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# Effect of Laser Parameters on the Surface Cleaning of Galvanised Steel by Laser Engraving Process

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**ABSTRACT**

*Laser cleaning is a method of removing layers of material from a surface by using laser irradiation. The energy from the laser provides a textured pattern on the melting surface, as well as colour changes and variations in surface roughness. This study looks into the effect of laser parameters on the cleaning surface of galvanized steel. In particular, the laser engraving method was used to irradiate the selected area by varying the laser power and irradiation cycle. The results show that the upper layer of galvanized steel can be rapidly removed, altering the surface profile and roughness. Increasing laser power and cycling the resultant colour change from white or bright to dark. In terms of surface roughness, the first irradiation cycle demonstrated increasing surface roughness as laser power was increased. The fourth cycle, on the other hand, showed a decrease in surface roughness as the laser power increased. In terms of surface finish, laser engraving at 16W power is recommended due to its best surface roughness of 1.17 µm. In terms of surface profile, laser engrave is suggested to be applied during the fourth irradiation cycle because the surface pattern demonstrated dark appearances and minimal surface roughness.*

**Keywords:** Laser engrave, surface cleaning, laser power, irradiation cycle, surface roughness

## 1. INTRODUCTION

Galvanized steel is a metal sheet-based substrate that has been zinc-coated for corrosion resistance. Galvanized steel can be used in the automotive, shipbuilding, agriculture, and mining industries due to its lightweight, high formability, and low cost [1-2]. Examples of galvanized steel products include tank walls, infrastructure, and agricultural components. The most efficient method of producing galvanized steel is the electroplating process. Electroplating is a process that involves hydrolysis of plating material via ion deposition onto another surface to avoid corrosion. Hot dipping is another method of producing galvanized steel. Hot dipping is a process that involves immersing steel in molten zinc at high temperatures, allowing the zinc to become permanently attached to the surface. The hot dipping process is preferred for fast and thick coating as well as mass production manufacturing [3-4].

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Surface cleaning refers to the removal of a thin layer from the surface in order to remove rusty areas, unwanted dust, dirt, varnish, and other debris.

Depending on the materials, applying laser cleaning to the surface may cause the color of the surface to become more visible, such as sharp, clear, or dark. The surface profile can also be altered by the irradiation laser, resulting in changes in surface roughness, hardness, and microstructure. In the case of galvanized steel, the surface cleaning process may delaminate the zinc coating on the surface, exposing the sheet metal substrate. This may result in changes in product appearance, precision, corrosion resistance, and friction coefficient [5-6].

Some technologies can be used successfully for surface cleaning process. Among the most common methods are abrasive waterjet and laser engraving. High-pressure water is used to clean the abrasive waterjet. The high-pressure compressor blasted water through a small conduit nozzle to delaminate the surface's outer layer. When the nozzle, pressure, and abrasive particles penetrate the surface beyond the material's strength, the technology can even cut the surface. Surface cleaning with a water jet can be done without causing any damage to the steel's surface. However, the abrasive action of the particles causes the system to produce a very low surface finish. Furthermore, the abrasive waterjet process necessitates the installation of a drainage system to drain excess water, which necessitates a large amount of space to facilitate the technology [7-8].

On the other hand, the laser engrave process is an effective alternative for cleaning the surface and producing high levels of surface finish. Essentially, the laser engraving process consisted of remelting the surface with laser beam energy to create a molten pool on the surface. The molten pool is being absorbed by vacuum, leaving surface texture patterns on the laser-affected area. The laser engraving process has several significant advantages, including the ability to manage a well-defined area using total automation and controls. The process also provides non-contact single-step operation, which reduces mechanical forces at the interface, tool deformation, and tool wear caused by heat and friction [9-10].

