

Alteration Of Copper Surface by Using Laser Engraving Process for Deep Pattern Marking



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Alteration Of Copper Surface by Using Laser Engraving Process for Deep Pattern Marking

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Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

DECLARATION

I declare that this Choose an item. entitled "Alteration Of Copper Surface by Using Laser Engraving Process for Deep Pattern Marking" 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

I dedicated this study to my beloved parent, who always keep supporting me with everything that I need through my journey and always be my side to support me with moral, love 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 to finish this study.

I also dedicated this to all my lectures and friends who always encouraged and helping me

to finish this study.

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ABSTRACT

Laser engraving is a technology that has potential to be one of the promising in industry area. Laser machines are specifically designed for engraving on different types of materials, cutting, etching, and marking. The parameters in this process are really important as when a parameter changes, the outcome will become different. The larger the gap of the parameter change will show a hugely different result. Furthermore, the duration of the engraving is also important as when the duration is increased, the depth of the engraving is also increased. The main objective for this study is to investigate the effect of the parameter for the laser engrave. The other objective is to evaluate the deep pattern marking based on the laser period. Lastly, to analyze surface quality of the copper after marking process by microscopic observation The raw material used for as the specimen is copper. There are several parameters that are important for this laser engraving process that are laser loop count, laser speed, laser power and laser frequency. The main material that will be used is a plate of copper $10 \text{cm} \times 10 \text{cm}$ with a thickness of 0.5mm. The parameters that change throughout the study are the frequency, the period of the engrave and the loop count of the laser. The best result among the results in this study are the one in 8 minutes duration and at the frequency of 100Hz and the loop count one. The best results are evaluated as we consider the best quality of the engravement that consist of the precision, roughness, and detailing.

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ABSTRAK

Ukiran laser adalah teknologi yang berpotensi untuk menjadi salah satu yang menjanjikan dalam bidang industri. Mesin laser direka khusus untuk mengukir pada pelbagai jenis bahan, memotong, mengetsa dan menanda. Parameter dalam proses ini sangat penting kerana apabila parameter berubah, hasilnya akan menjadi berbeza. Semakin besar jurang perubahan parameter akan menunjukkan hasil yang sangat berbeza. Tambahan pula, tempoh ukiran juga penting kerana apabila tempoh ditambah, kedalaman ukiran juga bertambah. Objektif utama kajian ini adalah untuk menyiasat kesan parameter untuk ukiran laser. Objektif lain adalah untuk menilai penandaan corak dalam berdasarkan tempoh laser. Akhir sekali, untuk menganalisis kualiti permukaan kuprum selepas proses penandaan dengan pemerhatian mikroskopik Bahan mentah yang digunakan sebagai spesimen ialah kuprum. Terdapat beberapa parameter yang penting untuk proses ukiran laser ini iaitu kiraan gelung laser, kelajuan laser, kuasa laser dan frekuensi laser. Bahan utama yang akan digunakan ialah plat tembaga bersaiz $10 \text{cm} \times 10 \text{cm}$ dengan ketebalan 0.5mm. Parameter yang berubah sepanjang kajian adalah kekerapan, tempoh ukiran dan kiraan gelung laser. Keputusan terbaik antara keputusan dalam kajian ini ialah satu dalam tempoh 8 minit dan pada frekuensi 100Hz dan kiraan gelung satu. Hasil terbaik dinilai apabila kami mempertimbangkan kualiti terbaik ukiran yang terdiri daripada ketepatan, kekasaran dan perincian.

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LIST OF SYMBOLS AND ABBREVIATIONS

- CO_2 Carbon Dioxide
- °C Degrees Celsius
- ALE Atomic Layer Etching
- 2D Two-Dimensional
- HeNe Helium-neon
- VB_s Vortex beams
- OAM Orbital Angular Momentum
 Nm Nanometers
 Cm Centimeter
 Millimeter
 % Percentages
 UHSS Ultra-High Strength Steel
 MOPA Master Oscillator Power Amplifier
 - AI Adobe Illustrator
 - USB Universal Serial Bus
 - Hz Hertz

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CHAPTER 1

INTRODUCTION

1.1 Background

Laser engraving technology has advanced rapidly in recent years, and it is now displacing traditional mechanical methods. With a high-power laser beam, laser engraving enables great precision for a wide range of materials in a contactless high-speed process. Laser engraving is faster than other commonly used applications like laser welding or cutting, which may reach speeds of several meters per second. (M. Ruutiainen, H. Roozbahani, M. Alizadeh, H. Handroos and A. Salminen, 2022).

Laser marking is an innovative material processing technique that leaves a permanent mark on materials. Through melting displacement, ablation, and evaporation, the materials are removed layer by layer via laser engraving in the laser channel. Laser processing techniques are suitable for cutting, marking, drilling, and micromachining in most materials, including metals, plastics, ceramics, and composites. Laser also offers high speed, accuracy, and versatility in completing the process.

