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Influence of Technological Parameters on Laser Marking Process of Copper Surfaces

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Abstract. **Laser marking technology today is a key part of the production of many products and devices used in our daily lives. At the same time, for specific types of products, the process must be optimized depending on the material used, laser system and marking method. Copper is such a metal that has a number of applications in the military industry, electrical engineering, electronics, household, etc. The scientific report investigates the influence of the technological parameters speed, raster step and number of repetitions on the contrast and roughness of marking for copper samples. A fiber laser technology system was used to perform the experiments, and the roughness measurements were performed with an OLS 5000 laser microscope. A wide range of marking speeds from 10 mm/s to 1500 mm/s was selected, where the contrast and roughness behavior of the marking is tracked for different raster steps in both single marking and double marking. It was found that as the speed increased, the contrast and roughness decreased. Also, with double marking, the contrast and roughness values are higher than with single marking. The velocity intervals in which the contrast has positive values and those in which it has negative values are established. The regularity was obtained that increasing the step of the raster leads to a decrease in contrast and an increase in roughness.**

Keywords:- Copper, Laser marking, Contrast, Roughness, Speed, Raster step

I. INTRODUCTION

One of the early applications of lasers was the marking of various mechanical and electronic components. One of the well-known and practical methods in modifying the surface of a material is Laser Surface Modification[1]. Today, laser marking has found its place in a wide range of specific industrial applications [2], [3], [4]. This is due to the fact that every single product cannot appear on the market without having its identification (logo, serial number, etc. alphanumeric information). In laser marking technology, a process of interaction of a laser beam with the surface of the material is implemented in order to change it or cause melting and evaporation, creating a certain informational design on the surface [5], [6]. This process enables precise marking on a variety of materials, from metals to plastics, without direct contact [7]. Today, we can say that laser marking has become an essential tool in multiple industries, thanks to advances in technology and its flexibility [8].

The use of fiber lasers and Nd:YAG lasers has become common practice, providing effective processing alternatives to traditional marking methods. The new systems can adapt to different geometries, expanding the possibilities for 2D and 3D laser marking [9]. Laser marking technology is critical for embedding unique data such as QR codes on products. This is how traceability is realized through all stages of production, and also from the manufacturer and warehouses to the end user[10].

Copper is an engineering material with excellent thermal and electrical properties that has wide applications in mechanical engineering, electronics, the defense sector and computer technology.[11] Copper materials used in these industry sectors, such as 3D integrated circuits (ICs) and electrical contact material, face severe corrosion and poor mechanical properties. Laser marking of surfaces on metal substrates is an effective method of protection against corrosion as well [12]. Many superhydrophobic films produced on a copper substrate do improve its corrosion resistance. However, they often further reduce

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the mechanical strength of the surface. Common strategies for realizing laser marking do not reduce the mechanical strength of the substrate [13].

This work develops an experimental method for laser marking on the surface of copper samples, with the focus of research on the influence of the technological parameters speed, raster step and number of repetitions on the contrast and roughness of copper sample marking.

II. MATERIAL AND METHODS

A. Material

Physically, the copper surface has its own values of absorption of light radiation. The copper light spectrum that is mostly absorbed is in the blue-green region, that is, at wavelengths from 450 nm to 570 nm of the radiation spectrum. The coefficient of surface reflection is *R*=1-*A*, that is higher for copper shown in Table 1[14].

TABLE 1: REFLECTANCE OF VARIOUS MATERIALS COMPARED TO COPPER'S REFLECTIVITY.

Material (Symbol)	***Iron (Fe)***	***Copper (Cu)***	***Aluminium (Al)***	***Gold (Au)***
reflectivity (R)	0.63	0.91	0.93	0.98

B. Anticipating Value

Materials contrast measurements theoretically could be defined as variation of spectral brightness of the laser processed and un-processed are of the surface. Contrast variable k_x^* is determined in relative values on percentages on defined reference scale.[15] Reference number N_f is determined for the image of the surface around the untouched area around matrix. And from the processed area, a N_x value is obtained. The contrast k_x^* is determined by linear interpolation from the expression (1).

$$k_x^* = \frac{N_f - N_x}{N_f} \times 100\% \qquad (1)$$

where:

N_f – The measured value of an untreated area (unmarked area).

