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The Change of Contrast is Investigation of 75 Steel Samples Laser Marked with Different Modes

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***Abstract*. The quality of the marked surfaces changes the optical characteristics. The aim of the study is to optimize the contrast in laser marking of Steel 75. The influence of the step in the raster marking and the influence of the repetition frequency of the pulses on the reflection coefficient were analysed. The experimental investigations of the reflectance were carried out using a spectrophotometer. For the marked samples, it was found that when directing electromagnetic radiation with a wavelength in the studied range, there are areas with absorption and reflection of light. The reflectance is plotted as a function of marking step and laser frequency for the marked Steel 75 samples.**

Keywords: laser systems, laser safety, laser beam, optical properties.

I. INTRODUCTION

Laser has become the most advanced and widely used tool in material processing due to its advantages such as high power, easy focus, high brightness and good directivity. The laser processing has advantages such as high precision, high speed and low cost. It can be automatically controlled by computer programming. The laser can affect materials with a complex shape. Since it is non-contact processing, it will not damage the material and is safe and dependable. Laser marking is a modern method of permanent marking. The main advantages of using a laser for marking are long life of the laser source, minimal operating costs and lack of consumables.

The laser marking is performed by interaction of laser beams with surface of material, which leads to a change in chemical composition and microstructure of materials. In fact that the surface roughness of processed material can be precisely modulated, resulting in the formation of stripes and nanostructures. The introduced micro-roughness improves diffuse effect, which is an especially important feature when considering the production of diffuse reflectors. Laser marking and laser engraving are the most sought-after identification methods and have successfully replaced inkjet markings and labels.

C75 is a standard Euronorm high carbon spring steel. It has a carbon content of 0.7-0.8% making it a multi-purpose carbon steel with good spring properties. It has numerous applications such as flat or automotive springs, machine knife blades, hand and agricultural tools, shims, doctor blades. That is why it is important to mark such details, a fast and flexible method is laser marking.

We have done several studies [1-6] in the field of changing the optical properties of marked surfaces of various materials. In research [1], a comparison of oxidant films formed on the surface of stainless-steel during laser treatment and heating in a furnace is presented. The optical properties of samples were investigated using a spectrophotometer. The reflectance spectra in the experiment were varied in the wavelength range 190–900 nm. Coloration of the treated area was seen at different

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laser parameters. The effects of laser irradiation on the surface microstructure and optical properties of ZnO films were investigated experimentally in [2]. X-ray diffraction (XRD) and atomic force microscopy (AFM) measurements have shown an improvement in crystalline quality with 514 nm Ar+ laser irradiation. After laser irradiation, a significant increase in UV absorption and broadening of the optical bandgap of the films was observed. In [3] they studied the effect of laser irradiation on the optical properties of thin films of amorphous chalcogenide $Ge_{12}Sb_{25}Se_{63}$. The structure and composition of the film were investigated by X-ray diffraction and energy-dispersive X-ray analysis, respectively. The optical properties such as refractive index and thickness of the films were found from transmission spectra based on reverse synthesis method. In article [4], the authors investigated effect of laser irradiation on the structural, electrical, and optical properties of SnO_2 films.

The films were treated with Nd: YAG laser pulses of different energy densities and with different pulse numbers. X-ray diffraction studies were performed to investigate the structural changes due to laser irradiation. Optical transmission studies have shown that the refractive index changes because of laser irradiation. In [5, 6, 7], CO_2 laser radiation on the optical properties of pure polyvinyl chloride was investigated. Optical properties (absorption, transmission, absorption coefficient, refractive index and optical conductivity) were investigated as a function of wavelength. [9, 10, 11]

One of the factors that affect the marking, along with the wear resistance, clarity and clarity of the written symbols, is the contrast. The factors that affect the contrast are related to the process of interaction of the laser radiation with the substance and the changes that occur in the treatment area (fig. 1). [12, 13]

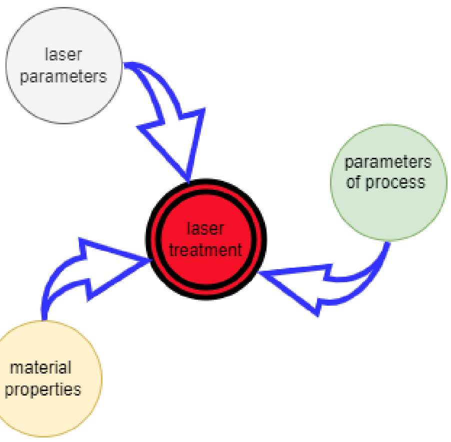

Fig. 1. Main groups of factors influencing the quality of marking.