Pulsed Nd:YAG lasers and continuous CO_2 lasers are the most common types of lasers used in manufacturing processes. Due to many advantages such as high intensity and -+small spot size, pulsed Nd: YAG lasers are suitable for machining processes. Laser machining is a dynamic process that is influenced by a number of variables that must be accurately managed (Noorossana et al., 2020)



Figure 1.1 Laser Marking Process (Noorossana et al., 2020)

1.2 Problem Statement

Laser engraving is a process that engraving on a surface using laser. The parameters in this process are really important as when a parameter changes, the outcome will become different. The larger the gap of the parameter change will show a hugely different result. Furthermore, the duration of the engraving is also important as when the duration is increased, the depth of the engraving is also increased. The material that is used in this study is copper. Copper have been commonly used in many industries such as building construction, power generation and transmission, electronic component, the production of industrial machinery and transportation vehicles.(Wan et al., 2021). Copper also has an extremely low chemical reactivity. This research aims to identify the ability of laser engraving to perform with a slight change in the parameter and the period of the engraving on copper plate.

1.3 Research Objective

The general purpose of this research is to analyze the period of time taken to reach the perfect yet good condition for engraving on copper plate. Specifically, the objectives are as follows:

- a) To investigate the effect of parameter consist of power, speed, frequency and the laser loop on the copper surface.
- b) To evaluate the deep pattern marking based on the laser period.
- c) To analyse surface quality of the copper after laser marking by microscopic observation.

1.4 Scope of Research

The scope of this research are as follows:

- Adjusting laser parameter of the laser engrave machine.
- Evaluate the microstructure of the after-laser surface as the result of the study.
- Study the application of laser engravement on copper plate with a certain

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section is focusing on the laser process, material and the parameter that used in this process. The effect of the laser process change by the parameter will also be put in this chapter. All the types of lasers engrave, the parameter and the other information about laser engrave were defined. (M. Ruutiainen, H. Roozbahani, M. Alizadeh, H. Handroos and A. Salminen, 2022)

2.2 History of Laser

Laser marking has been around for a while, especially in the electronics industry, where it evolved from laser resistor trimming. Laser marking has proven to be a cost-effective competitor to stamping, chemical etching, and other alternate techniques in the electronics industry, including the case of silicon wafer identification. In the general industrial world, laser marking has proven to be a cost-effective competitor to stamping, chemical etching (Baker, 1982)

Albert Einstein suggested under a certain circumstance atom could release an energy as light in 1916. Another person in 1928, German physicist Rudolf Walther Ladenburg found the stimulated emission. In that time, there is no practical use of it yet. Later in 1951, Charles H. Townes thought of a way to generate a stimulated emission at microwave frequency. In all these years, many improvements are being made to perfecting the laser and finally a very first semiconductor laser are made in 1962 by Robert N. Hall and co-workers at the General Electric Research and Development Centre in Schenectady

The first lasers with widespread commercial uses were helium-neon lasers. They found immediate application projecting straight lines for alignment, surveying, building, and irrigation since they could be adjusted to emit a visible red beam instead of an infrared beam. Ruby laser pulses were soon being use by eye surgeons to weld separated retinas back into place without cutting into the eye. The laser scanner for automated checkout in supermarkets, which was invented in the mid-1970s and became ubiquitous a few years later, was the first large-scale application for lasers. Compact disc audio players and laser printers shortly followed personal computers (Hecht, 2021).

2.3 Type of Carving 2.3.1 Engraving

Engraving is one of the well-known traditional graphics techniques. It first developed in the fourteenth century as an illustrative backup for developing printing on the book, but thanks to its unique expressive ability, it swiftly became an art form in its own. Artists utilize four basic types of engraving, silk screen and lithography, intaglio or in-hollow printing, letterpress, or relief printing with several different techniques in each class (Ostromoukhov, 1999).

Printmaking's history is littered with prosperous periods of processes that eventually collapsed for a variety of causes. When photography did not yet exist back then, facial engraving was amazingly well known in seventeenth and eighteenth centuries, this superb

artisanship got to be nearly unused, due to the extraordinary special requests that it made on the etcher. Figure 2.1 shows the example of copper plate engraving of post stamp. Proficient copper plate etchers are uncommon nowadays, and the fetched of genuine engraving is essentially as well restrictive to be utilized in regular printing. At the same time, conventional facial engraving has no question exceptionally particular request: its slick, sharp appearance recognizes it beneficially from photographs. In order to appreciate the graphic effect of engraving it is sufficient when compare the etching representations within the Divider Road Diary with representations in other daily papers created with conventional generic screening (Ostromoukhov, 1999).



Figure 2.1 Copperplate engraving of a post stamp (Ostromoukhov, 1999)

2.3.2 Etching

Today, etching technology that is famous is atomic layer etching (ALE). ALE is being compared with long-established traditional etching techniques, connecting with the ancient art of etching's basic principles. ALE is now faster than before thanks to plasma, which was previously thought to be too sluggish. Plasma etching has advanced significantly in the last 40 years, thanks to improved plasma sources and control technologies. At technology nodes with dimensions of less than 10 nanometers, the industry nowadays becomes more attached to determine the sharpness, precision, and shape of features. Our focus has turned to the underlying surface processes as we strive to etch logic and memory structures to within a few atoms on features less than 40 atoms wide (Kanarik et al., 2018).