N_x – Measured value in the laser-treated area (marked area).

C. Laser Source for Processing

For study processing was used Rofin powerline laser system, which is diode pumped Ytterbium (Yb) fibre laser operating at impulse mode. In table 2 listed important parameters of laser system, that were used for surface treatment in experiments.

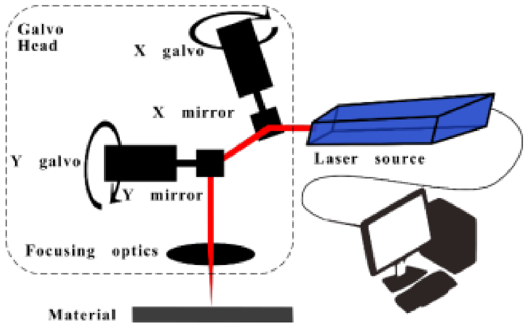

Figure 1: Schematic view of Rofin powerline laser system

TABLE 1: PARAMETERS OF USED LASER SYSTEM

Symbol	*Name*	*Values range*	*Units*
v	Scan speed	1 — 20000	mm/s
P	Average power	0 — 19,7	W
ν	Impulse frequency	20 — 1000	kHz
τ	Impulse length	4 - 200	ns
λ	Wavelength	1064	nm
d	Focal spot size	40	µm
	Working area	120 x 120	mm^2

D. Measurement device

"Lext" 3D Laser Measuring Microscope OLS 5000 was used for measurements of laser processing impact on the materials surface. In this case after laser processing, we measured the width and depth of laser beam influence on the material.

Figure 2: Photography of Lext" 3D Laser Measuring Microscope OLS 5000

Measurements were made using MPLFNN10XLEXT lens with x20 objective, and summary 451x zoom, numerical aperture (N.A. 0.6, working distance of 1mm, focusing spot diameter at 0.4 µm, measured field range at 640 µm x 640 µm and following technical data was given from manufacturer:

- Z measurement pitch: 2 µm;
- Z axis measurement accuracy: 0.15+L/20 µm;
- X and Y axis resolution: +/- 1.5%.

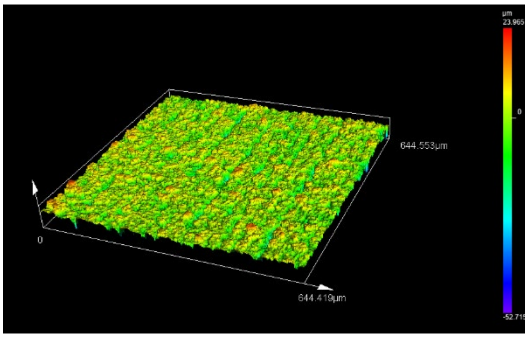

Figure 3. 3D surface field model of roughness.

E. Methodology

The study process was carried out on three polished copper plates with fibre laser of processed field 180 mm x 100 mm x 0.8 mm. According to processing steps was labelled as sample 1 and sample 2. On first steps was tested laser processing parameters that was studied in other papers according to copper surface treatment.

Plates was prepared by laser cutting and cleared with C_3H_7OH and blown with a stream of dry air to remove all debris that may affect the following measurements. Marked samples were stored in individual sealed air-tight bags.

The texturing parameters of the plates are shown below:

The processing of a copper sample 1 is carried out with the values of the parameters in Table 3. The processing speed (v, mm/s) and the raster pitch (Δx, µm) are changed, and the other parameters are kept constant. The designed matrix from Fig. 4 is realized. The size of each square is 5 mm x 5 mm with a distance between adjacent squares of 2 mm. Number of marking repetitions is 1 (one-time raster marking).