This paper is about the study of the change of some optical characteristics of laser-treated samples of steel 75 with the aim of process optimization. That makes it relevant.

The purpose of the study:

Conducting research on the influence of changing laser parameters on optical properties of steel 75 samples. To achieve the goal, the following scientific and research tasks are set to be solved:

1) To analyse the influence of the step Δx in raster marking on the change of reflectance and contrast

2) To analyse the influence of the pulse repetition rate v on the reflection coefficient ρ and the contrast

II. Research Materials and Methodology

A. Materials

The experimental work conducted was on C75 carbon steel samples. It is a carbon structural steel and belongs to the „spring-spring steel" subgroup. Its composition (shown in table 1), together with other structural steels, is shown in several literary sources - mainly reference books [7]. Steel is actively used in various industrial sectors to produce clutch discs, springs of assorted sizes, engine valves and other parts working in conditions of friction and exposed to vibration. Also, steel is used to produce cold weapons. [8]

TABLE 1 Composition of Steel C 75 [8]

Chemical composition	*Ni*	*C*	*Si*	*Mn*	*S*	*Cr*	*P*
Percentage content	≤0.25	0.70-0.80	0.17-0.37	0.40-0.70	<0.05	≤0.25	<0.04

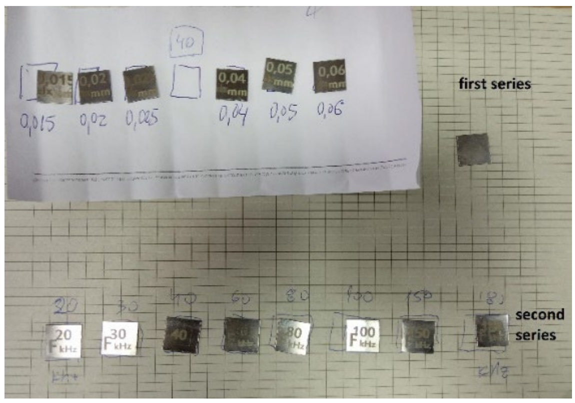

Fig. 2. Object of research.

In fig. 2 shows two series of steel 75 specimens at different marking steps Δx and marking frequency v and other process parameters held constant. The individual test samples were made with dimensions suitable for studying the optical properties in a special chamber in the SPEKOL 11 spectrometer.

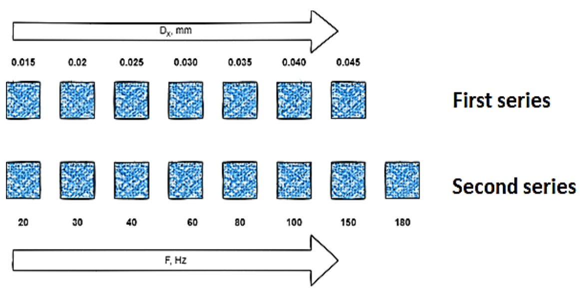

Fig. 3. Schematic of the laser treated surfaces.

Fig. 3 shows a diagram of the chosen methodology. The first series of experiments were prepared seven samples of steel 75 were laser marked with Fiber laser with the parameters showed in table 2.

TABLE 2 PARAMETERS OF LASER-MARKED WAFERS FROM THE FIRST TEST SERIES

Parameters	***Sequence of the Marked Plates According to the Research Methodology***						
Power P, W	15						
The pulse repetition rate *v*, kHz	40						
Pulse duration τ, ns	100						
The bitmap step *Δ*x, mm	0.015	0.02	0.025	0.030	0.035	0.040	0.045

The second series of experiments is with eight marked plates of steel 75 with laser marking parameters showed in table. 3.

TABLE 3 PARAMETERS OF LASER-MARKED PLATES FROM THE SECOND SERIES OF RESEARCH

Parameters	***Sequence of the Marked Plates According to the Research Methodology***						
Power P, W	15						
Pulse duration τ, ns	100						
The bitmap step *Δ*x, mm	0,03						
The pulse repetition rate *v*, kHz	40	30	40	60	80	100	150

B. Apparatus used in the study

a. *Equipment for laser marking of samples*

The samples were marked with Fiber laser, the parameters of which are described in table 2 and table 3. In fig. 4 shows the laser used to mark the metal plates, and fig. 5 shows the principal diagram of creating the laser radiation with the Fiber laser.

Fig. 4. Fiber Laser from the trials.