Etching is the process of disrupting bonds that attach atoms to one another to remove them from a substrate. The binding energy is a common energy, given that Each atom has a barrier that is determined by its precise location and orientation on the surface. Figure 2.2 shows the comparison of removal mechanisms. There are many alternative ways to modify or remove energy binding with chemistry, temperature, and collisions



Figure 2.2 Comparison of Removal Mechanisms (Keren J. Kanarik, Samantha Tan, and Richard A. Gottscho, 2018)

2.3.2.1 Chemistry

Reaction on the surface can produce less tightly linked to the surface and can easily be removed. Plasma is more widely employed in the semiconductor industry because it dissociates gases into extremely reactive radicals.(Sarkar Phyllis et al., 2022) Chemical etching is typically transport-limited, which means the etch rate is a strong function of reactant flux. Without a crystallographic dependence, it is generally isotropic.

2.3.2.2 Temperature

If the kinetic energy of vibrating surface atoms exceeds the energy of gravity, they will sublime. According to the Arrhenius law, the etch rate for thermally induced etching depends on temperature. The typical substrate temperature operating range is -20 to 150 °C. Thermal etching is isotropic, absent crystallographic dependencies (Lin et al., 2008).

2.3.2.3 Collisions

An atom can be rejected when an object that has strong energy hits the surface if the atom collects enough kinetic energy while moving upward through momentum transfer to remove surface binding energy. The most common bombarding object in the semiconductor industry is the surface erect to ion accelerated. (Keren J. Kanarik, Samantha Tan, and Richard A. Gottscho, 2018)

2.3.3 Aquatint

Aquatint is a hypersensitive dance of shapes, colors, and abstract imagery that depicts the emotional response to intense natural settings. Strong, sensual, earthy atmosphere, but created by systematic nature inside a manufactured vacuum. A universal yet personal sensory mapping is perhaps an essential function of abstraction in an all-encompassing universe of instantly recognized sights and details (Dondieu et al., 2020). When referred to as conventional art by painterly and industrialized delivery, which is meticulous thought about presenting beauty and the quasi-religious adoration that might cause the countryside, aquatint is romantic, critical, and similar to recollections and dreams than film.

2.4 Laser Engraving

The main purpose of laser engraving is to engrave a design or idea onto a material surface using laser machine. The designs that need to be engraved are uploaded to the computer and sent to the laser engrave machine's controller. When the process of Laser Engraving starts, to produce the high heat needed for vaporization, the laser must reach specific areas with large amounts of energy. It is important for the process to have the highest laser radiation sensitivity possible for the material to be graved in order to contact the material exceptionally quickly and efficiently. It will produce an excellent outcome to the product without melt edges by increasing the level of sensitivity to laser radiation (Fernando, 2019).

While laser engraving changes the roughness of a material's surface by melting it, laser graving also creates depth gaps by sublimating the substance's surface. This indicates that the surface absorbs energy quickly enough to change from solid to gas without ever being liquid. To achieve sublimation, the laser graving system must generate enough energy to ensure that the material's surface reaches its vaporising temperature in milliseconds. The materials are evaporated into vapours when the temperature reaches its vaporisation temperature optimal value and being measure the depth and width (Lanzilotti & Pinto, 2022). The typical method for determining the right thickness and associated laser parameters is an iterative procedure in which laser parameters are individually tweaked to identify their precise thickness and width with the gravure that results.



Figure 2.3 Laser Engrave on Aluminum plate show under microscope (Karbasi, 2010)

Figure 2.3 shows a laser engrave product under microscope. Laser engraving technology is usually used to engrave metal workpiece such as copper, steel, zinc, and aluminium. Other than metal, engraving also can be perform on different kind of material such as ceramic and wood. The most impressive feature of this process is the ability to engrave a 2D codes that maintain great readability after post-processing. Shotblasting, e-coating, and heat treatments are some of the procedures that include in this process.

To generate deep crevices, laser engraving sublimates the material surface. That is mean the material surface absorbs enough energy to change from solid to gas without transform to liquid. This vaporization method needs certain temperature depending on the different type of materials as shown in Table 2.1.

Material	Vaporization Temperature
Aluminium	2327°C
Copper	2595°C
Iron	3000°C
Lead	1750°C
Magnesium	1110 °C
Zinc	906 °C

Table 1 Different material with the vaporization temperature

2.4.1 Type of laser

A laser is a device that uses optical amplification to produce a beam of coherent light. Gas lasers, fiber lasers, solid state lasers, dye lasers, diode lasers, and excimer lasers are among the many types of lasers. All these lasers share the same basic set of components.

2.4.1.1 Gas Laser

He-Ne gas lasers are widely used in scientific research, high precision measurement, information transmission and processing, and medicine due to their excellent optical quality. Laser wavelength and intensity modulations are required in some practical applications, such as absorption spectroscopy.(X. Zhang et al., 2018).

Figure 2.4 portrays a HeNe laser. The laser cavity, which is the space between the two reflectors, comes first. A glass tube is conveniently placed between the mirrors. This glass is used to keep helium and neon gases under control. The helium and neon gas in the cavity is also referred to as the gain medium. The substance that generates laser light is known as the gain medium. On the left and right sides, a cathode and an anode are attached. The anode and cathode are used to conduct electricity through the gain medium. The electric current excites the helium atoms in the medium, causing them to become excited.