TABLE 2: LASER PARAMETERS FOR MARKING OF SAMPLE 1

Parameter	Value
Pulse Duration (τ)	100 ns
Raster Step (Δx)	30, 35, 40, 45 and 50 µm
Speed (v)	10, 25, 50, 100, 400, 800, 1200, and 1500 mm/s
Power (P)	10 W
Frequency (ν)	20 kHz
Focal Length (F)	184 mm

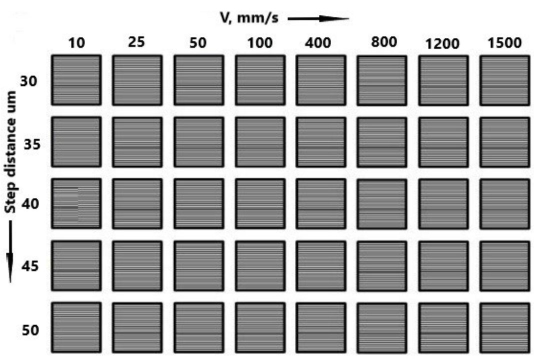

Figure 4: The designed matrix for performing the experiments on sample 1 and sample 2

The processing of a copper sample 2 is carried out with the same values of the parameters in Table 3. Number of marking repetitions is 2 (double raster marking with angles 0° and 90°). The designed matrix from Fig. 4 is realezed. The size of each square is 5 mm x 5 mm with a distance between adjacent squares of 2 mm.

III. RESULTS AND DISCUSSIONS

The machined samples of copper plates presented in Fig. 5 and fig. 6 were examined under a laser microscope to analyze surface changes, texture formation and several other analytical results. To measure surface contrast, plates were scanned with a scanner and formatted in .tif format. The required format image of each textured sample square was analysed with Adobe Photoshop CS4 for the N_f and N_x values to be determined. Areas and plaques not marked were removed from the study and the analysis was narrowed. Scanned photos and their graphic images follow below.

The experimental matrix of Fig. 5 is obtained for different values of the speed (horizontal) and the raster pitch (vertical). The specific values of these two quantities are presented in Table 3. A one-time raster marking was done. The dependence of the contrast of the mark on the speed for three raster steps is given in Fig. 7 as Fig. 7a is for speeds from 10 mm/s to 100 mm/s, and Fig. 7b is for speeds from 100 mm/s to 1500 mm/s. Analysis of the graphs shows that:

- **For interval of speed from 10 mm/s to 100 mm/s**

the contrast changes from 61.8 % to 7.50 % for a raster step of 30 µm;
the contrast is changed from 56.5 % to 5.50 % for a raster step of 40 µm;
the contrast changes from 52.8 % to 3.50 % for a raster step of 50 µm;

- In this interval, the marked images are darker than the unmarked surface and the contrast has positive values. The power density of laser radiation is above the critical power density of melting, and the process is laser marking by melting;

- **For interval of speed from 400 mm/s to 1500 mm/s**

the contrast changes from -14.0 % to -21.5 % for a raster step of 30 µm;
the contrast changes from -17.5 % to -25.0 % for a raster step of 40 µm;
the contrast changes from -21.0 % to -28.5 % for a raster step of 50 µm;

- In this interval, the marked images are lighter than the unmarked surface and the contrast has negative values. The power density of laser radiation is below the critical power density of melting, and the process is laser marking by oxidation.