The effect of process parameters on the microstructure and phase composition of oxide film, which is frequently focused on the ferrous and nonferrous materials has been discussed in the majority of works on laser engraving [5,6,10,11]. However, the characteristics of galvanized steel being surface lasered are rarely reported. The influence of laser parameters on surface roughness and surface profile of galvanized steel is investigated in this study. A fibre laser source was used to investigate the effect of process parameters such as laser power and irradiation cycle on surface roughness and surface profile. The best parameters were proposed to engrave a texture pattern in order to penetrate surface characteristics at the microscopic level.

## 2. MATERIAL AND METHODS

The primary material in the study is galvanized steel in the form of metal sheet. The material was prepared in the following dimensions: 120 mm width, 200 mm length, and 3 mm thickness. Tables 1 and 2 show the alloying element and mechanical properties of galvanized steel, respectively.

**Table 1** Mechanical properties of galvanized steel [1]

| Properties | |
|---|---|
| Modulus of Elasticity | 200GPa |
| Bulk Modulus | 160GPa |
| Shear Modulus | 80GPa |
| Yield Strength | 147-384 $N/m^2$ |
| Tensile Strength | 278-422 $N/m^2$ |

**Table 2** Chemical composition of galvanized steel [1]

| Element | Chemical Composition (Wt% Present) |
|---|---|
| Carbon (C) | 29-162 |
| Silicon (Si) | 1-157 |
| Manganese (Mn) | 177-644 |
| Phosphorus (P) | 3-21 |
| Sulphur (S) | 1-17 |
| Vanadium (V) | 1-70 |
| Aluminum (Al) | 18-63 |

The laser engrave machine used in this study is depicted in Figure 1. This fiber laser engrave machine, modelled as LH20-E-A has maximum power of 20W with capacity to engrave up to 175mm x 175 mm area. To draw the engraving area and set the laser parameters, the Ezcad software was used as an interface. The EZCAD interface is represented in Figure 2. The parameters used in this experiment are shown in Table 3.


**Figure 1.** Fiber LH20-E-A Laser engraving machine.

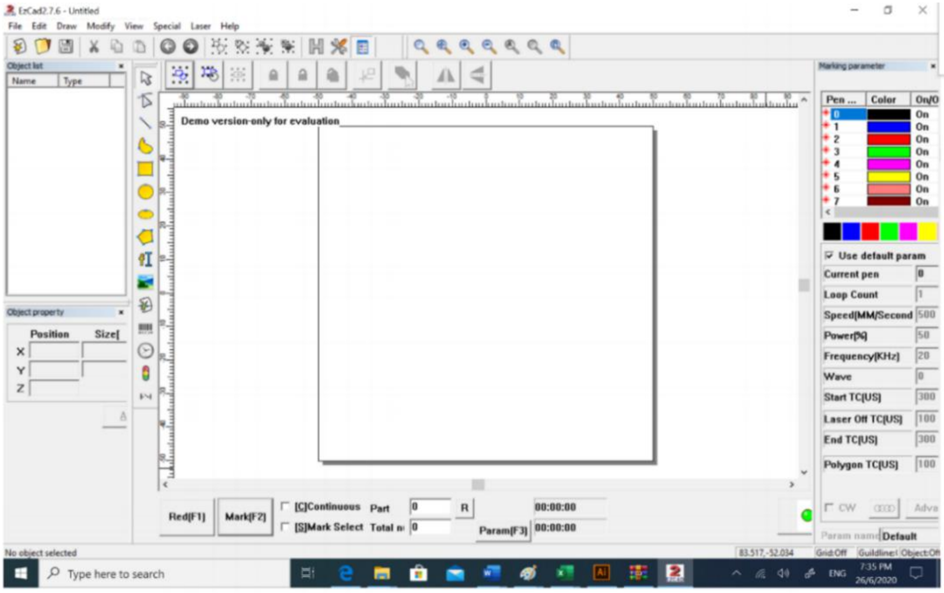
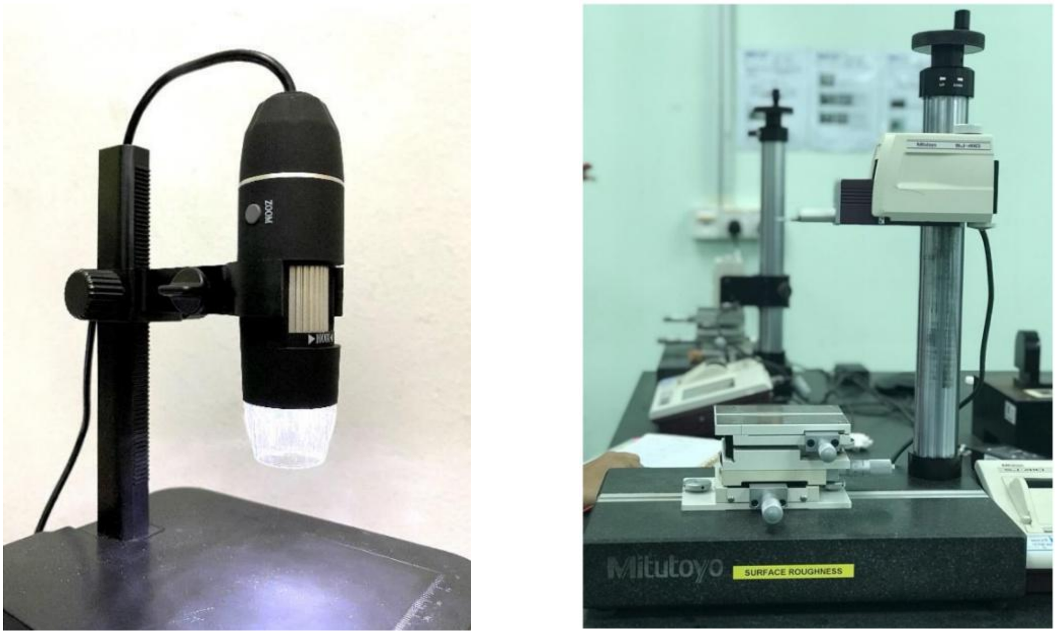