Figure 2.4 HeNe Laser Tube (Khan et al., 2017)

2.4.1.2 Solid-State Laser

Vortex beams (VBs) are structured beams with helical wavefronts that carry orbital angular momentum (OAM) and have been widely used in a variety of domains including optical data transmission, optical tweezer, quantum entanglement, and superresolution imaging. The ability to generate vortex beams with high performance is critical for these advanced applications. In contrast to extra-cavity schemes that transform other modes into vortex modes, such as spatial light modulation, mode conversion, and others, solid-state vortex lasers can output vortex beams directly and have advantages such as a compact structure, high robustness, ease of integration, and low cost. (Z. Zhang et al., 2022)

2.4.1.3 Fiber Laser (Fiber Optic)

Fiber lasers are made up of a gain medium housed inside a cavity designed to provide optical feedback. The discovery and subsequent use of rare-earth ions such as erbium, neodymium, and ytterbium in the manufacture of optical fiber amplifiers enabled the construction of fiber lasers in which an optical amplifier acts as a gain medium. Fiber lasers were found to produce higher energy and shorter pulses at a lower cost than solid state bulk lasers. As a result of their ability to generate ultra-short pulses at high repetition rates, fiber lasers found numerous applications in industry, medicine, research, defense, and security (Biswas, 2017).

2.4.1.4 Liquid Laser (Dye Laser)

Figure 2.5 shows the basic schematic of liquid laser. Figure Dye lasers are a type of liquid laser that generates lasing wavelengths by utilizing the emission properties of organic dyes. The laser dyes currently available can generate variable laser light over a wide range of wavelengths, typically 50–100 nm. Figure 2.5 shows a simple schematic design for liquid laser. Choosing different dyes for different wavelength ranges allows for wavelength variation beyond the visible. For many years, liquid dye lasers were widely used due to their versatility and tunability. Advances in semiconductor laser tunability and cost reduction have reduced their popularity in recent years (Potter & Simmons, 2021).



Figure 2.5 Liquid Laser basic schematic (Rajeev Kumar Dohare et al., 2021)

2.4.1.5 Semiconductor Lasers (Laser Diodes)

Laser diodes, like other diodes, have voltage-current characteristics. Depending on the material used in the diode, current flows in only higher than a certain critical voltage. The current grows rapidly with the voltage above the critical voltage. Figure 2.6 shows the graph of voltage-Current of semiconductor laser. A fixed voltage makes the laser diode work abnormal because the current can be too sensitive to this voltage and depends on the device's temperature.



A high current may cause a significant increase in temperature and finally destroy the diode. Additionally, a constant power mode is used, which automatically adjusts the driving current to achieve the desired output power.

Diode lasers are highly efficient. Typically, in the order of 50%, and sometimes can be more than 60%. Electrical resistance, dispersion, absorption, and spontaneous emissions are common factors that limit efficiency. Laser diodes emitting around 940-980 nm have particularly high efficiency, whereas diodes emitting around 808 nm are slightly less effective.(Durna et al., 2020)

2.4.2 Laser Engraving Parameter

Dharmesh K. Patel investigated the optimization in parametric of the engrave process for various materials by using a technique called grey relational. Laser engraving parameters are being optimized on Stainless Steel 304 using a Q-switched diode-pumped frequencydoubled Nd: YAG green laser. Marking and engraving is possible with a laser engraving machine by changing the input parameters such as laser loop, laser power, laser frequency, and laser speed.(Dharmesh K. Patel & Dr. D. M. Patel, 2014)

2.4.2.1 Power

The engraved depth and color difference were significantly affected by the feed speed ratio by laser power interaction regimens. Figure 2.7 shows the effect of feed speed and output power. As a result, the engraved depth and color difference increased when laser output power increase, but the feed speed ratio decreased (NS Badrishah et al., 2018).



Figure 2.7 Engraved with feed speed and output power (NS Badrishah et al., 2018)

2.4.2.2 Speed

The laser parameter speed determines the movement of the laser head. Fast velocities contribute to short exposure durations, whereas moderate velocities contribute to long

exposure durations. When the speed is too high, the laser beam has no effect on the substance that it is marking with a slow speed.

2.4.2.3 Frequency

The scan speed and time have a significant impact on surface roughness and highest engraving depth. In contrast, frequency has little effect. The scan speed should be reduced to reduce surface roughness; however, this causes a decrease in engraving depth. The roughness of the surface will increase as the frequency increase.(Kadhim A. Hubeatir & Mohanned Mohammed Hussein Al-Khafaji, 2020)

2.5 Type of Material Suitable for Laser Engraving

2.5.1 Copper

Copper is a trace element that serves as a catalyst for heme synthesis and iron absorption. Copper is the third most abundant trace element in the body, after zinc and iron. Copper, like silver and gold, is a noble metal. High thermal and electrical conductivity, low corrosion, alloying ability, and malleability are all useful industrial properties. The majority of metallic copper is used in electrical applications. Copper is a component of intrauterine contraceptive devices, and its release is required for their contraceptive effects (Barceloux & Barceloux, 1999)

A method for creating an engraved printing plate is known. This method is based on a plate with the necessary engraved parts, preferably in copper. These engraved parts are filled with a metallic-repelling filling fabric. In this manner, a metallic layer for case chromium is stored on the surface of the plate, which acknowledges the wetting specialist. Finally, the engraved portion's filling fabric is expelled using a solvent, a chemical operator, or mechanically (Ostromoukhov, 1999). Copper is a commonly used material in various industries due to its excellent electrical and thermal conductivity, as well as its corrosion resistance. However, the surface of copper can be easily damaged or contaminated, which can affect its performance (Barceloux & Barceloux, 1999). In this report, we present the results of our study on the alteration of copper surfaces using laser engraving for deep pattern marking.

