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Investigation of the optimization process of laser surface marking on polyamide samples

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Abstract. **Give Thermoplastic laser marking technology is becoming increasingly popular in the electronics industry. Using marking codes requires more information to store, which requires the marking to be of good contrast and durability over time. The main goal of the research was to achieve high-quality marking on polyamide surfaces. A nanosecond fiber laser was used to laser mark polyamide samples. An experimental marking matrix of 8 columns and 6 rows was developed, respectively varying the marking step, scanning speed, marking repeats. The dimensions of the marked squares are 10×10 mm. Surface changes and marking quality were examined using a laser scanning microscope. Markings with good contrast were found, as well as marking modes with partial and full melting modes. Roughness and contrast were measured for the optimal marking modes. Graphical dependences are constructed for the effect of roughness and contrast on propagation speed and distance in laser marking. For the study, the average laser power was fixed. During the experiment, it was found that laser marking on polyamide can lead to different shades of gray and yellow, and the surface after laser treatment has become rougher.**

Keywords: fiber laser, laser marking, polyamide, roughness, contrast.

I. INTRODUCTION

Currently, lasers are increasingly used, especially in industry and in various industries, and laser marking on thermoplastics is especially in demand [1], [2], [3]. One of the most common thermoplastics is polyamide, which has many advantages over other polymers: good hardness, chemical resistance, corrosion and wear resistance [4]. Thermoplastics can be marked with: ablation, bleaching or darkening (thermal), carbonization, color marking, engraving, foaming and melting [5]. But laser marking on materials such as polyamide is based on laser heating of the processed material, and the heating is below the melting temperature or the initial point of thermal decomposition [6]. However, polyamide cannot be marked; problems can arise both with direct printing and with laser marking [7], [8].

Therefore, the author Li in his study added glass fiber to polyamide in order to obtain a good marking. The marking mechanism was a combination of carbonization with microbubbles. The results of Li's study were as follows: the optimal formulation was achieved with a combination of medium dye loading [9]. Authors Estella Neiss and Li used the same laser, Nd:YAG, in their experiments. However, Estella's technology was direct marking without additives. The average laser power was fixed at 5.5 W for all experiments, but the pulse repetition frequency rate (20-60 kHz) and scanning speed varied from 200-600 mm/s. The results of the study showed that the quality of the marking depends on the speed and frequency, and as a result, various shades of gray and white with a slightly rough surface can be obtained. Knowing the energy density and area, it is possible to estimate the duration of exposure required for marking. The reference energy density for polyamide is 0.18 to 0.55 J/mm2. In the second part of the study by Estella and others, 2 lasers were compared: Nd:YAG (pulse repetition frequency 10 kHz, pulse duration 1 ms, average power 30 W) and fiber laser (pulse repetition

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frequency 20 kHz, average power 20 W). The results showed that the duration of exposure is the same, although these two lasers show very different characteristics [10]. But the authors of McKee and others believe that more successful marking parameters with a solid-state YAG laser are: an average power of about 20 W and a pulse repetition rate of 20,000 pulses per second [11]. Jia and others conducted their research based on a nanosecond pulsed laser. An analysis of the results showed that the best processing quality on polyamide can be obtained when the energy density of a single laser pulse is 25 J/cm^2, the pulse repetition frequency is 30 kHz [12]. When marking on polyamide, different lasers can be used, however, it is mentioned that high-energy lasers are used for marking the surface of materials [13]. Author Lawrence and others used a 60W CO_2 laser. Four patterns were applied on the surface of polyamide samples: with a step of 50 µm and 100 µm. For each circuit, laser power 7W and scanning speed 600mm/s. The results of the study were similar to those of the author Estella Neiss, as the laser-treated polyamide samples were significantly rougher than the original sample. But the author Lawrence found that the surface pattern was sharper along one hatching axis than the other [14]. Scott also noted that polyamides are one of the most difficult polymers for laser marking. But he achieved good contrast using a fiber laser with a short pulse in the range from 20 ns to 50 ns [15]. Hofmann and others used 5 different lasers in their work and came to the conclusion that providing an energy density of about 0.9-1 J/cm2 is sufficient for marking white polymers, but due to the uneven intensity of the beam along the profile, areas with strong and weak color are obtained. Overexposure is usually recognized by a light gray tint that shows a foamy structure under the microscope. Also, the authors noticed an interesting fact that samples of seemingly the same color and the same polymer composition react differently under the same exposure conditions, some give clear traces, and some do not react at all [16]. Recently, there has been a lot of interest in the use of laser marking and texturing in various fields of industry [17], [18], [19] and [20].