**Figure 2.** Ezcad interface for laser engraving operation.

**Table 3** Parameters involved in this experiment

| | **Parameter** |
|---|---|
| **Power** | 4W (20% power) |
| | 8W (40% power) |
| | 12W (60% power) |
| | 16W (80% power) |
| **Cycle** | 1$^{st}$ , 2$^{nd}$ , 3$^{rd}$ , 4$^{th}$ |
| **Speed** | 2000 mm/s |
| **Frequency** | 20 kHz |

The surface profile of the engraved area was observed by USB Microscope as the galvanized steel was engraved, as shown in Figure 3 (a). In addition, as shown in Figure 3 (b), the surface roughness values for each engraved area were examined using a Mitutoyo Surftest stylus profilometer.




(a) (b)

**Figure 3.** (a) USB Microscope (b) Surface roughness tester.

## 3. RESULTS AND DISCUSSION

Figure 4 shows the outcome of laser engraving on galvanized steel. Before cleaning, the surface was coated with a coaten zinc layer, which made the surface appear reflective and shiny. The surface was white at 4W laser power. The white appearances were consistent from the first to the fourth irradiation cycle. There is evidence of overlap marks in the centre of the engraved area for the first and second irradiation cycles. When the laser power was increased to 8W, the surface appearance displayed a variety of colours. Starting with a white appearance on the first irradiation cycle, the colour darkened as the cycle lengthened. The final colour at the fourth irradiation cycle and 8W power is uniform bronze, as shown in Figure 4 (n). When the power is increased to 12W, the majority of the engraved surface area is in dark colour. Figure 4(c) depicts a colour mixture of dark grey and white at the first irradiation cycle. As the cycle increased to the fourth irradiation cycle, the colour changed to dark bronze. When the laser power was increased to its maximum of 16W, the majority of the engraved surfaces turned a deep bronze colour. Overall, it can be seen that increasing the laser and irradiation cycle power changes the colour from white or bright to dark appearances.