2.5.2 Aluminum

Vehicle demand has recently increased dramatically, resulting in high fuel emissions. As a result, reducing vehicle weight is critical in order to reduce carbon dioxide emissions. Making chassis components out of Ultra High Strength Steel (UHSS) was one of the most effective solutions (R. Zhang et al., 2016). In comparison to steel, aluminum has low formability, particularly at room temperature, making stamping more difficult. A large body of recent research has focused on methods to improve the formability of aluminum alloys.

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter focuses on the proposed research techniques for the effects of laser engraving parameters on copper plate surface. This methodology allowed for a thorough understanding of the impact of the laser engraving parameters of speed, power, and frequency on the copper surface. This study is mainly focusing on studying the period of time for a plate of copper with a certain thickness to produce a perfect image without putting a hole in the plate through laser engrave by using a different parameter setting.

Copper is primarily produced commercially through smelting or leaching, which is usually followed by electrodeposition from sulphate solutions. The major use of copper products all over the world is for electrical energy. Copper has a characteristic which conducts electricity with more efficient than others electrical conductor. Because of this superior conductivity, copper has become the international standard to be use in electrical conductors compared to other.

A flowchart has been created to illustrate the whole process of the study. In Figure 3.1 show the complete chart of this study. This chart shows the overview of the process of laser engravement from literature review to the finding result after being analyzed and reported.



Figure 3.1 Flowchart of Final Year Project

Figure 3.2 Flowchart of Final Year Project

3.2 Selection of Material, Machine, and Software

This subtopic will discuss the important part of the study. The material chooses for this study will be copper. The machine that will be used in this study is Master Oscillator Power Amplifier (MOPA) Fibre Laser. Adobe Illustrator, Imag-R, and EzCAD are the computer programs that will be used to complete this study.

3.2.1 Type of Material

Copper was selected as the material for this study. The workpieces originally come with three different thicknesses as shown in Figure 3.2. The disadvantage of using those three workpieces is that the diameter is too small, which is $1.5 \text{ cm} \times 1.5 \text{ cm}$. When the first run been conducted, the material was slightly difficult to manage. A solution for this is to get a new workpiece with a $10 \text{ cm} \times 10 \text{ cm}$ plate as in Figure 3.3.



Figure 3.3 Three different material of copper specimen



Figure 3.4 Copper plate with diameter $10 \text{cm} \times 10 \text{cm}$

Figure 3.5 Copper plate with diameter $10 \text{cm} \times 10 \text{cm}$ in choosing copper for this study. Copper has excellent thermal conductivity and thermal transfer properties and is widely used in wiring. Because heat is quickly dissipated, the thermal properties of the copper laser marking machine are ideal for laser marking systems. The properties of metal are shown in Table 3.1.

ONIVERONT LERMINAL I	ALATOIA INCLAINA
Properties	Value
Atomic number	29
Atomic mass	63.546 g.mol
Yield Strength under load	0.5%
Density	8.9 g.cm ⁻³ at 20°C
Melting point	1083 °C
Boiling point	2595 °C
Ionic radius	0.096 nm (+1) ; 0.069 nm (+3)
Isotopes	6
Electronic shell	[Ar] 3d ¹⁰ 4s ¹
Standard potential	$+ 0.522 \text{ V} (Cu^{*}/Cu) ; + 0.345 \text{ V} (Cu^{*}/Cu)$

	Table 2 Propert	ties of Copper	
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3.2.2 Type of Software

In order to obtain the design to be used for this study, a number of software will be used. The pattern that will be engraved by Master Oscillator Power Amplifier (MOPA) will be created by using Adobe Illustrator. Adobe Illustrator (AI) is a graphic design tool that can be used especially for creating vector art. The design from the AI can be exported to ImagR as shown in Figure 3.6. Using ImagR is easy because it includes an auto-adjust feature. When a user first uploads an image to the website, it converts the image or design to greyscale to be use for laser engraving machine. The user can then crop and resize the image to the desired dimensions. After resizing the image, you can either manually adjust the brightness, contrast, sharpening, and other settings, or use the auto button. The design will finally upload to EzCAD software laser engraving machine as shown in Figure 3.7.



Figure 3.6 ImagR online website

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		+ 2	On
		+ 3	On
		• 5	On
	R	+ 6	On
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	9I =-	₩ Use defaul	t param
		Current pen	0
		Loop Count	1
bject property ×		Speed[MM/Se	cond 500
Position Size[Power(%)	50
×		Frequency[KH	z) 20
Y		Wave	0
z	N R	Start TC(US)	300
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	Hcd[F1] Mark[F2] [S]Mark Select Total n: 0 Param[F3] 00:00:00	Occurrent in	

Figure 3.7 EzCAD Software

3.2.3 Type of Machine

3.2.3.1 Master Oscillator Power Amplifier (MOPA) fiber laser machine

The machine that is available for laser engraving in Manufacturing Laboratory at Faculty of Manufacturing Engineering in University Technical Malaysia Melaka (UTeM) is Master Oscillator Power Amplifier (MOPA) fiber laser machine as in Figure 3.8.

