Investigation of Surface Roughness of Carbon Steel Machined Parts after Nanosecond Fiber Laser Marking

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Abstract. ***Laser marking with a nanosecond fiber laser is one of the most common ways to permanently mark various engineering materials. The roughness of the machined surface and its observation is essential to evaluate the impact on the contrast of the marking as well. Experimental studies of the roughness obtained as a result of the laser marking, were inspected using a 3D measuring laser microscope OLYMPUS LEXT OLS5100. Analysis of the graphical dependence of the roughness function on the four process parameters: laser power, frequency, speed of marking and step.***

Keywords: Carbon steel, Laser marking, Roughness, fiber laser, surface texturing.

I. INTRODUCTION

In industrial production, some of the finished components and parts are required to have a certain roughness class. The operational properties of machine parts largely depend on the quality of the surface layer of the parts. Roughness affects other surface properties such as: coefficient of friction and wear, corrosion resistance, hydrophobicity, etc.[1]. There are different techniques for superficial processing, including mechanical and chemical methods [2]. One of their biggest drawbacks is the long processing time. In the 1970s, a new reliable and relatively economical industrial technology for laser processing of materials appeared. This technology is developing extremely fast and has been used in various industrial productions in recent years [3]. One of the directions in laser surface treatment is laser marking. In this process, a laser beam affects the surface, changing its roughness. The surface layer melts or evaporates as a result of this process, changing the roughnessWhen the roughness increases, we have a surface scoring effect, and when the roughness decreases as a result of laser exposure, we have a polishing effect [4]. In this effective method, through raster processing, the required grade of roughness is achieved. The advantages of the laser

method compared to the traditional ones are processing without tools, high flexibility at automation and low operational costs, high speed of processing, environmental friendliness and that it is non-contact.

The roughness of the surface during laser processing depends on several groups of factors, which are related to the parameters of the laser source, the technological process and the properties of the material [5].

Various scientific teams have investigated the changes in the roughness of products as a result of laser processing.

D Przestacki, [6] has investigated roughness in turning and laser machining. They achieved it with a laser power of 600 W roughness almost 30 % lower than that obtained by traditional turning. The Angelov, N. [7], used numerical experiments on the effect of laser wavelength

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2023vol3.7317
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on CuBr laser (λ_1 = 511 nm), ruby laser (λ_2 = 690 nm), diode laser (λ_3 = 940 nm), fiber laser (λ_4 = 1.06 µm) and CO_2-laser (λ_5 = 10.6 µm). Numerical experiments with different types of lasers are at the same power density and lasing scan rate, and the heating temperature at the lasing wavelengths is determined. Ukar et al. [8] have achieved a change of roughness up to 80% after laser treatment on instrumental steel. Guisario et al.[9] studied the the modification on the surface, induced from high powered laser on three different surfaces. Perry et al. [10] researched the laser roughness modification process and worked on developing a model to forecast its change. Bögli et al.[11] present one of the most common tools for evaluating surface roughness.

The purpose of the present study is to evaluate the influence of the average power *P,* processing speed *v,* step *Δx* between raster lines on the roughness of a carbon steel specimen. The analysis of energy density E_{eff} shows the relationship between the increase in roughness and the energy absorbed per square centimeter on the sample.

II. Equipment, Materials and Methodology

The experiments were carried out with a fiber laser technological system "PowerLine F-20 Varia" manufactured by GmbH ROFIN with length on the wave on the laser radiation 1.064 µm.

The main parameters on the laser technological system are shown in Table 1.

TABLE 1 PARAMETERS ON THE LASER SYSTEM

Scanner	
Working area	120 mm x 120 mm
Scan speed	0 ÷ 20,000 mm/s
Positioning accuracy	0.5 µm
Focal length	184 mm
Laser	
Laser source	Rofin Laser
Wavelength	1064 nm
Maximum power	19.7W
Pulse energy	0.0 ÷ 1.00 m J
Operating mode	Pulsed mode
Frequency	2 ÷ 1000 kHz
Pulse duration	4,8,14,20,30,50,100,200ns

To study the roughness, samples of C75 carbon steel were marked using a raster method. The treated areas are in the shape of a square measuring 10 x 10 mm, and the distance between them is 2 mm. A series of tests were made, each line having the following parameters:

- For the speed *v* (mm/s)

100	200	*300*	400	500	600	700

at constant power *P*= 30 W and step *Δ x*= 30µm

- For the step *Δ x* (µm)

20	*30*	35	40	45	50	60

at constant speed *v*= 300mm/s and power *P*= 30 W

- For the power P (W)

6	8	10	12.5	15	17.5	19.7

at constant speed *v*= 300mm/s and step *Δ x*= 30µm

Permanent parameters for the process of laser marking for all samples are the frequency *v*=40 kHz, the duration of the impulse τ = 100 ns, the diameter of the working stain *d* =50 µm, the defocus Δf = 0 mm and the number of repetitions *N* = 1.

