser frequency and speed were fixed parameters, while the laser strength and laser loop count were variable parameters, as shown in Table 3.2. Meanwhile, Table 3.3 displayed the suggested constant parameters that were used throughout the trial.

Designation	Engraving	Recommended	Unit
	Parameter	Data	
Stainless Steel	Laser loop count	1,2,3,10	-
and the second se	Engraving speed	100 - 1000	Mm/s
TI TE	Laser power	20,40,60,80,100	Watt
043	Laser frequency	80	kHz

# Table 3.2 Engraving Parameters

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

#### Table 3.3 Recommended Constant Parameter for Laser Engraving

#### 3.5 Surface Roughness Test

For each test run, surface roughness was measured with the Mitutoyo Surftest SJ-301 stylus profilometer. The Mitutoyo Surftest SJ-301 type profilometer easily and accurately tests the roughness of the material's surface. Before and after the laser engraving process, the surface roughness of the workpiece material was examined using an imaging method and a surface profilometer. The Mitutoyo Surftest SJ-301 stylus profilometer displays the predicted depth of roughness (rz) in microns and microns (m), as well as the average roughness value (Ra). All of the samples' Ra values were measured with a 5mm field size. Three measurements were taken for each engraved section to eliminate the possibility of measuring errors. The final Ra value's mean value was recorded.



Figure 3.6 Mitutoyo Surftest SJ-301 Stylus Profilometer Instrument

#### 3.6 Microstructure of Specimen

A digital microscope, such as the one shown in Figure 3.7, is useful for inspecting and analyzing the grain measurements of the engraved material. The engraved region and base-metal workpiece micrographs were studied in the sample microstructures.



#### **3.7.1 Expected Results**

3.7

The expected results of laser engraving on stainless steel are shown in Table 3.4. The result allows for the characterization of a surface after it has been laser-lasered at precise settings. Furthermore, the look of the surface on the stainless-steel workpiece revealed the choice of which surface was ideal 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	Cycle	HALAYSIA	AWA L			ace become darker as	
	FIG	(e) 2.78 μm	(f) 1.98 μm	(g) 1.52 μm	(h) 1.51 μm	s the ir	
Third Irradiation Cycle	لك UN	البينيا مار IVERSITI	EKNIKAL	يتي نيد MALAYSIA	وينوش MELAKA	radiation cycle increase	
		(i) 1.86 µm	(j) 1.24 μm	(k) 1.49 μm	(l) 1.22 μm	ed	
Forth Irradiation	Cycle					•	
		(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

Figure 3.8 shows another expected result from this research. The distribution of surface roughness for stainless steel is showed in Figure 3.8. When the laser parameters is changed, such surface roughness graphs allow for the prediction of surface quality. From a practical engineering standpoint, determining the roughness of a surface is crucial. Surface roughness enables designers to assess the accuracy of processed components by estimating characteristics such as friction or vibration created between two contact surfaces. Furthermore, the surface roughness value allows engineers to determine a component's ability to provide lubrication and estimate the component's life.



Figure 3.8 Surface roughness of engraved stainless steel

Furthermore, the purpose of this research is to present the results of laser engraving on selected metal using the best parameters. Figure 3.9 shows a laser marking result using the best parameters utilized during the laser engraving process.(Genna et al., 2015)



Figure 3.9 Laser marking surface appearance with the best parameters on stainless steel

#### 3.8 Summary

This chapter starts with an overview of the research design that will be used throughout the research. The methodology chapter discusses the sort of material, graving settings, and machine type used in the experiment. The engraving process was carried out on stainless steel using the Master Oscillator Power Amplifier (MOPA) Fiber Laser. In addition,

#### **CHAPTER 4**

#### **RESULT AND DISCUSSION**

#### 4.1 Introduction

This chapter presents the result and analysis on the effect of laser parameter when laser engraving lines on stainless steel. The parameters involved in this experiment were laser speed, laser loop count, and laser wobble diameter. The power and frequency were specified to remain constant throughout this experiment which is power at 100watt and frequency at 80 KHz. The tests performed in this research are effect of laser parameters and microstructure observations.