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Figure 3.8 Fiber Laser Machine

3.2.3.2 Digital USB Microscope

The perimeter of the laser machine will be tweaked to conduct the study. The USB microscope that is shown in Figure 3.9, can be used to inspect the micrographic on the copper plate surface after the laser engraving.



UNIVERS Figure 3.9 Digital USB Microscope

3.3 Parameter

A parameter is a numerical or a measurable aspect that forms one of a hard and fast that defines a system or sets the conditions for its operation. A parameter is also a limitation or boundary that can describe the scope of a certain system or project. In laser engraving, cloth is removed according to the desired measurements and the parameters required by the laser engraving device (Kasman, 2013). The parameter can be changed in the software as shown in Figure 3.10.

Use default para	me	
Current pen	0	
Loop Count	1	
Speed(MM/Secon	100	
Power(%)	80	
Frequency(KHz)	20	

Figure 3.10 Parameter section in EzCAD Software

3.3.1 Power

Power is the power of your laser that is measured in watts. The more powerful the laser, the higher the wattage. If all of your other settings are the same, the more powerful the laser, the deeper the mark will be.

3.3.2 Frequency

To understand frequency, we must first understand the laser beam in a fiber laser. UNVERSITITEKNIKAL MALAYSIA MELAKA The laser beam is not a constant source of energy. The laser, on the other hand, emits light in pulses at regular intervals. The rate of the pulses is determined by frequency. The number of pulses decreases as frequency decreases, but the energy output per pulse increases. The number of pulses increases as the frequency increases, but the energy output per pulse decreases.

3.3.3 Speed

The speed setting controls how quickly the laser moves across the mark. The more material that is displaced, the slower the speed. The faster the rotation, the less material is displaced.

The loop count indicates how many times the laser will pass over the mark. More loops result in more depth. It can increase depth by increasing the power of your laser, decreasing the marking speed, decreasing the frequency, or some combination of the three. However, this produces a lot of heat and can leave a dark, rough mark. it might even deform the material being marked.



Table 3 Table of result with changing parameter of Speed, Time, and Power.

The Methodology section discussed the very thing that was used in the study. The material used, type of machine and type of software used to include the parameter that was used in the study. The microstructure of the finished engravements is observed under a digital USB microscope.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The aim of this chapter is to present the findings and results of our study on the alteration of copper surfaces using a fiber laser engraving machine. Our objective was to identify the best parameters for creating deep patterns on copper surfaces through engraving. To this end, we conducted the study and observed the altered surfaces under a digital microscope. The findings and results of the study are discussed in relation to the original objective of the study.

4.2 Laser Engraving

Laser engraving is a widely used process for creating intricate patterns and marks on various materials, including metals. In this study, we investigate the use of laser engraving for deep pattern marking on copper surfaces. The illustration that is being used to complete the study is shown in Figure 4.1. This illustration is chosen with the list of several aspects that can be evaluated. The line and edges that the engraving produces, the angle and circle shape, and the small detail that engraving on a copper plate can printed. To complete this study, a certain parameter is being used that consists of power and speed which are set as constant, loop and frequency as the variable. The study is conducted with four separate categories which are relative to the duration of the illustration being engraved. The category is leaving the engravement for 2 minutes, 4 minutes, 6 minutes, and 8 minutes. As for the original plan, the study also consists of 10 minutes, but the duration is too long as the copper

plate that being used are not too thick, and the result will only be useless as the laser will cut through the plate as Figure 4.2 which from the testing sample.



Figure 4.1 FTKMP black and white design.



Figure 4.2 Laser engrave with 10minutes duration.

The study that has been conducted focuses on different parameters. Although the parameters are changing, the study uses two categories to separate them which use 4 different durations for the engravement. The duration for the engravement is within 2 minutes, 4 minutes, 6 minutes, and 8 minutes. At the end, the only result that we take are the 2 minutes and 8 minutes as the others do not show too many differences. As for the parameters, Table 4, and Table 5 show how the studies are conducted.

2 Minutes Duration						
	Frequency: 50Hz	Frequency: 100Hz	Frequency: 150Hz	Frequency: 200Hz		
Loop: 1	FT	FT	FT	FTK		
Loop: 10	FT	FT	FIK	FT		
Loop: 100	FT	FTK	FR	FT:		
29	ل منیسیا ما	4	ی سبي به	اودو		

Table 4 2 minutes duration result

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 Table 5 8 minutes duration result

8 Minutes Duration							
	Frequency: 50Hz	Frequency: 100Hz	Frequency: 150Hz	Frequency: 200Hz			
Loop: 1	FT	FT	FR	FT			



4.2.1 Precision

According to study findings, the laser intensity, engraving speed, and blackand-white contrast of various engraving materials vary essentially. Laser loss can be delayed by engraving slowly and at a low intensity. Most materials perform better while moving more slowly (Xie et al., 2020). The precision of the engraved result such as clean, precise line and a lack of jagged edges or rough spots are the ways to use for confirming the acceptance of the best result. Figure 4.1 shows the best result gathered from the study that uses a certain parameter.