The above research and analysis by various authors show that achieving high quality marking on polyamide is a multi-factorial task. The main objective of the present study is to emphasize the influence of two factors having a significant role in the laser marking process, namely; changing the marking step and scanning speed.

II. Materials and Methods

2.1. Substrates. Scientific study on marking on polyamide 12 plates. Melt temperature 185.6 °C – 186.5 °C, melting enthalpy ΔH_m- 110.7 J/g – 120.2 J/g and crystallization point T_c 155.3 °C – 156.3 °C. Plate dimensions: height 79 mm, width 100 mm and thickness 3 mm. The polyamide samples were laser marked with a planned matrix of 8 columns and 6 rows. The size of one square is 10×10 mm with a distance of 1 mm between them. The samples were not processed and marked in a warm air environment. They are marked as delivered.

2.2. Laser Marking Setup. All experiments were carried out using fiber laser Rofin-Sinar Powerline F-20 (Fig. 1.). This is a fiber optic laser operating at a wavelength of 1064 nm. When marking on a sample of polyamide was fixed: the average output power P (W), constant pulse duration τ (ns) and pulse repetition rate v (Hz) shown in Table 1. The laser system is equipped with a galvanometer that allows the beam to be deflected. The laser beam was focused on the target through an L-Theta lens with a focal length of 184 mm. The beam diameter at the focus was 40 µm. A fan and a temperature controller were used to stabilize the substrate temperature.

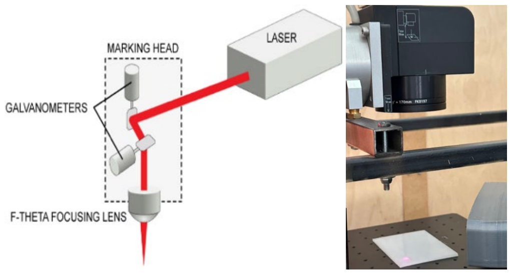


Fig.1. Fiber laser system Rofin Powerline F-20 Varia.

Table 1 Laser System Parametrs

Wavelenght (λ), nm	1064
Output Power (P), W	0.1 to 19.7
Pulse Duration (τ), ns	4, 8, 14, 20, 30, 50, 100 and 200
Pulse Repetition (v), kHz	2 to 1000

2.3. Surface characterization methods. Two matrices were scanned using an HP Scanjet G3010 scanner. Color format, file type: TIF, resolution 2400 DPI. The Adobe Photoshop program was used to measure the contrast of each square of the matrix. To calculate the contrast in percentage, the formula (1) was used:

$$K = \frac{N_f - N_x}{N_f} \times 100\% \quad (1)$$

Where N_f is the contrast of the material before processing, N_x is the contrast of the material after processing. Surface changes and marking quality of each matrix were examined using an Olympus OLS5000 3D laser scanning microscope Fig. 2. Microscope parameters: increase x113, area 2566 x 2572 µm, objective 5x, step 25, pitch 20 µm.

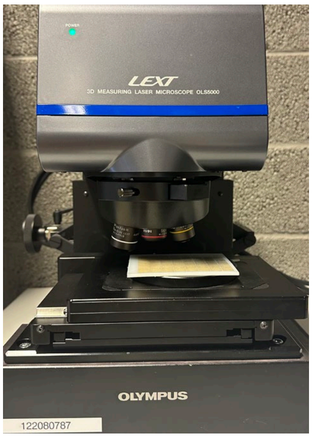


Fig.2. Laser scanning microscope Olympus OLS5000 3D.