#### 4.2 Trial Study

Prior to performing effects of laser engraving parameters on stainless steel, extra image editing is required. It is required to raise its brightness and contrast in order to enhance the quality observations of the visual edges. The material size for the experiment is 1.5cm x **ERST TERMENTED** 1.0cm. The illustrations for the stainless-steel plate shown in Figure 4.1 is the size of the material that been used for experiment study. (Sobotova & Demec, 2015)



56

#### Figure 4.1 Material Size

The Master Oscillator Power Amplifier (MOPA) Fiber Laser was being utilized to test the laser engraving procedure on the stainless-steel plate in Figure 4.2. Constant parameters were used to evaluate the illustration design in three different parameters that involved for the experiment which is laser speed, laser loop count and laser wobble diameter. The laser parameter was set to a power of 100watt and with a frequency of 80KHz. Stainless steel plate produces a range of results depending on the parameters used.



Figure 4.2 Engraving Test on Stainless Steel

#### 4.3 **Result of the experiment**

A Power Amplifier with a Master Oscillator (MOPA) Stainless steel is engraved using a fiber laser. There a three types of result sampling and analysis throughout this experiment. Each particular test consists of laser speed, laser loop count and laser wobble diameter. The laser power is determined by increasing its value from the lower range to higher range, while maintaining frequency at 80KHz. The experimental part is followed by microscopic observation analysis. Microscopic analysis was conducted using Digital Industrial Microscope 100X Electronic endoscope.



Figure 4.3 Laser Engraving Result with different speed

Numbe	Speed (mm/s)	Power (Watt)	Frequency (kHz)	Loop Count
r				
1	100	100	80	1
2	200	100	80	1
3	300	100	80	1
4	400	100	80	1
5 APL MA	500	100	80	1
6	600	100	80	1
7	700	100	80	1
-8 UNIVE	800 RSITI TEK	100 NIKAL MA	ہتیں بی <del>م</del> 80 LAYSIA MI	اوييوم LAKA
9	900	100	80	1
10	1000	100	80	1

Table 4.1 Laser Speed result

Figure 4.3 shows the result of laser engraving on stainless steel plate with different speed level thus maintaining power by 100watt power, frequency by 80 kHz and laser loop count by 1 time. As shown in the figure, the engraved line created on the surface shows some differences of the laser speed depending on level too travel from the top to the bottom. The engraved line that applied at low range speed such as 100 to 400 mm/s shows some burning to the surface caused by low speed travel across the material yet the surface is still smooth. But as the speed increases, the engraved line shows less burning line on the surface however at the speed 900 to 1000 mm/s, the surface shows small arises on the line surface. This explains that the faster the time travel to engraved the material, the better the outcome of the engraved line. The speed at which the beam moves across the surface during processing it is being controlled by laser scan head beam delivery system that controls the speed. The lower the speed, the more material being displaced. And the greater the speed, the less material is displaced.

TEKNIKAL MALAYSIA MELAKA

60



Figure 4.4 Laser Engraved result with different loop count

Figure 4.4 shows the result of the engraved line looping on the same surface depending on levels from lower to higher with parameters of 100watt power, 80kHz frequency and maintaining speed at 1000 mm/s. Each number represent the loop count times on the surface line. From the figure above, the engraved line shows that multiple loop count will create thicker line or more depth resulting on more loops travels across the surface. Due to this, it generates additional heat which impair the cleanliness of the marking line engraved and damaging the material. Based on the result of the material, the depth marked on the surface seems obvious due to constant parameters applied.

Number	Speed (mm/s)	Power (Watt)	Power Frequency (Watt) (kHz)	
1	1000	100	80	1
2	1000	100	80	2
3	1000	100	80	3
4	1000	100	80	4
stat 5 MALA	1000	100	80	5
6	1000	100	80	6
Sanna Tol	1000	100	100 80	
UNI <sup>8</sup> ERS		 IIKA100 мл		ELA <sup>8</sup> KA
9	1000	100	80	9
10	1000	100	80	10

