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Laser-Induced Colourization on Metal Surface for Product Design

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Abstract. Colour generation by laser-induced colourization has several advantages compared to dye technology, such as higher resolution, minimal pixel areal and fastness colours. However, current colourization methods need to be pre-designed and the mechanism of laser-induced colourization are still need understanding. Here we investigate the effects of laser parameters on metal surface colourization. Different processing parameters induced transient local heat generation on metal surface that leads to different heat accumulation and oxide compound, which caused different interference with white light and then generating different colour appearance. The colour transition process also obeys the paint theory. This work provides a better way for product designer, engineer and surface researchers.

Keywords. Laser-induced colourization, nanosecond laser pulse, repeated frequency, product design.

1. Introduction

Laser has been widely used in drilling, ablation, and surface treatment. Laser-driven excitation of surface colourization on metal product design opens a new toolbox to product design. However, the interaction of laser-materials is the essential nature in all every application on metal material. As a bright technology for surface treatment, laser-induced colourization contributed a higher resolution with fastness colours on metal surface. A remarkable property for laser-induced colourization is plasmons that leads to exhibit scattering properties and producing colours by exploiting plasmonic effects on surface. Another feature for laser-induced colourization is that the thermal effect produced by nanosecond laser generated a large of metallic oxide on metal surface, which interference with the white light source and then presented a different colour. Therefore, this technology can be used in any metal colouring or any other applications where paint or pigments are not allowed.

Owing to the requirement on ablation characteristics and cold processing, the ultra-short laser have been used for materials colourization. From nanosecond pulse to femtosecond pulse, researchers still working on this topic. Jean-Michel Guay et. al investigated the colourization process on silver coins weighing up to 5kg, they find that the colours are related to parameter and accumulated fluence [1]. Xiaolong Zhu et al studied a printing method on nanoimprinted plasmonic meta surfaces, they find that the pulse energy density and surface morphologies can generates different colour appearances [2]. Fan at al investigated the picosecond laser on copper colourization, they find that lower scanning speed causes a denser distribution of nanoparticles with a nearly constant mean radius, where each colour can be generated by a set of parameters [3,4]. Wu

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et al studied the influence of picosecond laser such as scanning gap, scanning speed and pulse energy on colouring effects [5]. However, the picosecond laser [6,7] raised a high cost for customer, it is of great meaning to investigate the application of nano laser on metal colourization [8,9]. The biggest challenge for nanosecond laser is that the large clusters and chunks produced by nano pulse processing [10-12], which means the application of laser-induced colourization with nanosecond laser is still need exploration. Here, we investigate the effects of parameters on colours generation, and analyze the mechanism of laser colourization on metal surface. Finally, we designed a gradient picture on metal surface with a set of parameters, which means that the application of nanosecond laser on colourization is capable for product design.

2. Experimental setup

As presented in Figure 1, the experimental system consists of a laser, fiber, scanning system and focus lens. Nanosecond laser pulse generated by the laser machine, and the two of scanning galvanometers are controlled by an industrial computer where can read the scanning path or text. A stainless steel was fastened on the focal position of laser beam that is for the colourization experiments.

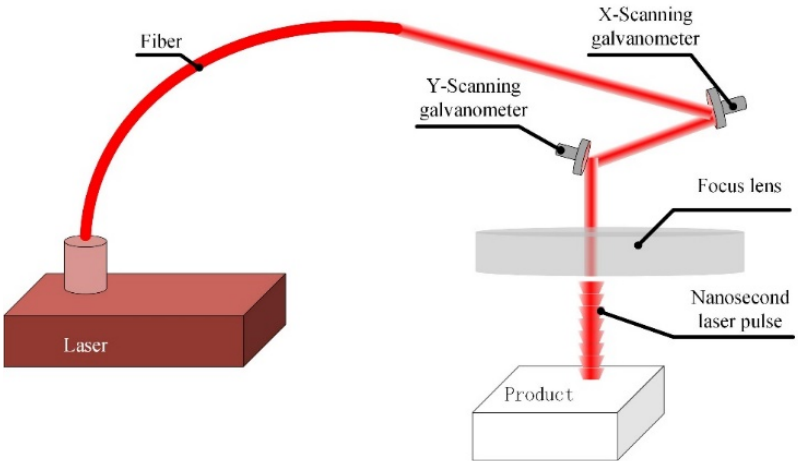


Figure 1. Experimental system for laser-induced colourization on metal surface.