The main parameters of the Fiber laser are:

- Wavelength λ = 1,064 nm;
- Nominal power Pn = 20 W;
- Pulse repetition frequency *v* = (40 ÷ 180) kHz;
- Pulse duration τ = 100 ns;
- Pulse energy Ep = 1 mJ.

b. *Apparatus for experimental studies of the reflection coefficient*

The measurements were carried out with a spectrophotometer SPEKOL 11 (fig. 5 and fig. 6) of Carl Zeiss, Jena, Germany. It is a single-beam spectrophotometer with a microprocessor. In the lower part of the main body there is a diffraction monochromator, and in the upper part, executed in the form of a module, an electronic part of the device connected to the current stabilizer for the light source - a halogen lamp. Two light-sensitive vacuum photocells serve as radiation receivers: the first with spectral sensitivity in the range (340÷620) nm and the second with sensitivity in the red region of the spectrum (620÷850) nm.

To measure the spectral reflection coefficient, the Rd/0 attachment to SPEKOL 11 is used, in which the measured sample is placed - fig. 6. The Rd/0 attachment provides a comparative measurement of the reflectance with one of the CIE (International Commission on Illumination) recommended illumination geometries and measurement observation – geometry „d/0“.

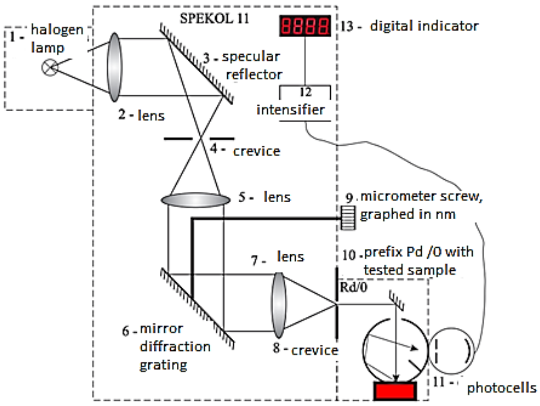

Fig. 5. Scheme of spectral reflection coefficient measurements with SPEKOL 11 spectrophotometer and attachment Rd/0.

Fig. 6. Single-beam spectrophotometer with microprocessor „SPEKOL 11”.

To reduce the influence of the specular composition of the reflected flow in case of mixed reflection of the sample, a special screen is placed in the sphere, preventing the direct impact of rays from the sample on the photocell - fig. 6.

The measurement of the reflection coefficient of the studied sample is conducted in comparison with a standard with a reflection coefficient close to 100 %. The materials recommended by the CIE are white surfaces of barium sulphate ($BaSO_4$), magnesium oxide (MgO), etc., whose spectral reflection coefficients change slightly in the range of 0.95÷0.98 for the wavelengths of the visible spectrum of light.

The reflection coefficient is measured by irradiating the metal plates with electromagnetic radiation from a halogen lamp with a wavelength in (450÷560) nm range with a wavelength 10 nm step.

III. Results and Discussion

On fig. 7 there is a graphical dependence of the reflection coefficient ρ as a function of the wavelength λ.

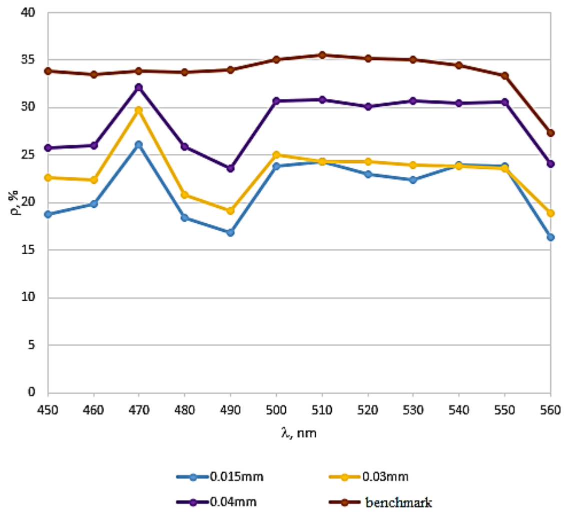

Fig. 7. Dependence of reflection coefficient as a function of wavelength for labelled samples at variable labelling step.

Measurements with a spectrophotometer revealed a different course of in separate wavelength regions. At a marking step of 0.02 mm of the laser beam, the machined surfaces have the lowest reflectivity, and at 0.04 mm the highest reflectivity. When irradiating a marked plate with a light beam with a wavelength λ of (500÷550) nm, a uniform contrast is observed on the surfaces.

In the second series of research, we examine the zones of laser impact when the reflection coefficient changes in the range of (470÷560) nm. In fig. 8 shows the graphical dependence of the reflection coefficient and the wavelength.