Figure 4.1 Copper plate with 2 minutes duration.

Figure 4.2 also proved that the duration of the laser engraving increased to 8 minutes. The outcome gives the same result with using the same parameter that is used on Figure 4.1. Figure 4.2 shows the result for the same perimeter which is using 100hz frequency and 1 loop count. The speed for the process is the same, which is 4000rpm and using 100% power as the constant in this entire study.



The other parameters that have been used are resulting in different quality and simply not the best outcome to get. Most of the results show how an even the line that have been created. The result is shown in Figure 4.3 and Figure 4.4 for 2 minutes and 8 minutes duration, respectively.

For the 2 minutes duration, the result shows how most of the other parameters are produced. The lines are making uneven shape which is wavery in a way that it follows the shape of the laser engrave step. As show in picture number 1,4 and 5 which when the engrave are at approximately 45 degrees. For picture 2 and 3 show a different

pattern as it is horizontal line, and the effect are shows at the beginning and the end that show the uneven pattern. For picture number 6, the pattern is also horizontal, but the line below is uneven. This all shows that this is not the best parameter to be used in the period of 2 minutes.



Figure 4.3 2 minutes results; 1,4 and 5 are show approximately 45-degree laser line shape after engraving, 2, 3 and 6 show horizontal laser line shape after engraving.

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As for the 10 minutes duration, the results are slightly different from the 2 minutes result. This is due to the duration of the engraving process are longer that gives the depth to the copper plate. Though the depth for the engravement is not too deep, the results are shown clearly.



Figure 4.4 8 minutes results; 1,5 and 6 show approximately 45-degree laser line shape after engrave, 2 and 3 show vertical laser line shape after engrave, 4 show horizontal laser line shape after engrave.

The results for number 1 until 6 are the same as each other. With the 45-degree cut in picture 1, 5, and 6, the engravement shows uneven cut and burning around the edges. While number 2 and 3 are engrave as vertical, the number 4 is engraved with horizontal. This is not a setting effect of the laser engrave. But the condition of the engravement depends on the time for the engravement stop referring to Figure 4.5. As the error will always occur due to human error, the directions of the final engraved is not constant.



Figure 4.5 Uneven engrave due to sudden stop.

4.2.2 Roughness

For aesthetic reasons, smooth laser engravings are frequently preferred since they can give the finished product a more polished and polished appearance. Additionally, smooth laser engravings might be more resilient to fading and abrasion over time (Sikora et al., 2019). Because they lack distracting flaws that could conceal the engraving, smooth laser engravings are frequently simpler to read and comprehend.

To investigate the smoothness of the product, a roughness test is needed to precisely get the data. Unfortunately, we are not doing the testing as the objective of the project is to investigate the product only by microscope observation.

In a study(Genna et al., 2010), the roughness of the surface is depending on the frequency of the feed and as equivalent to the speed of the laser as shown in Figure 4.6.



Figure 4.6 Roughness Ra as a function of frequency, for two scan speeds and line spacing.

Other than the frequency of the laser engraving, material removal rate is one of the reasons that affect the roughness of the surface after engravement as shown in Figure 4.7. The material removal rate is depending on the material uses and to obtain the low roughness, the high material removal rate is needed



Figure 4.7 Material Removal rate as a function of roughness Ra, for different plates and two line spacing.

4.2.3 Detailing

The detailing of laser engraving refers to the level of detail and precision that can be achieved in the engraved design. Laser engraving allows for the creation of detailed and intricate designs, as the laser beam can follow complex patterns and create precise and clean lines.

There are various circumstances that can lead to the engraving having such fine detail. The factors are the laser parameters, the material properties, the image resolution, and post-processing (Masood et al., 2011).

4.2.3.1 Laser parameters

The engraving's finer details can be affected by the laser's power, focus, and speed. Lower power and faster rates can yield shallower and less detailed engravings, whereas higher power and slower speeds can result in deeper engravings with greater detail. Figure 4.8 shows the difference for the laser parameters. In Figure 4.8, the parameters used are shown in Table 6. Those results are picked randomly as it is to shows the difference in the usage of the laser parameters.

Power: 100%	Power: 100%
Speed: 4000 mm/s	Speed: 4000 mm/s
Frequency: 50Hz	Frequency: 200Hz
Loop: 1	Loop: 1
Power: 100%	Power: 100%
Speed: 4000 mm/s	Speed: 4000 mm/s
Frequency: 50Hz	Frequency: 100Hz
Loop: 100	Loop: 10

Fable 6 Parameter	used fo	or Figure	4.8
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Figure 4.8 The difference of the parameter uses in two minutes duration which show illustration of 1 JULAI 2018.

4.2.3.2 Material properties

Copper's weak mechanical characteristics, such as its low wear resistance and tendency to oxidize easily when exposed to harsh conditions, drastically reduce its service life (Ma et al., 2022). Copper has a low melting point compared to other metals, which can make it easier to work with using laser engraving techniques. However, if the laser is set to a power level that is too high, the copper may melt and cause the engraving to be less detailed or have a melted appearance as in Figure 4.9.



Figure 4.9 The melting copper removes the details from the illustration in 8 minutes engraving duration as the heat are high.