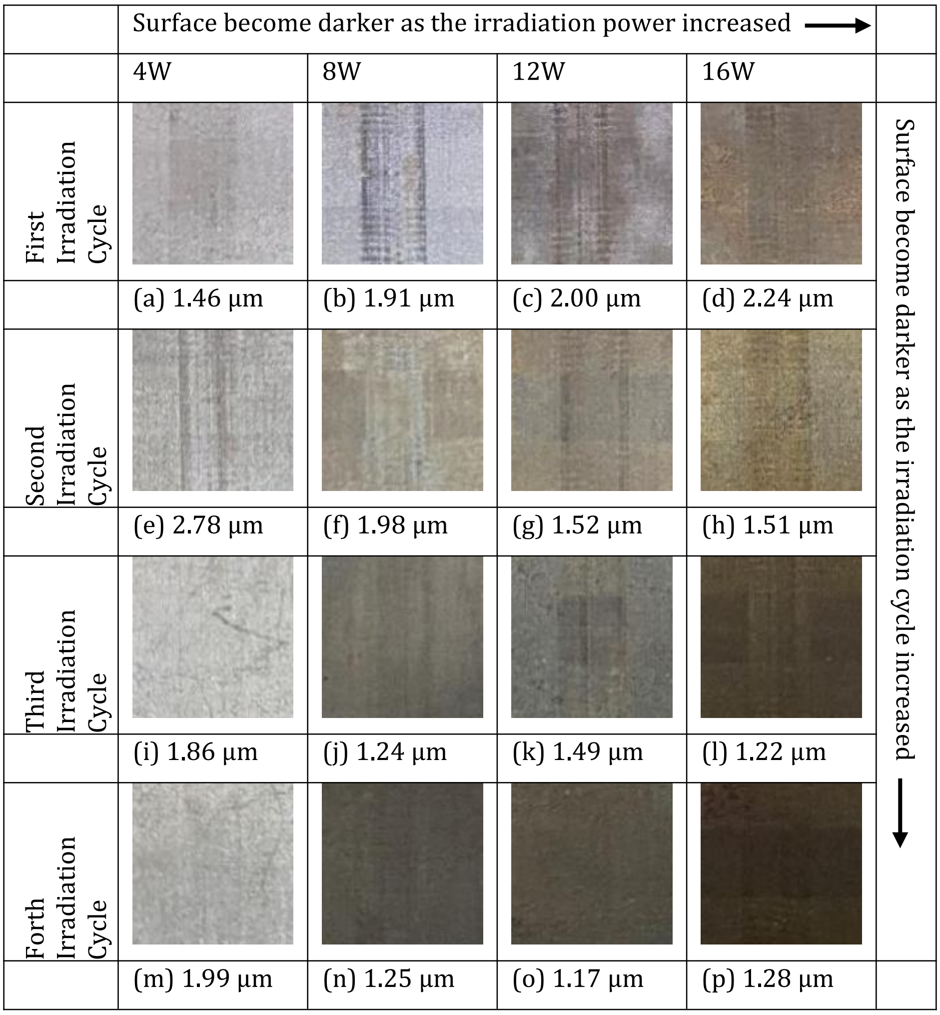



**Figure 4**. Surface profile of engraved galvanized steel with corresponding surface roughness.

The appearance of the surface is a critical outcome of the laser cleaning process. During the laser engraving process, high localized laser power leaves the surface in the form of a micro-crater. When this micro-crater is modified into a different shape or pattern, the cleaned surface can be transformed into an appealing display in the form of symbols, fonts, or logos. As a result, the laser engrave process is appropriate for use in code marking processes for bearings, engine chasis, or machinery components. Furthermore, the laser engraving process can be used to create an appealing product for souvenirs such as plaques, coins, or signage for the tourism industry [11-12].

Figure 5 presents the distribution of surface roughness for galvanized steel. Overall, the surface roughness decreased as the irradiation cycle increased. There are two patterns that can be distinguished from the variant of surface roughness. The first pattern was captured during the first irradiation cycle, when the surface roughness increased as the laser power increased. The second pattern was recorded for the second, third, and fourth irradiation cycles, and the surface roughness decreased as the laser power increased. Within 16W laser power and the fourth irradiation cycle, the minimum surface roughness was measured at 1.17 µm. Maximum surface roughness was measured at 2.93 µm within 4W power and the second irradiation cycle.

