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THE IMPACT OF LASER ENGRAVING PARAMETERS ON THE COLORIMETRIC PROPERTIES OF STEEL SURFACES

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Introduction

In a study of laser-induced color marking (Antończak et al., 2013) it was found that initial temperature of a sample, as well as its size, does not have an impact on color variation of similar samples, while parameters such as speed and power had dominant influence on color change. They also found that lower frequencies gave more saturated colors. Amara et al. (2015) concluded that the difference in the thickness of an oxidized layer was responsible for different color generation on steel surfaces. This can indicate that varying speed and line distance has an influence on forming different oxide layers. In a formation of color on stainless steel study (Linggamm et al., 2021) it was found that defocusing distance, hatch distance and pulse width have a great effect on obtaining color on stainless steel surface. The study shows that the same colors can be produced with different laser parameters, but the brightness and saturation of colors can differ. Linggamm et al. (2021) also investigated roughness of the surface of the color obtained. The study concluded that roughness of the surface is an important aspect of color making where smoother surface and large value of pulse width produces brighter and lighter colors because the heat is distributed more evenly. Respectively, the rougher the surface the color gets darker. The study also found that pulse width and defocusing distance had more influence on coloring stability than hatching distance. A review on parametric optimization of laser engraving on various materials (Mehta & Thakkar, 2015) concluded that almost all laser parameters and their effects on different surfaces have been studied and that it is possible to create a proper optimization of the laser parameters for high production with great quality which could be beneficial for graphics industry.

Problem Description

This study investigated the effects of fiber laser engraving parameters on the colorimetric properties of steel surfaces. The laser parameters examined for color generation included power, speed, frequency, hatching, and pulse width.

Methods

Representative color samples were measured using an iProfile Pro spectrometer and surface structures were observed under a microscope to identify correlations with the resulting color parameters. Additionally, the study explored the color variation that occurred when altering the angle of the laser beam while engraving larger surface areas.

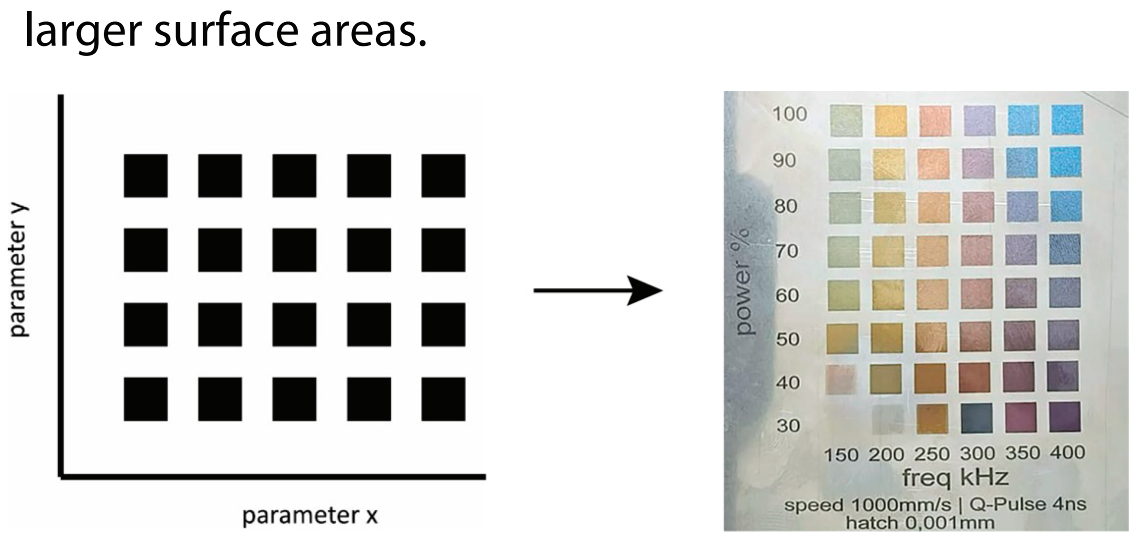

Figure 1
Laser parameter matrix for color testing

Results

In this section, we present the analysis of the test samples created using various laser parameters. The samples were examined using both a spectrometer and a microscope to provide a comprehensive evaluation of the surface coloration. The spectrometer measurements offer quantitative data on the colorimetric properties, while the microscopic analysis allows us to observe the surface structure and texture in detail. By combining these methods, we aim to identify key correlations between the laser settings, surface morphology, and the resulting color stability and intensity.