2.4. Laser treatment. Two samples were made for the marking study on polyamide. By varying the scanning speed and step between marking lines, various surface roughness can be obtained. But by changing only the scan speed and marking step, the results were not positive. Thus was added an important parameter repetitions. Therefore, for the first matrix, six scanning speeds ν (mm/s) – one step 100 mm/s and 8 different marking steps Δx (μm)- one step 5 μm and 4 repetitions for each square were chosen shown in Table 2.

TABLE 2. FIRST MATRIX LASES SYSTEM PARAMETERS

Scanning Speed (ν), mm/s	100, 200, 300, 400, 500, 600
Marking Step (Δx), μm	10, 15, 20, 25, 30, 35, 40, 45
Repetitions,	4
Pulse Duration (τ), ns	200
Pulse Repetition (ν), kHz	20

For the first and second matrix, was used the same pulse repetition frequency ν =2 kHz, pulse duration τ = 200 ns, power P =19.7 W, area size 10x10 mm, angle step of 45° and start angle of 90° were used. For the second matrix was changed repetitions and marking step shown in Table 3. A scanning speed was fixed. The results of laser processing can be seen on Fig.3.a and Fig.3.b.

TABLE 3. SECOND MATRIX LASES SYSTEM PARAMETERS

Repetitions	2, 4, 6, 8, 10, 12
Marking Step Δx, μm	10, 15, 20, 25, 30, 35, 40, 45
Scanning Speed (ν), mm/s	100
Pulse Duration (τ), ns	200
Pulse Repetition (ν)	2 kHz

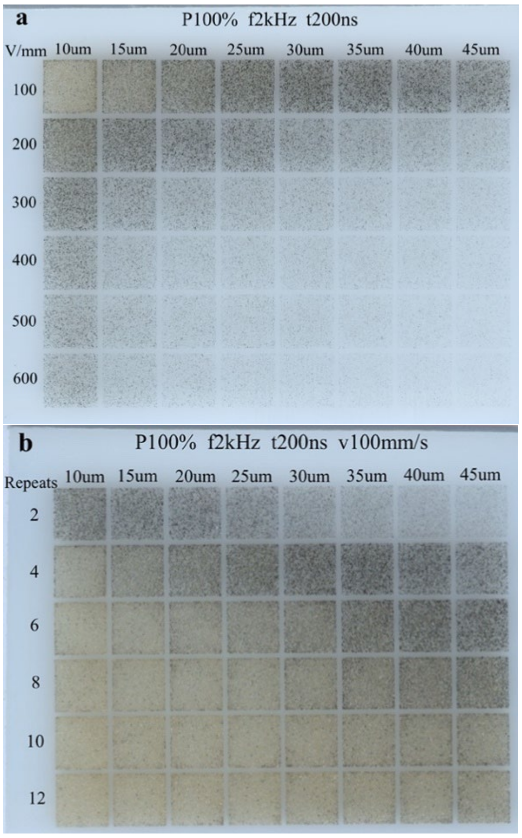


Fig.3. Laser marking of polyamide samples with a fiber laser a) first matrix: scanning speed 100 mm/s - 600 mm/s and marking step 10 μm - 45 μm b) second matrix: repeats 2-12 and marking step 10 μm -45 μm.

III. RESULTS AND DISCUSSION

To measure the experimental results, two different analyzes were performed for each matrix: a contrast analysis and a roughness analysis. If look at figure 3 (a), at first glance, the highest contrast appears at scanning speed ν = 100 mm/s.