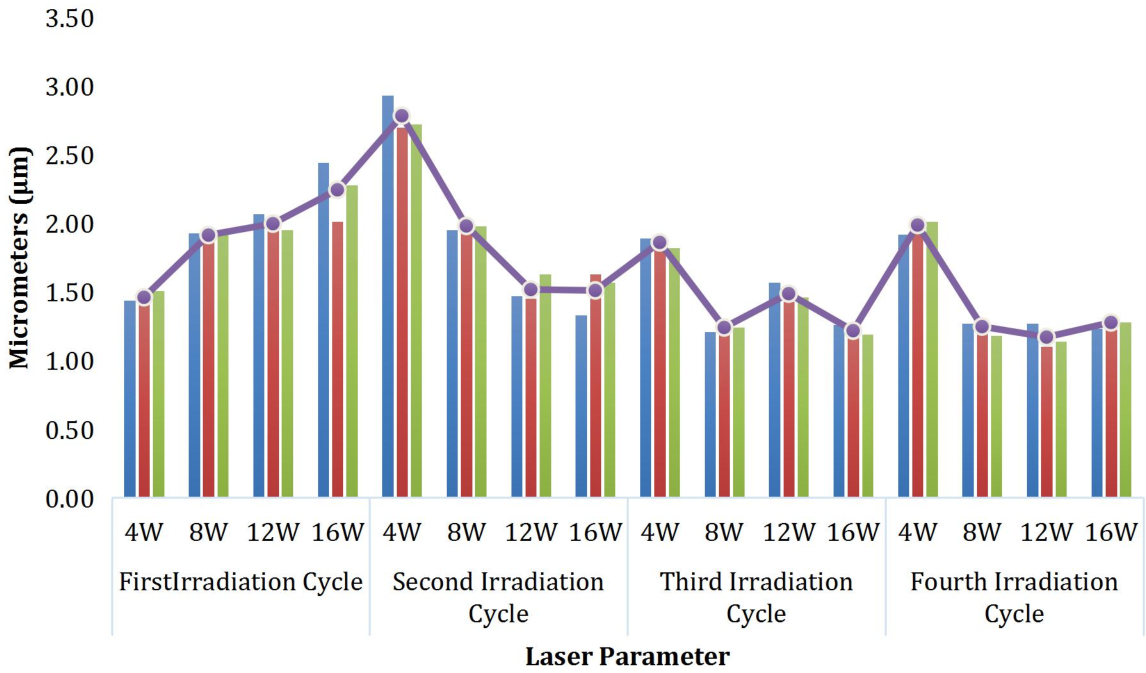



**Figure 5.** Surface roughness of engraved galvanized steel.

Determining the roughness of a surface is critical from a practical engineering standpoint. Surface roughness allows designers to evaluate the accuracy of processed components by predicting variables such as the amount of friction or vibration produced between two contact surfaces. Furthermore, the surface roughness value enables engineering to predict the capability of a component to provide lubrication and estimate the component life of a part [13-14].

The results from the Figure 5 shows that the roughness of the engraved surface increases with increasing laser power, particularly during the first irradiation cycle. According to Shi et al. [15], as the laser power increased, so did the amount of energy bombarded onto the surface. This energy is absorbed by the upper layer of galvanized steel, resulting in a molten state. This molten area is absorbed by the vacuum, resulting in craters in the laser-affected zone. More laser power produces larger and deeper craters, increasing the surface roughness of the cleaned surface.

However, when the second, third, and fourth irradiation cycles are applied to the surface, the surface roughness tends to decrease as laser power is increased. This is due to the fact that the multiple paths of laser power create a larger molten pool at the engraved area. When this laser path overlaps, the peak and valley on the engraved surface can be removed using a repeatitive removing layer per unit area, resulting in lower surface roughness [16].