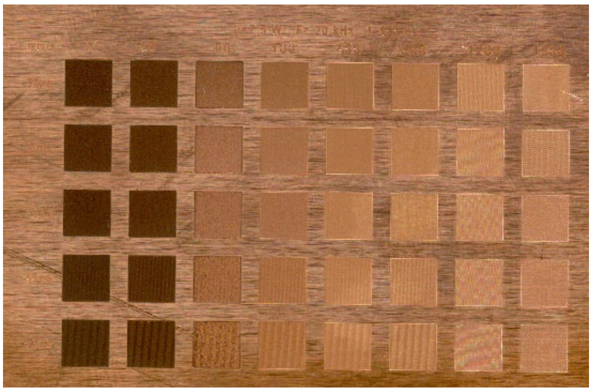

Figure 5: The experimental matrix with one-time marking

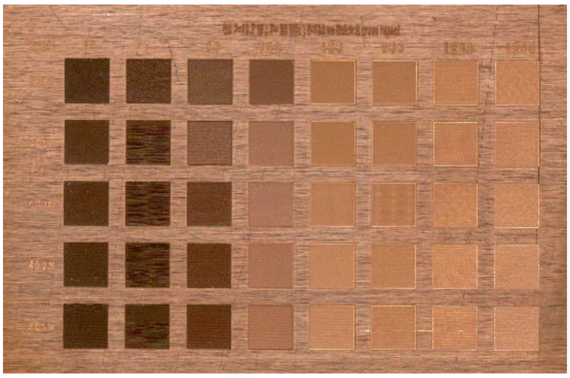

Figure 6: The experimental matrix with double marking

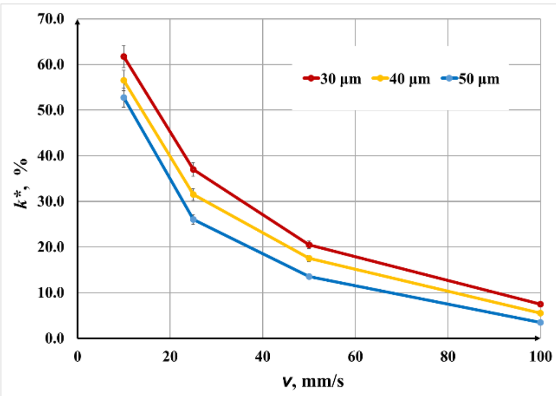

Figure 7a: Graphics of the dependence of the contrast on the speed from 10 mm/s to 100 mm/s for three powers for one-time marking

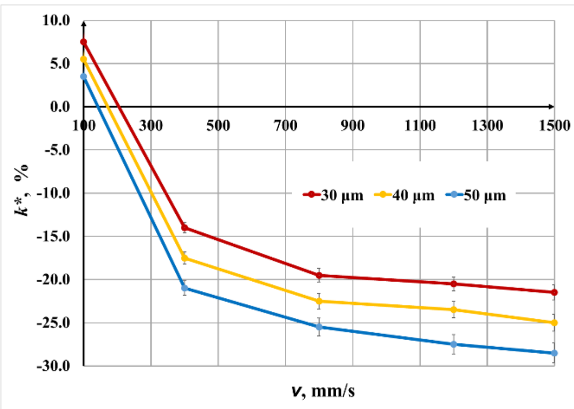

Figure 7b: Graphics of the dependence of the contrast on the speed from 100 mm/s to 1500 mm/s for three powers for one-time marking

The experimental matrix in Fig. 6 is again for different values of speed (horizontal) and raster pitch (vertical), which are the same as for the experimental matrix in Fig. 5. The difference is that in this case cross-marking is applied twice (at angles 0° and 90°). The velocity dependence of the mark contrast for three raster steps is shown in Fig.8 with Fig.8a for speeds from 10 mm/s to 100 mm/s and Fig.8b for speeds from 100 mm/s. s to 1500 mm/s. From the analysis of the drawn graphs it follows:

- As the speed increases, a non-linear decrease in contrast is observed for the three investigated raster pitches.
- As the raster pitch increases, a decrease in contrast is observed;
- **For interval of speed from 10 mm/s to 100 mm/s**

the contrast changes from 66.8 % to 14.5 % for a raster step of 30 µm;

the contrast is changed from 62.5 % to 10.5 % for a raster step of 40 µm;

the contrast changes from 59.8 % to 8.50 % for a raster step of 50 µm;

- The obtained contrast values for double marking are about 12% higher than for one-time marking;
- In this interval, the marked images are darker than the unmarked surface and the contrast has positive values. Raster marking by melting is realized;
- **For interval of speed from 400 mm/s to 1500 mm/s**

the contrast varies from -9.0 % to -19.5 % for a raster step of 30 µm;

the contrast changes from -11.5 % to -21.5 % for a raster step of 40 µm;

the contrast changes from -14.0 % to -24.5 % for a raster step of 50 µm;

- In this interval, the marked images are lighter than the unmarked surface and the contrast has negative values. The process that has been carried out is laser marking by oxidation.

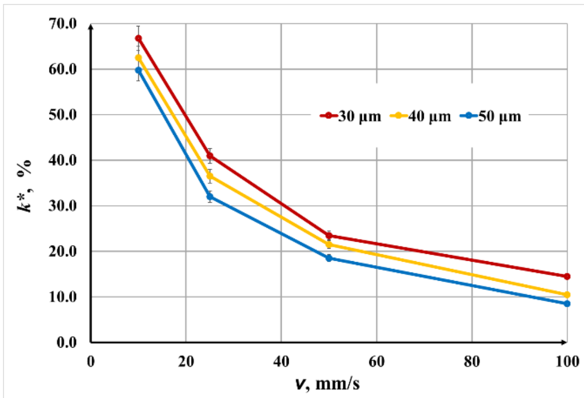

Figure 8a: Graphics of the dependence of the contrast on the speed from 10 mm/s to 100 mm/s for three powers for double marking