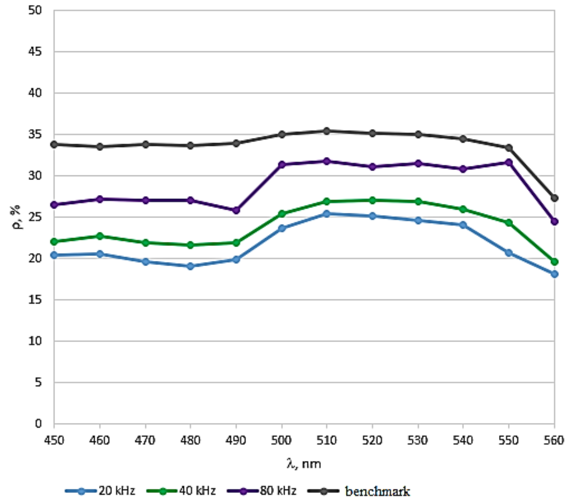

Fig. 8. Dependence of the reflection coefficient as a function of the wavelength for marked samples for the second experimental series.

For laser-marked surfaces with constant parameters and a marking frequency of 20 to 40 kHz, the same surface contrast is seen in the range of (500÷540) nm, while for surfaces marked with laser frequencies higher than 60 kHz, the range is more-wide (500÷550) nm. Marked surfaces with a frequency higher than 60 kHz in the studied range, there is no significant difference in the reflection coefficients. It was found that as the marking frequency increases, the reflection coefficient increases.

For laser-marked surfaces was determined contrast by measuring the sample with unmarked surface saturation of the resulting marking surface. The contrast of the marking was determined by the formula (1).

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

where:

N_f - background of unmarked surface

N_x - the saturation of the resulting mark

On fig. 9 there is a graphically presents the dependence of the contrast on marked samples for the first experimental series.

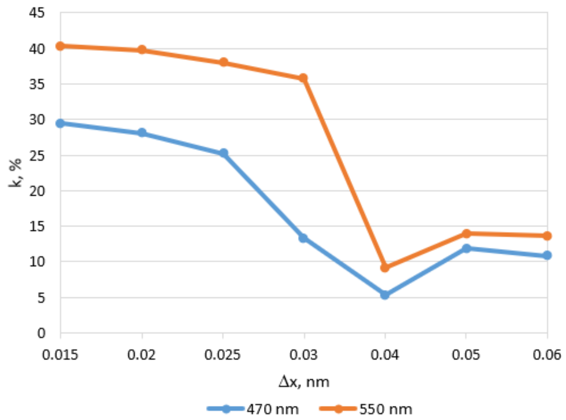

Fig. 9. Dependence of the contrast k of the mark on the step Δx for a sample of carbon steel C 75.

On fig. 10 as the marking step increases to 0.04 nm, the contrast decreases at both λ=470 nm and λ=550 nm SPEKOL irradiation.

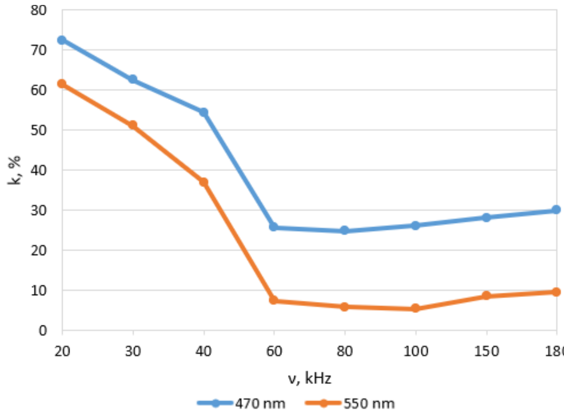

Fig. 10. Dependence of the contrast k of the mark on the frequency *v*, kHz for a sample of carbon steel C 75.

IV. Conclusion

The research we present relationship between reflectance in marking area as laser parameters change. The relationship between reflection coefficient and raster marking step Δx in range of 0.015 mm to 0.06 mm of laser impact area was also analysed. The influence of repetition frequency of pulses in range of 20 kHz to 180 kHz on reflection coefficient with irradiation of a light beam with a wavelength of (450÷560) nm on marked area was analysed. The variation of contrast during irradiation of marked surfaces with certain parameters was studied. A study of the influence of technological parameters on reflection coefficient, made on steel plates 75, contributes to reflectivity of marked surfaces, for example, for camouflage of various military objects. In further research, we will prepare a mathematical model on the current research as the authors in [14, 15, 16, 17, 17, 18].

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