Figure 6 presents the isolated data of surface roughness for laser irradiation at 12W. It is clear that engraving with the fourth irradiation cycle has the lowest surface roughness at 1.17. Surface roughness decreased up to 42% from the first to the fourth irradiation cycle. Figure 7 depicts the effect of laser irradiation power on surface roughness in terms of irradiation power. Surface roughness decreased from 2.00 to 1.17 when the irradiation power was increased from 4W to 12W. When a 16W laser was used to engrave the surface, the surface roughness increased slightly to 1.28. Overall, increasing the laser power from 4W to 12W reduce the surface roughness up to 41%.

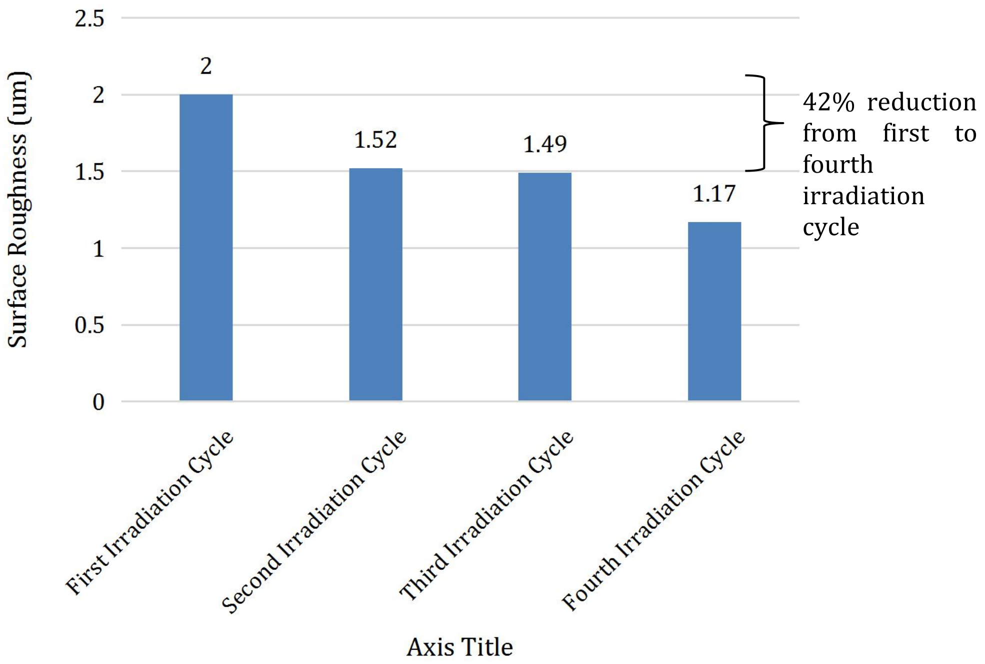



**Figure 6.** Surface profile at $4^{th}$ irradiation cycle for 12W power.

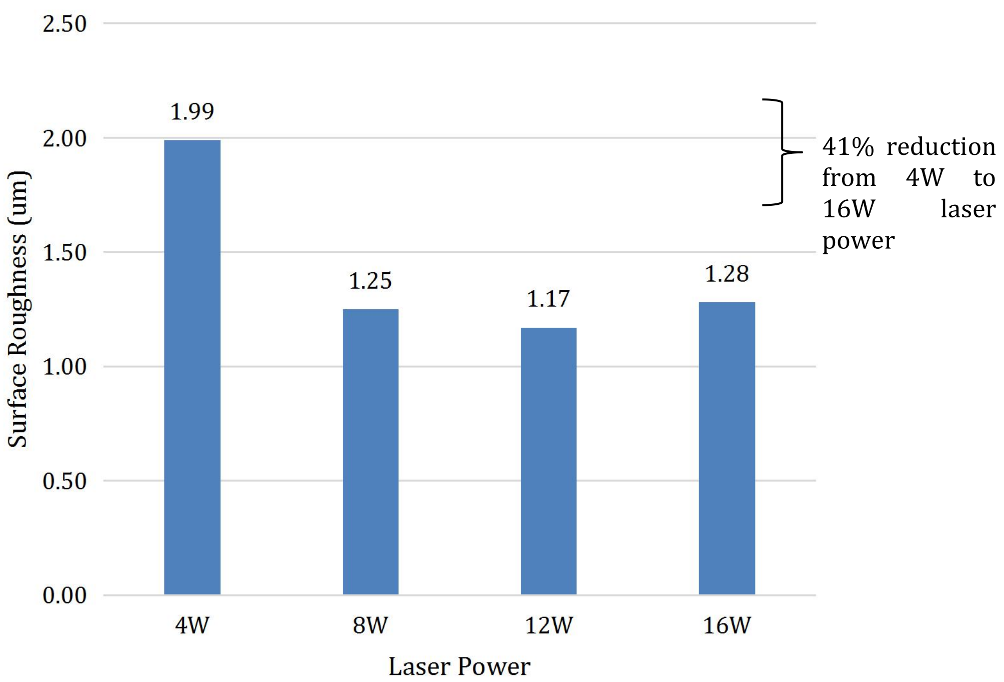



**Figure 7**. Surface roughness at $4^{th}$ irradiation cycle.

Figure 8 (a-d) depicts the surface profile of engraved galvanized steel during the 4th irradiation cycle operation after laser engraved from 4W to 16W. The surface was white at the lowest power setting of 4W. The colour of the surface darkened as the power increased to 8W. The surface quality is further improved when the power is increased to 12W, where the surface appears dark-brownish in colour, with burning marks beginning to appear at this stage. It should be noted that at 16W power, there is obvious surface overburn, which is to be expected due to the excessive power irradiated the material [10]. Figure 8 (e-h) represents additional analysis through microscopy observation. In terms of surface roughness, increasing power results in an increase in surface roughness, as shown in Figure 8(e). The initial surface roughness was measured at 1.99 μm. When the power is increased from 4W to 8W, there are obvious overlap marks in the form of parallel lines at the central area of