4.2.3.3 Image resolution

Images with a higher resolution have more pixels, which means they are more detailed. When a high-resolution photograph is utilized for engraving, the finished engraving will typically be more detailed and clearer. The engraving, on the other hand, will be less detailed and may appear pixelated or hazy if a low-resolution image is used for it. Less detail will be present in the engraving the lower the image resolution. Figure 4.10 shows the difference between high resolution illustration and low-resolution illustration.

To get the finest results in terms of detail, it is crucial to pick an image with a resolution suitable for engraving. The size of the engraving and the capabilities of the engraving machine being used will determine the ideal resolution(Imran & Athitsos, 2020).



Figure 4.10 First picture shows a poor resolution compared to the other.

4.2.3.4 Post-processing

One of the methods is to use touch-up techniques, like hand-sanding or polishing, to smooth out the engraving's surface and increase the level of detail. These methods can help to smooth out any uneven or rough areas and highlight the engraving's finer details.

Utilizing color-filling methods is another way that post-processing might impact the laser engraving's level of detail. It may be feasible to draw attention to particular details and make them more visible by coloring in the engraving. The contrast between the colored fill and the material can aid in bringing out the details, which can be especially useful if the material being engraved is a black color.

4.3 Result of the laser engraving

Table 7 and 8 show all the results of the laser engraving within 2 minutes and 8 minutes long. Several parameters were used to investigate the effect of laser engraving. The only parameters that change during the study are the Loop, Frequency, and duration of the engraving. There are two perimeters that are constant though out the study, which are the power and the speed of the laser engraving.

4.3.1 2 minutes



Table 7 The frequency and loop result of the laser engraving for 2 minutes.



By referring to the quality of the result in Table 7, we can determine that when the loop increases, the burning mark will increase, and the quality of the marking decreases. It is because the loop will increase the heat as every loop counts. As for the frequency, the effect can depend on the value. If the value of the frequency increases, the burning mark decreases which given the marks on the copper plate better. Though, as the heat from the count of the loop becomes higher, the burning mark becomes less as the frequency increases. The best overall result for these 2 minutes duration is the result from the parameter of frequency of 100Hz and loop count 1.

4.3.2 8 minutes

Table 8 The frequency and loop result of the laser engraving for 8 minutes.





Table 8 shows a good trend separating the effect of the frequency and the loop. As the frequency of the laser engravement increases, the burning mark also increases and the quality of the engravement in terms of the precision decreases. The loop also affects the burning mark and quality of the engravement. The loop count is best when it is only one as the more the loop, the worse the marking on the copper surface. Overall, the quality at the best in these 8 minutes duration is the frequency at 100Hz, and the loop count 1.

4.3.2.1 Highlight

Figure 4.11 shows the effect of heat from the laser engrave. The color of the copper changes due to the heat of the laser engrave. A striking feature of copper and copper alloys is their surface appearance, which is influenced by factors like color, gloss, lightness, texture, and shape. The conditions at the time of observation and the observer affect the color.(Asadipour et al., 2022).

As for the gap that happens in Figure 4.11, it is because the material used is only 0.5mm thick. The duration of the engraving is not suitable for the thickness of the copper plate. This is one of the reliable results as the objective is to get the deep pattern of the laser engrave.



Figure 4.11 Results from 8 minutes duration from laser engrave



CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Basically, the outcome of this study supports us to:

- 1) The copper thickness that was used in this study is not a good one. This is because to achieve the second objective which is evaluate the deep pattern, a thick plate is really needed. But to achieve the best quality is one more thing which we can get by evaluating the trend of the results. The best result can be evaluated as we consider the best quality of the engravement that consist of the precision, roughness, and detailing. So, the best outcome of the study is the one that in 8 minutes which frequency 100Hz and the loop count one.
- 2) The illustration that is used for the laser engraving are important as the detailed UNIVERSITI TEKNIKAL MALAYSIA MELAKA and the resolution need to be at the best to be able to transfer the illustration to the copper plate with such detailed. The illustration is selected carefully and intentionally as it will give the result more variable and can be investigate the shape of the illustration in the aspect of perfect transfer to the copper plate.
- 3) The post-process is important to the study as the copper can be reactive to the surrounding and form an oxidation that will affect the result of the study. This is one of the important processes that need to bring forward.

5.2 Recommendation

There are some tips on how to improve the final year thesis project.

- Scanning electron microscope analysis to study the material structure in lasermaterial interaction. An electron microscope is a type of microscope that uses a beam of electrons to create a high-resolution image of a sample. There are several types of electron microscopes, including transmission electron microscopes (TEM) and scanning electron microscopes (SEM). Electron microscopes can produce images with a much higher resolution than optical microscopes and can be used to study a wide range of samples, including biological specimens, materials, and nanostructures.
- 2) For selecting the parameters to be used in the study, we are recommending using the Taguchi Method. The Taguchi method involves designing experiments using a set of predetermined levels for each process variable and collecting data on the performance of the process or system at each level. The collected data is then analyzed using statistical techniques to identify the optimal combination of levels for each variable, which will produce the desired performance.

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APPENDICES

APPENDIX A GANTT CHART FOR PSM 1



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APPENDIX B GANTT CHART FOR PSM 2



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