Table 4.2 Laser Speed result



Figure 4.5 Laser Engraved result with different wobble diameter

Figure 4.5 above shows the result of laser engraved on stainless steel at various wobble diameter with same parameters of 100watt power, 80kHz frequency, speed at 1000 mm/s and loop count by 10 times. The wobble is designed to add thickness to a single line, the laser then engraved it into a spiral. The diameter set will be the diameter spiral which will be actual 'stroke width'. The parameters settings used for the wobble diameter can be obtained in advance settings. Based on the figure surface it shows the thickness of straight lines were increasingly affected due to increasing number of diameter and loop count on the surface. As shown in Figure 4.5, number 3 uses 0.3 mm in wobble diameter shows the best effect of the laser parameters in straight line engraving. In addition, wobble is an alternative technique that can make thicker lettering by making an outline and hatching the interior.

Number	Speed	Power	Frequency	Loop	Wobble
	(mm/s)	(Watt)	(kHz)	Count	(mm)
1	1000	100	80	10	0.1
2	1000	100	80	10	0.2
3	1000	100	80	10	0.3
SA MAI	1000	100	80	10	0.4
5	1000	100	80	10	0.5
مار <u>م</u>	1000	100	80	. 10	0.6
UN7VE	RS1000TE	K100CA	L M 80_AY	SIAIME	LA 0.7
8	1000	100	80	10	0.8
9	1000	100	80	10	0.9
10	1000	100	80	10	1.0

 Table 4.3 Laser Wobble Diameter result

#### 4.4 Analysis Result of Microscopic Observations

The microscopic observation was performed with an Industrial electronic Microscope Camera x100 for faster and better macro view assessment. The surface and engrave quality were observed in the straight-line engraved field. The influence of laser parameters on the engraved substance and carved layer on the surface may be readily seen using a microscope. In addition, OBS Software were included for optimizing the use of the microscopic. The Electronic Microscope produce crisp visual results, as it facilitates in viewing more closely on the stainless-steel surface. The findings for the engraved line surfaces under microscope were followed by previous testing.



Figure 4.6 Equipment of Microscopic Observation



Figure 4.7 Microscopic Observation on engraved material



#### 4.4.1 Result of Microscopic Observation Laser Speed
300	
	At 300 mm/s speed shows the material has more material placed onto the surface
	due to low speed travels across material to complete a straight line. The surface
	shows some melted material seems there is less speed and more material heating
	onto the surface. The main effect happen onto the surface is laser ionization.
400	At 400 mm/s speed shows the material has more material placed onto the surface due to low speed travel across material to complete a straight line. The surface shows some melted material seems there is less speed and more material heated onto the surface. The main effect happen onto the surface is laser ionization
500	
	At 500 mm/s speed shows the material has more material placed onto the surface due to low speed travel across material to complete a straight line. The surface shows some melted material seems there is less speed and more material heated onto the surface. The main effect happen onto the surface is laser ionization

600	
	At 600 mm/s speed shows the material has slightly less material placed onto the
	surface due to faster speed travels across material to complete a straight line. The
	surface shows less melted material seems there is fast speed and less material
	heating onto the surface. The main effect happen onto the surface is laser
	ionization.
700	NALAYSIA SALAYSIA CONTRACTOR
	At 700 mm/s speed shows the material has slightly less material placed onto the surface due to faster speed travels across material to complete a straight line. The
	surface due to faster speed navers across material to complete a straight line. The surface shows less melted material since there is fast speed and less material heated. The main effect happen onto the surface is laser ionization.
800	
	At 800 mm/s speed shows the material has less material placed onto the surface
	due to faster speed travel across material to complete a straight line. The surface
	shows less melted material becaused of fast speed and less material heated onto
	the surface. The main effect happen onto the surface is laser ionization.