the engraved surface, as shown in Figure 8(f). When the power was further increased to 12W, the overlap marks became darker with a uniform countuor of laser marks, to record minimum surface roughness of 1.17 μm (Figure 8(g)). There is evidence of dark sport at the highest power setting of 16W, implying that the surface was irradiated into an overburned state (Figure 8(h)). These darker spots amplify the surface roughness slightly higher to 1.28 μm.

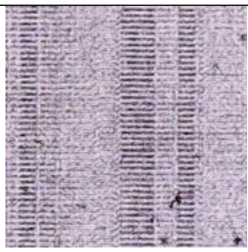
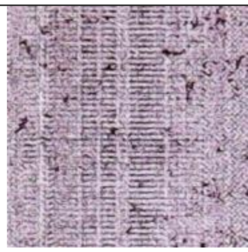
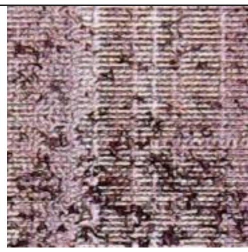
| | | | |
|---|---|---|---|
|  |  |  |  |
| (a) | (b) | (c) | (d) |
|  |  |  |  |
| (e) | (f) | (g) | (h) |
| 4W power, 1.99 μm surface roughness | 8W power, 1.25 μm surface roughness | 12W power, 1.17 μm surface roughness | 16W power, 1.28 μm surface roughness |

**Figure 8.** Surface texture at $4^{th}$ irradiation cycle from 4W to 16W irradiaton power.

Figure 9 (a-d) shows the surface profile of engraved galvanized steel at 12W from the first to fourth irradiation cycle. The surface finish appeared brightly coloured during the first irradiation cycle. As the irradiation was increased to the fourth cycle, the colour became darker bronze, with surface burning marks caused by repeated layer removal on the lasered surface (Figure 9(d)). Further examination at the microscopy level in Figure 9(e-h) reveals that the surface marking appeared in the same form under all conditions. There is some overlap in the marks for the irradiation of the second and third cycles (Figure 9(f) and (Figure 9(g)). However, the feed mark is slightly smaller at the fourth irradiation cycle (Figure 9(h)). The surface roughness was initially recorded at 2.00 μm before decreasing to 1.17 μm after the fourth irradiation cycle. Obviously, laser engraving can significantly improve the surface characteristics in this situation.