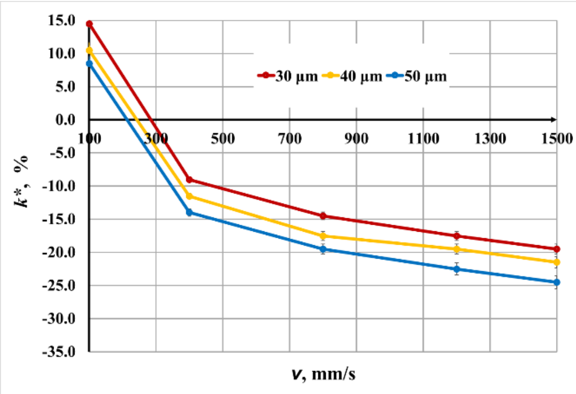

Figure 8a: Graphics of the dependence of the contrast on the speed from 100 mm/s to 1500 mm/s for three powers for double marking

A microscopic image of an unmarked area is given in Fig. 9a. In Fig. 9b is a microscopic image of a one-time raster marked area with parameters speed v = 1500 mm/s and step Δx = 30 µm. The parameters held constant are given in Table 3. The process of laser marking by oxidation has been realised, because the power density of the laser radiation is below critical for this speed.

Figure 9: Laser microscope image of a) unmarked surface, b) one-time raster marked square.

The dependence of the roughness on the speed for three raster pitches for one-time marking is presented in Fig. 10. In Fig. 10a shows this dependence in the speed interval from 10 mm/s to 100 mm/s, and in Fig. 10b – from 100 mm/s to 1500 mm/s. These patterns follow the analysis of the graphics:

- Low speed processing surface roughness values are drastically higher that processing at high speeds.
- As the speed increases from 10 mm/s to 25 mm/s, the roughness increases sharply, at a speed of 25 mm/s the roughness becomes maximum;
- At speeds from 25 mm/s to 100 mm/s, the roughness decreases sharply, and at speeds from 100 mm/s to 400 mm/s, the decrease in roughness is smoother. In the interval from 400 mm/s to 1500 mm/s the roughness does not change (see Fig. 10b);
- About 50% lower roughness difference is obtained at raster pitch 30 µm versus 50 µm.

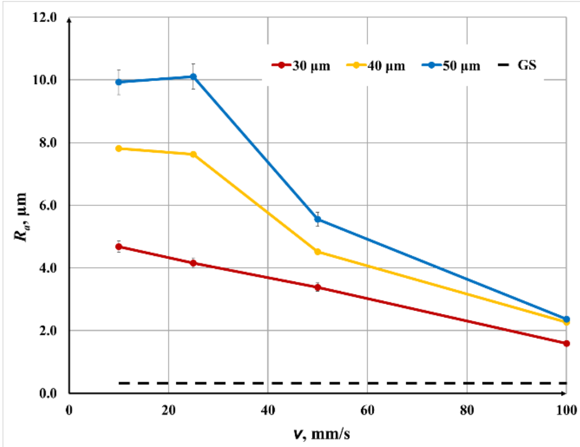

Figure 10a: Graphics of the dependence of the roughness on the speed from 10 mm/s to 100 mm/s for three raster steps for one-time marking

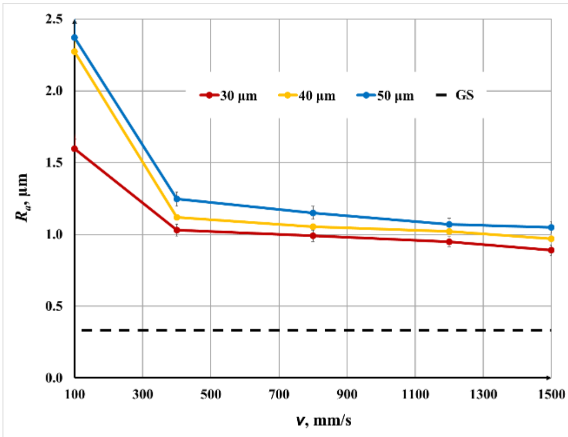

Figure 10b: Graphics of the dependence of the roughness on the speed from 100 mm/s to 1500 mm/s for three raster steps for one-time marking