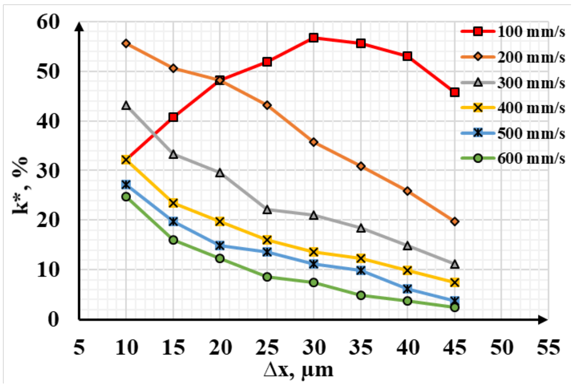


Fig.4. Contrast changes of marking at first polyamide sample depending the scanning speed and marking step.

The results of the first matrix, where the scanning speed and marking step were changed, showed that the highest contrast is observed at a scanning speed ν = 100 mm/s and a marking step Δx = 30 μm Fig. 4. But if seen at other speeds, can see that the more marking step and scanning speed, the lower marking contrast becomes. This is confirmed by trend lines, which indicate that the contrast is getting smaller.

The graph highlights the results at 2 repetitions, which show that by changing the marking step, the contrast sharply decreases. But if look at repetitions from 4 to 12 increasing the marking step, the contrast increases. This is confirmed by the trend lines that go up.

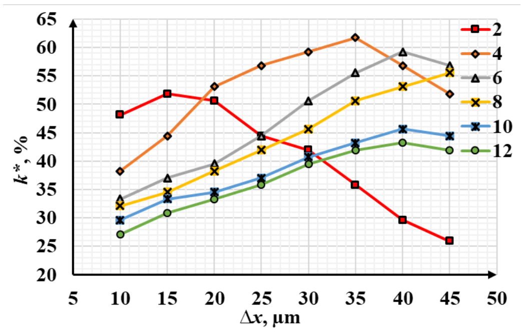
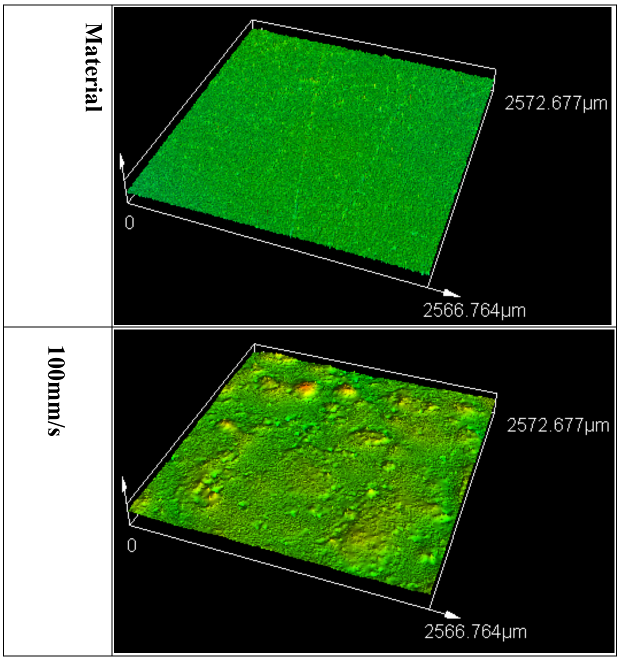


Fig.5. Contrasting marking changes on the second polyamide sample depending the marking step and repetitions.

The texture of the markings on the polyamide surface were analyzed using a laser microscope. Figure 6 shows examples of images obtained using a microscope of the first matrix with a marking step Δx = 10 µm and a scanning speed v =100, 200, and 400 mm/s. As can be seen in the figure, the roughness of the raw material is different from the roughness of the material processed by the laser beam, and this is affected by different scanning speeds. The most roughness changes are appears at the smallest scanning speeds v = 100 and 200 mm/s, increasing the speed the roughness of the polyamide becomes less.