It can be proposed that the most appropriate parameters for surface appearance are the fourth irradiation cycle at 12W laser power. Figure 10 shows the best parameter used during the laser engraving process. Because of the high parameter used with 2000 mm/s speed, the surface was carved deeper with a darker appearance.

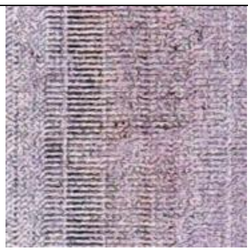
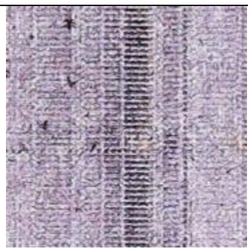
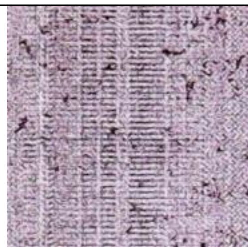
| | | | |
|---|---|---|---|
|  |  |  |  |
| (a) | (b) | (c) | (d) |
|  |  |  |  |
| (e) | (f) | (g) | (h) |
| First Irradiation Cycle, 2.00 µm surface roughness | Second Irradiation Cycle, 1.52 µm surface roughness | Third Irradiation Cycle, 1.49 µm surface roughness | fourth Irradiation Cycle, 1.17 µm surface roughness |

**Figure 9.** Surface profile at 12W irradiation power from first to fourth irradiation cycle.


**Figure 10.** Surface appearance for best selection of parameter.

Figure 11 depicts additional observations of the intricateness quality of laser engrave. It demonstrates that there is a groove formation as a result of laser melting at the area for each laser irradiation in the form of engraved lines. The zinc coating is expected to have vanished from the engraved area, revealing the steel substrate [17-18]. Furthermore, the formation of a groove increases the surface's ability to create fluid retention, especially when exposed to a humid environment. This condition increases the risk of corrosion when the steel substrate is exposed to the respected environment for an extended period of time [19]. To reduce the risk of rust, the engraved surface should be coated with antirust lubricant, such as clear aerosol spray.

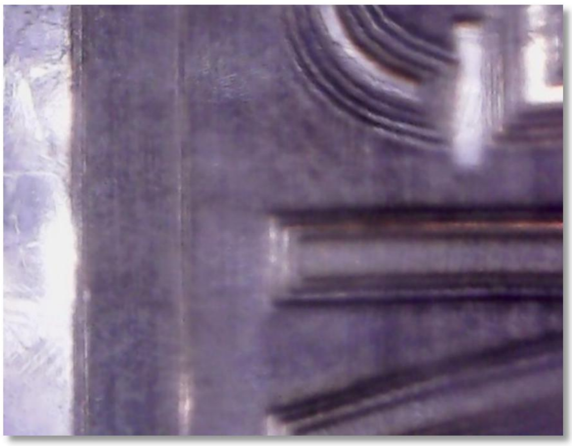


**Figure 11.** Higher magnification of surface observation.

## CONCLUSIONS

The effect of laser engraving parameters on the cleaning surface of galvanised steel is investigated in this study. To observe surface profile and surface roughness, the laser power and irradiation cycle were varied.

i. Increasing the laser power and irradation cycle contributed to the colour shift from white or bright to dark appearances.
ii. Due to the finest surface roughness of 1.17 μm, laser engraving is recommended to be performed at 12W power and the fourth irradiation cycle.
iii. Surface roughness increased as laser power increased in the first irradiation cycle.
iv. Surface roughness decreased as laser power increased in the second, third and fourth irradiation cycle.

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