$$E = f_{repeated\ frequency} \times P_{power} \times W_{pulse\ width} \qquad \text{(Eq. 1)}$$

In order to investigate the effects of repeated frequency of nanosecond pulse on colourization, we firstly kept the pulse width, laser power, focal position, scanning gap and speed as 8ns, 40W, 0mm, 0.001mm, 1000mm/respectively. The repeated frequency was set from 350kHz to 140kHz with a10kHz step. The different repeated frequency generates the changing of laser energy, this can be described in Eq.1 which $f_{\text{repeated frequency}}$ is the repeated frequency of pulse laser, E is the input energy of laser beam, P_{power} is the power of laser beam, $W_{\text{pulse width}}$ is the pulse width of each nanosecond pulse.

A microscope was used to capture the colours on metal surface.

3. Analysis and discussion

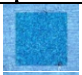
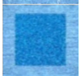
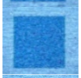
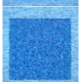
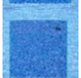
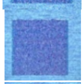
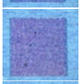
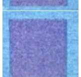
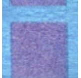
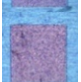
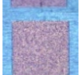
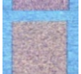
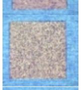
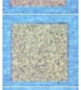
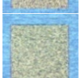
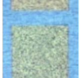
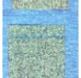
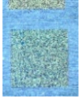
As described in section 2, the effects of repeated frequency on colour firstly studied for a better understanding on laser-induced colourization. The experimental results are presented in Table 1.

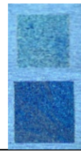
As shown in Table 1, 350kHz repeated frequency generated a blue on metal surface. With the decrease of repeated frequency, the colour trends to change from blue to purple colour. When the repeated frequency downs to 310kHz, the colour presents a purple on the metal surface. This phenomenon can be explained by the fact that the change of repeated frequency decreased the laser energy on metal surface, which means that the heat accumulation has been changed and caused a variation on the degree of oxidation. Finally, the presented colour been changed into a purple. According to the colour theory on paint, the purple can be generated by mix the blue and red. This also can be certified by the next experiments. As the continuous decreasing on repeated frequency, a purple-red colour starts to shown on the metal surface when the repeated frequency reach at 270kHz. This phenomenon can be explained by the fact that the interference characteristics of oxide compound is changed due to the variation on heat accumulation. With the decrease of repeated frequency, the colour trends to become red on the metal surface. The colour is completely changed into red when the repeated frequency reached at 240kHz.

According to the colour theory on paint, the orange colour can be generated by mix the red and yellow. As described above, red colour can be obtained at 240kHz repeated frequency. In theory, a yellow colour can be obtained when the oxide compound changes linearly from what the red is. Therefore, we kept decreasing the repeated frequency on metal surface. A yellow colour is obtained when the repeated frequency reached at 200kHz. During the experiments, red-yellow colour gradually presents on the metal surface when the repeated frequency downs from 240kHz to 200kHz. This transition process as described as red-yellow is named orange colour in paint theory. As can be seen in Table 1, the metal surface presents yellow colour when the repeated frequency changed from 200kHz to 170kHz. This phenomenon means that the yellow colour have a widest process window on repeated frequency. However, the red colour only shown at 240kHz, which means that the red colour is of a narrow process window on repeated frequency. With the decreasing of repeated frequency, the deep blue is obtained when the repeated frequency reached at 140kHz. According to the colour theory, the green colour can be obtained by mix blue and yellow. Therefore, the yellow-blue as well as green colour starts to present on the metal surface when the repeated frequency changed from 160kHz to 150kHz.

The oxide compound can be influenced by the heat accumulation on the metal surface, and the repeated frequency defines the heat accumulation when keep the heat dissipation condition as constant during the experiments. As discussed above, different colours can be obtained by changing the repeated frequency of nanosecond laser. Furthermore, the colour transition process of laser-induced colourization obeys the colour theory in paint when changing the repeated frequency for generating different colours.