The dependence of the roughness on the speed for three raster pitches for double marking (with angles 0° and 90°) is shown in Fig. 10. In Fig. 10a gives this dependence in the speed interval from 10 mm/s to 100 mm/s, and in Fig. 10b – from 100 mm/s to 1500 mm/s. These patterns follow the analysis of the graphics:

- Again as with single marking, for a speed of 10 mm/s to 25 mm/s the roughness increases sharply, for a speed of 25 mm/s to 400 mm/s the roughness decreases, and for a speed of 400 mm/s to 1500 mm/s the roughness does not change.
- As the raster pitch increases, the roughness increases;
- When comparing the roughness for double marking compared to one-time marking, it can be seen that double marking roughness is significantly greater than that of one-time marking, all other parameters being equal. It is 40-90% greater in the speed interval from 25 mm/s to 100 mm/s.

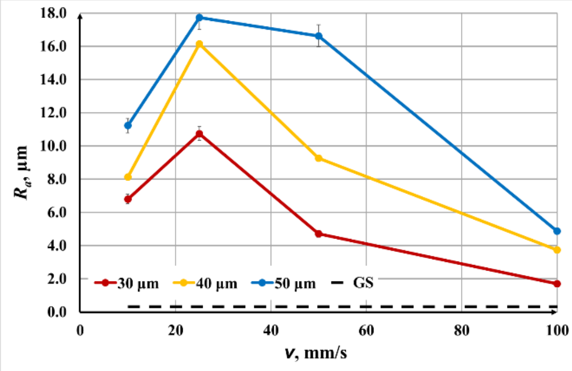

Figure 11a: Graphics of the dependence of the roughness on the speed from 10 mm/s to 100 mm/s for three raster steps for double marking

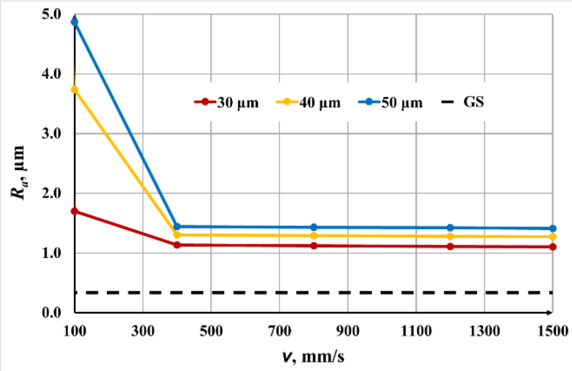

Figure 11b: Graphics of the dependence of the roughness on the speed from 100 mm/s to 1500 mm/s for three raster steps for double marking

IV. Conclusions

In the scientific report, the influence of speed, raster step and number of repetitions on the contrast and roughness of the marking was investigated, and some regularities were established:

- with increasing speed, a non-linear decrease in contrast is observed for the three investigated raster steps. In the speed range from 10 mm/s to 100 mm/s the contrast is positive (darker marking than unmarked areas) and in the speed range from 400 mm/s to 1500 mm/s the contrast is marking (lighter marking from the unmarked areas);
- as the raster step increases, the contrast decreases, with the contrast for the 30 µm raster step being about 10% higher than the contrast for the 40 µm raster step and about 15% higher than the contrast for the 50 µm raster step;
- with double marking, the regularities are the same, but with higher contrast values;
- in one-time and double marking for speeds from 10 mm/s to 25 mm/s the roughness grows and for a speed of 25 mm/s it reaches a maximum, and in from 25 mm/s to 400 mm/s the roughness decreases. For speeds from 400 mm/s to 1500 mm/s, the roughness hardly changes;
- As the raster step increases, the roughness increases for both one-time and double marking.

The quality of the marking strongly depends on the contrast and roughness of the marked surface, which must be within certain limits for its perception (visually and with readers and obtaining a marker with a certain colour or instances of this colour. Therefore, it is necessary to establish the influence of other parameters on contrast and roughness such as effective energy, pulse energy, pulse power and overlap coefficients (pulsed and scanning). Such studies would contribute to a more complete definition of the limits of the technological parameters necessary to achieve a high quality of the resulting marking.

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