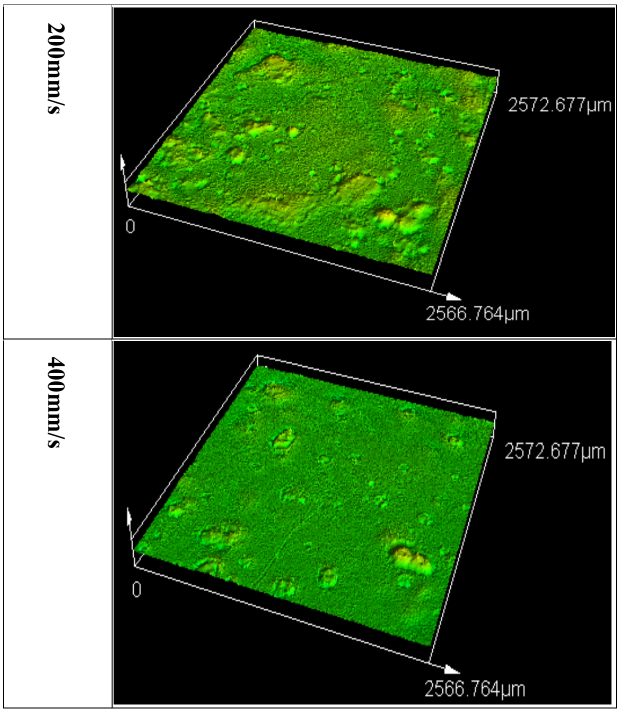


Fig.6. 3D image of the first matrix, first column scanning speed from 100 to 600 mm/s, marking step 10 µm.

If emphasize on at one of the lines of the first matrix Fig. 3(a), you can see that the roughness becomes smaller. This is confirmed by the graph in Fig. 7. At scanning speeds v =100, 200, 300, 400, 500 and 600 mm/s, the roughness decreased with an increase in the marking step. The greatest changes in the surface roughness of polyamide were observed at a scanning speed ν =100 mm/s and marking step Δx =15 µm.

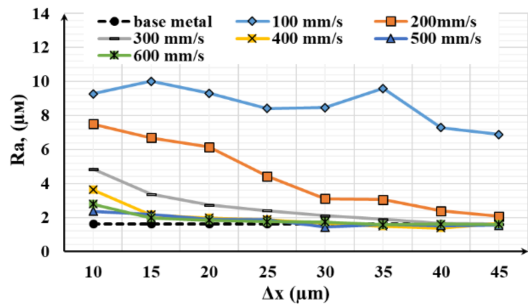


Fig.7. Change in the surface roughness of the first polyamide matrix with a change in scanning speed and marking step.

Fig.8 shows examples images for second matrix using microscope with a marking step Δx = 10 µm and repetitions 2, 4 and 12. Based on the results, can be seen that repetitions also affect the surface roughness. But can see that the largest changes in roughness are precisely with 4 repetitions. At 12 repetitions, the changes in roughness are not as significant as at 2 and 4. The rest of the repetitions are approximately the same at first glance.