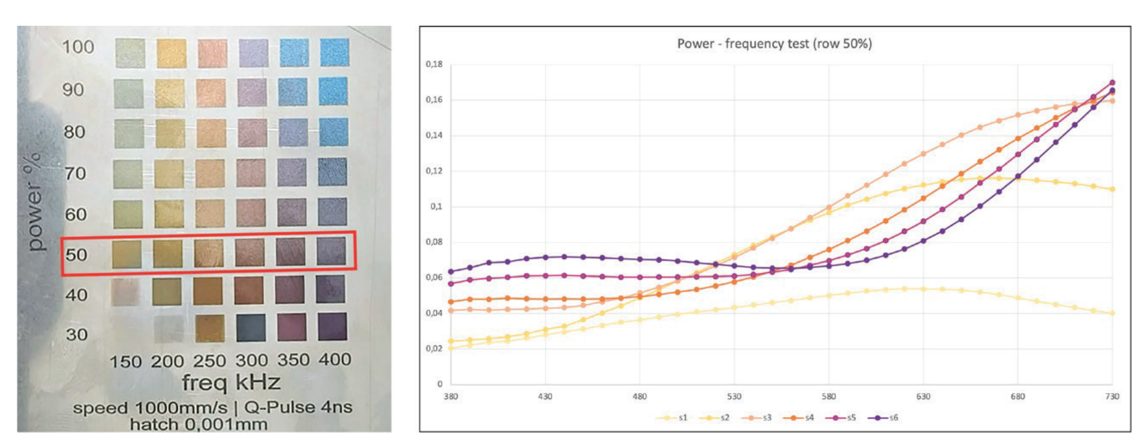

Figure 2
Power-frequency test results

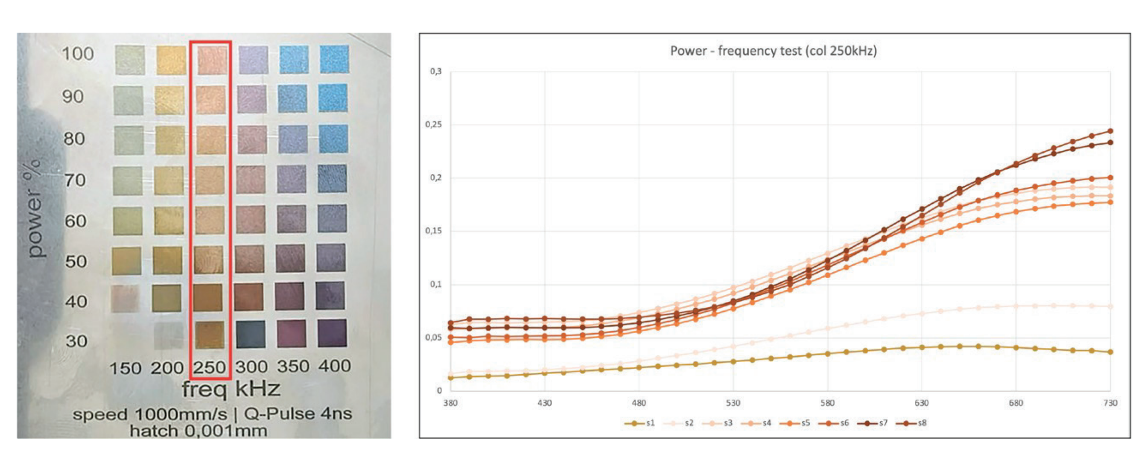

Figure 3
The influence of laser power on surface coloration

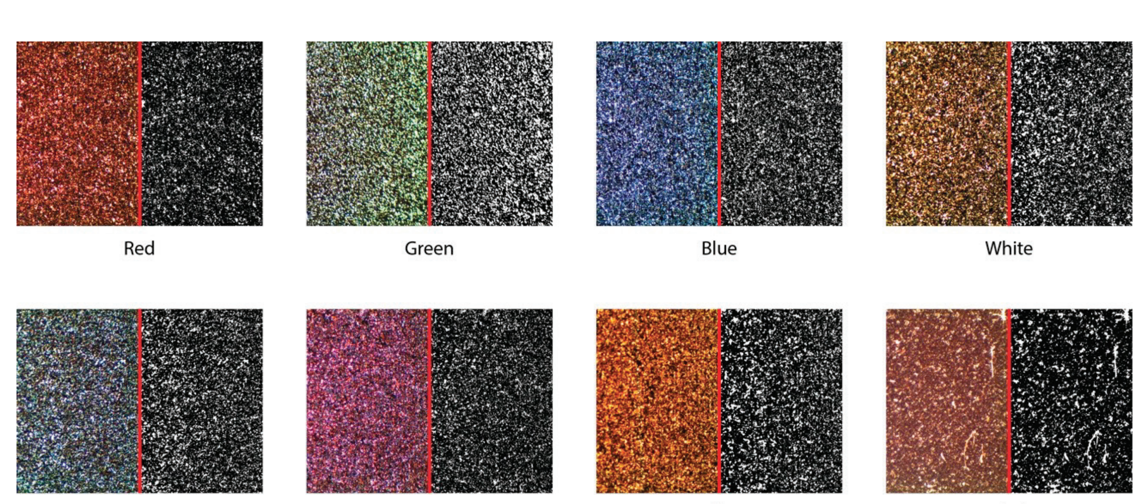

Figure 4
Surface structure complexity

The Figure 5. shows the results of a test examining how changes in the working area of laser engraving affect the color output on steel surfaces. The concentric circles on the left represent different engraved areas, with diameters ranging from 60 mm to 150 mm, simulating the effects of engraving over increasingly larger surface areas.

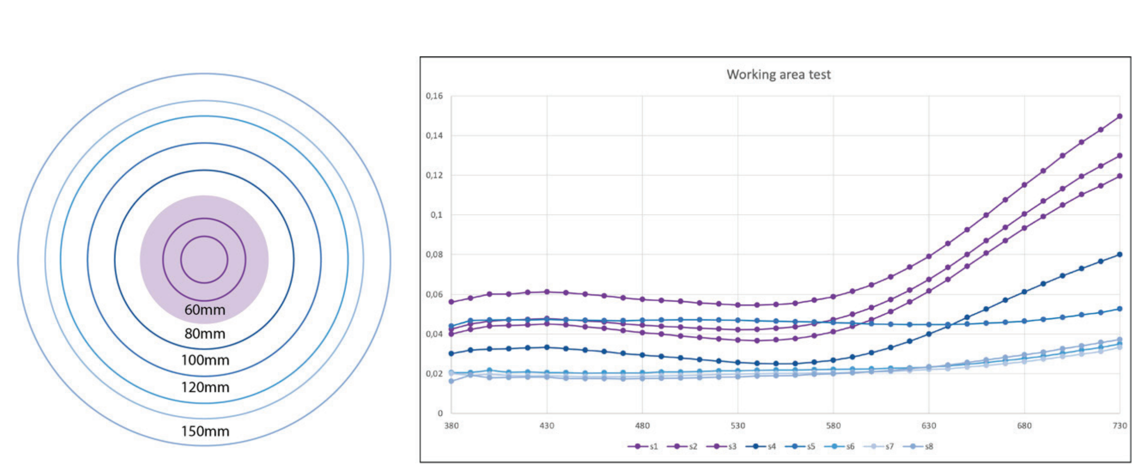

Figure 5
The influence of the laser beam angle on surface coloration

Discussion / Conclusion

The results of this study demonstrate a clear correlation between laser parameters, such as power, frequency, speed, pulse width, and hatching, with the color and saturation achieved on steel surfaces. Variations in laser power indicate that lower power levels (below 40%) generally do not produce saturated colors, while mid-range power levels (50%-80%) yield the most vibrant hues. As the frequency increases, particularly in the range between 250 kHz and 400 kHz, the colors shift from warmer tones to cooler tones. This highlights the critical role of frequency in color control, while power modulates the intensity and saturation of the colors. Furthermore, the tests investigating the combination of speed and frequency revealed that optimal speeds between 1000 mm/s and 1200 mm/s result in the best color saturation. Higher speeds, although reducing engraving time, lead to less saturated colors due to the reduced interaction time between the laser and the surface. Interestingly, certain colors can be achieved using different laser parameter combinations. For example, the same color can be produced with a combination of 200 kHz frequency and 600 mm/s speed, as well as with 400 kHz frequency and 1200 mm/s speed. This indicates that multiple parameter settings can lead to the same visual outcome, allowing flexibility in optimizing laser settings for different production requirements. Experiments exploring the impact of the engraved area size showed that color changes as the surface area increases. On smaller areas (60 mm), the colors were more saturated and uniform, while on larger areas (>100 mm), color saturation decreased due to changes in the incident angle of the laser beam, which affected oxidation intensity.

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