 Table 4.4 Results of Laser Speed Microscopic Observation



## 4.4.2 Result of Microscopic Observation Laser Loop Count









 Table 4.5 Results of Laser Loop Count Microscopic Observation

Wobble	Microscopic Observation of the engraved surface
Diamete r (mm)	(Speed 1000 mm/s, Power 100-watt, Frequency 80kHz and 10 loop count)
0.1	
0.2	لويوررسيني تيكنيكل مليسيا ملاك

## 4.4.3 Result of Microscopic Observation Laser Wobble Diameter

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 Table 4.6 Results of Laser Wobble Diameter Microscopic Observation

As shown in Table 4.6, the sample 0.1 mm of wobble diameter shows the melted traps of welding occur on the material surface seems smaller than 1.0 mm of wobble diameter. This is mainly because of the changes in parameter of wobble diameter makes the laser beam to increase it diameter. The engraved line on the surface 1.0 mm of wobble diameter shows more material placed on the surface due to multiple cycle of looping and wide diameter of wobble makes the surface to melted its material and formed a gutter shape around the straight line.

#### 4.4.4 Microscopic Observation

The microscopic observation of the engraved parts produces the most noticeable lines and shapes form. When the samples were observed under the microscope, it was discovered that the lines structure was changed as a result of technological parameters such as laser speed, laser looping and laser wobble diameter. For the laser speed observations, the structure of the engraving did not affect as much as the engraving speed was increased. It is also because of the looping count for the laser speed is for one time. But when the number of loop count increase, the heating effect induced by the re-melting of the structure by the laser beam becomes more visible and noticeable. Loop count also depends on wobble size diameter to penetrate onto the sample. The influence of the wobbling mode parameters, laser speed, and laser power has its importance in engraving. The wobble diameter as being observed using electric microscope shows the depth of penetration into engraved line, the bead height, the bead width and the effect of laser beam wobbling on the melting of the substrate. (Voropaev et al., 2022)

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### **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATIONS**

## 5.1 [CONCLUSION

The goal of this study is to develop a straight-line engraving using a Master Oscillator Power Amplifier (MOPA) Fiber Laser on material stainless steel. The study's initial goal, to construct a straight-line pattern utilizing laser engraving on stainless steel material. From the perspective of straight-line pattern engraving and quality, the effect of laser parameters applied on stainless steel surface has provided positive result. The surface of the stainlesssteel material is very effective for getting the greatest parameter for laser engraving.

The second goal in this study is to evaluate the effect of the process laser parameter on the surface of the stainless steel such as the speed, frequency and power that used to run the laser engrave machine during the process. A combination of parameters such as laser speed, laser loop count and wobble diameter settings were found to be important in achieving the best laser parameters for laser engraving on stainless steel, as demonstrated by this experiment.

The study's ultimate purpose is to examine the microscopic appearance of stainlesssteel during laser engraving. Increasing the laser speed and loop count will have a significant influence on the surface material. Higher laser speeds and one loop count, when compared to lower laser speed and one loop count, may resulting in marking effects on the material surface. The use of higher of laser speed combined with greater amount of loop count results in increasing amount of heating effects on the engraved line such as melting.

## 5.2 **RECOMMENDATION**

The following are some recommendations for further research:

- For more investigations, experiment with additional engraving settings including laser frequency and higher engraving speed.
- Different shapes of line numbering or lettering to consider as experiment samples includes font size and font themes.
- Carrying out additional test to assess surface roughness test, engraving depth measurement and corrosion observation.



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## APPENDICES

## APPENDIX A Gantt Chart of PSM1.

		Semester 6 (2022)														
Ν	Activities		Weeks													
0.		1	2	3	4	5	6	7	8	9	1	1	1	1	1	
											0	1	2	3	4	
1	PSM 1 briefing															
2	Title review and Introduction															
3	Meeting with Supervisor															
4	Material Finding															
5	Chapter 1 completion															
6	Machine introduction and testing															
7	Chapter 2 completion – Literature															
	review															
8	Chapter 3 completion - Methodology															
9	Draft review and update															
10	Final report submission															
11	Project presentation								V/							

5) APPENDIX B Gantt Chart of PSM2. all

# Activities (2022-2023)

No	Activities	(2022-2023)													
•			Weeks												
		1	2	3	4	5	6	7	8	9	10	11	12	13	
1	PSM 2 briefing														
2	Meeting with supervisor														
3	Conducting the experiment														
4	Data Collection														
5	Analyzing Data and Result														
6	Report Writing														
7	Full report review by supervisor														
8	Report submission														
9	Poster Preparation														
10	Presentation														