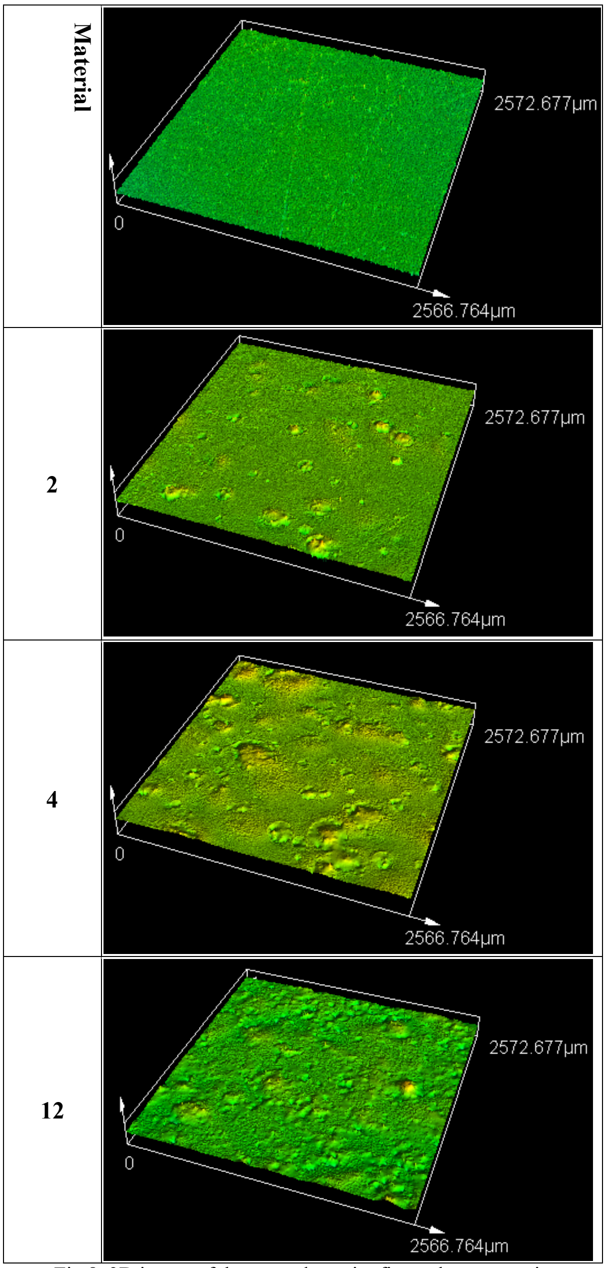


Fig.8. 3D image of the second matrix, first column scanning speed from 100 to 600 mm/s, marking step 10 µm.

But if we compare all the results of changing the roughness at different marking steps and repetitions, then we can see that with repetitions 2 and 4, with an increase in the marking step, the roughness decreases. With repetitions 6, 8, 10 and 12, with an increase in the marking step, the roughness increases. With 2 repetitions, by increasing the marking step, the roughness decreases. The greatest roughness was found with a 12-fold repetition and a marking step Δx = 45 µm, the smallest changes in roughness - with a 2-fold repetition and a marking step Δx = 45 µm (Fig. 9).

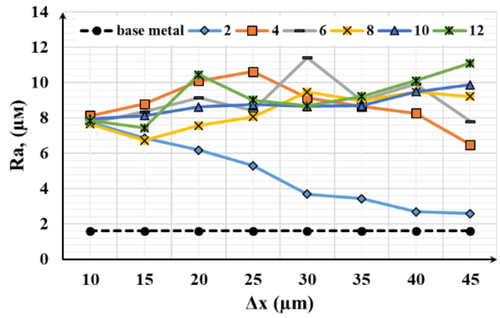


Fig.9. Change in the surface roughness of the second polyamide matrix with a change in the marking step and repetitions.

IV. Conclusion

This scientific publication describes the features of the process of marking polyamide with a laser. Material such as polyamide is difficult to mark, this was confirmed by the first unsuccessful attempts, in which only the scanning speed and marking step were changed. By adding a parameter such as repetitions, the results improved. A fiber laser source with a wavelength of 1064 nm was used in the experiments. The results showed that by varying the scanning speed, marking pitch and repetition, high contrast markings and a rough surface can be achieved. The greatest contrast was found at 2 and 4 repetitions, scanning speed of 100 mm/s. The highest roughness was obtained with the following parameters: 12 repetitions, scanning speed 100 mm/s, and marking step 45 µm. However, in the first matrix, with 4 repetitions, increasing the scanning speed and marking step reduced the roughness. These results confirm that scanning speed, repetition, and marking pitch affect marking. It has also been found that different shades of gray and yellow can be obtained by laser marking polyamide. In the future, it would be interesting to carry out such experiments with smaller marking steps or, for example, using a CO_2 laser and different colors of polyamide.

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