Table 1. Different repeated frequency of nanosecond laser corresponding to different colours

Repeated frequency/kHz	Colour picture	Colour description
C350		Blue
340		Blue
330		Blue
320		Blue
310		Blue-Purple
300		Purple
290		Purple
280		Purple
270		Purple-Red
260		Purple-Red
250		Purple-Red
240		Red
230		Red-Yellow/Orange
220		Red-Yellow/Orange
210		Red-Yellow/Orange
200		Yellow
190		Yellow
180		Yellow
170		Yellow-Blue
160		Yellow-Blue

150		Yellow-Blue/Green
140		Deep-blue

Besides the repeated frequency, there are still have many parameters on colourization during the laser-metal interaction. As is presented in Figure 2, non-fading colours can be obtained by adjusting processing parameters. Cyan is generated as described in Figure 2(a) by increasing the laser power to 45W from blue colour mentioned above. For obtaining a high-resolution colour, a golden colour can be generated in Figure 2(b) by decreasing the repeated frequency to 175kHz from yellow colour mentioned above. A green colour is obtained by increasing the input energy of laser pulse as shown in Figure 2(c). Blue colour still be obtained in Figure 2(e) when decreasing the power to 30W while a 40W generated the same colour. This phenomenon means that the repeated frequency is the key factor to generate blue colour. A brown colour can be generated by downing the input energy of laser pulse as shown in Figure 2(d). A purple can also be obtained by increasing the repeated frequency to 600kHz as shown in Figure 2(h), and the same colour is generated when the repeated frequency down to 140kHz. This is because that the input energy is decreased when the repeated frequency change to extremely high or low.

As is shown in Figure 3, an example of gradient design on product surface which means that the design method with nanosecond laser can be used to generate different colours with a set of parameters, and the scanning galvanometer can draw different patterns that controlled by industrial computer. Firstly, the relationship between colour and processing parameters should be obtained by a lot of experiments, and then the different colour area should be set on different layer with different processing parameters. Finally, we can get a product with different colour on metal surface.

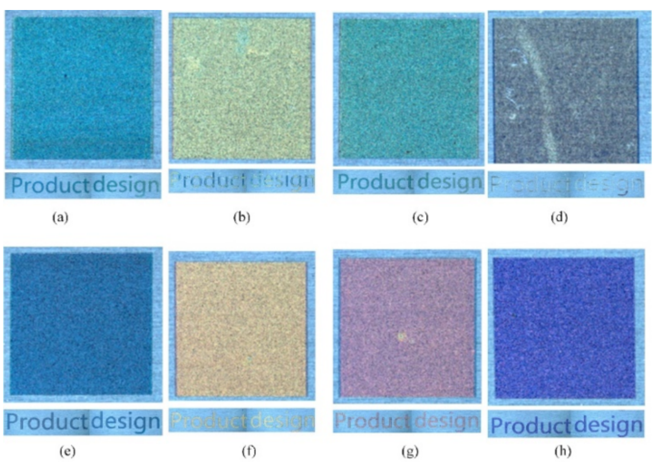


Figure 2. Different colours on metal surface from nanosecond laser-induced colourization. a) Cyan with 1000mm/s, 8ns pulse width, 350kHz frequency and 45W power; b)Yellow with 1000mm/s, 8ns pulse width, 175kHz frequency and 40W Power; c) Green with 800mm/s, 8ns pulse width, 300kHz frequency and 50W power; d) Brown with 0.003mm scanning gap, 1000mm/s, 8ns pulse width, 145kHz frequency and 50W power; e) Blue with 900mm/s, 8ns pulse width, 300kHz frequency and 30W power; f) Golden with 1000mm/s, 8ns pulse width, 200kHz frequency and 45W power; g) Pink with 1000mm/s, 8ns pulse width, 240kHz frequency and 40W power; h)Purple with 1000mm/s, 4ns pulse width, 600kHz frequency and 40W power;

Figure 3. Example of gradient design with laser-induced colourization

4. Conclusions

This work studied the effects of processing parameters on colour generation during laser-induced colourization on stainless-steel product surface. Firstly, different colours is generated by setting different repeated frequency of processing pulse. This phenomenon can be explained by the fact that the different repeated frequency caused the difference on heat accumulation, which resulting the different interference between surface oxide compound and white light and then presents a different colour. Furthermore, the colour transition obeys the paint theory, which means that researchers and engineer can obtain an ideal colour by high-precision adjusting parameter when they know the base colour from paint theory. This work presents a convenient way to fast obtain a non-fading design on product, and this technology can be used in engineering as well as scientific research.

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