The starting material (substrate) has a hardness of from HV 442 HV to 452 HV and a roughness from R_a = 0.264 µm to R_a = 0.36 µm, from R_z = 13.597 µm to R_z = 21.268 µm, from R_q = 0.41 µm to R_q = 0.56 µm. The chemical composition of the substrate is shown in the Table 2 below.

TABLE 2 CHEMICAL COMPOSITION C75

C	Si	Mn	P	S	Cr	Ni	Al
0.70	0.225	0.662	0.009	0.001	0.214	0.071	0.01

The laser system and schematic diagram of the raster method used in processing the carbon samples are shown in Fig.1.

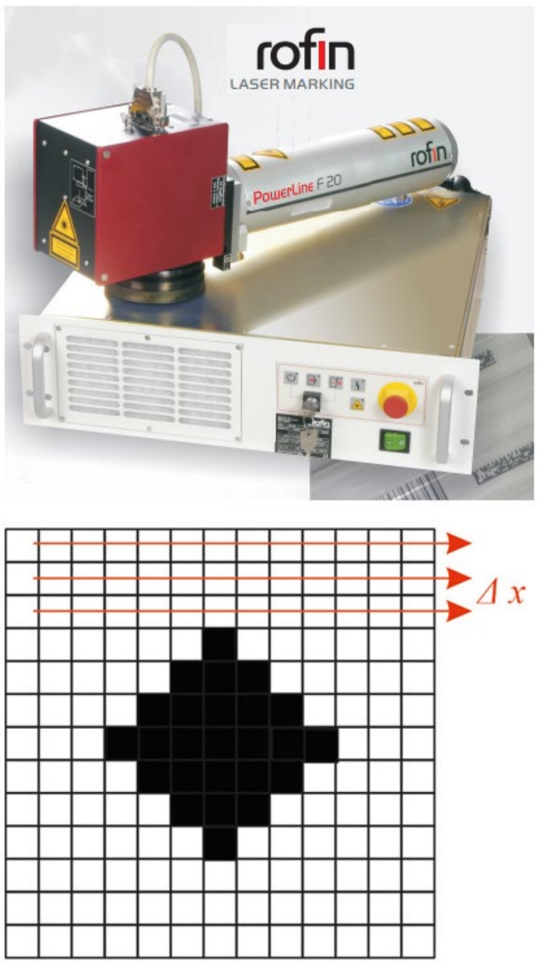

Fig.1. Fiber laser Rofin PowerLine F20 and laser marking strategy.

According to the purpose of the experiment, the present study analyzed the influence of the power P, the speed of processing v and the step Δx between raster lines on the surface roughness R_q. The following functional dependencies are investigated:

$$R_q = R_q\,(P),\ R_q = R_q\,(v),\ R_q = R_q\,(\Delta x)$$

The factors that affect the roughness of the mark are shown in Fig. 2.

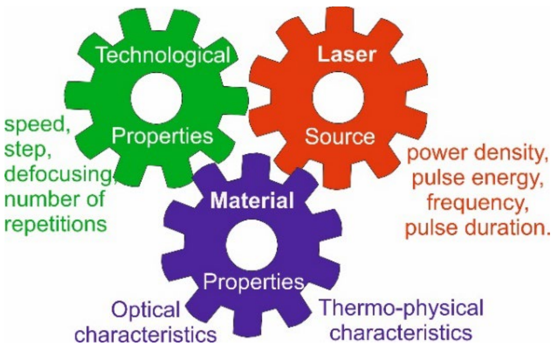

Fig. 2. Factors affecting roughness and marking.

To determine how the effective incident energy density E_{eff} affects the surface roughness, it is necessary to determine linear energy density LED (1) and linear pulse density LPD (2)

$$LED = \frac{A.P}{V}\ ,\mathrm{J/cm} \qquad (1)$$

where $A = 0.7$ absorption coefficient.

The LED value is numerically equal to the absorbed energy per unit length in the laser marking area.

$$LPD = \frac{v}{V}\ ,\text{number of pulses /cm} \qquad (2)$$

The LPD value is numerically equal to the number of pulses per unit length.

The quantity E_{eff} gives the absorbed energy of the laser radiation per unit area (13) from the laser impact zone.

$$E_{eff} = LED \text{ x } LPD,\ \mathrm{J/\,cm^2} \qquad (3)$$

The measurements on the surface of the samples from carbon steel C75 ware performed with a confocal laser scanning (CLS) microscope Olympus model "OLS5100-EAF" (Table 3). Received micro structural images were made with the help of a 20 × lens, magnification 451 ×, as the examined area for each measurement 644 × 644 µm with a precision of measurement of ± 0.03 µm. From the resulting 3D images from the laser system on the microscope are measured roughness R_q for the whole researched area 644 × 644 µm. For each of the treated areas (information blocks) five roughness measurements were made R_q with the average value of the measurement taken as the result. From received values are built graphic dependencies on changes in roughness, depending on the power, the speed, the step and the effective incident energy density E_{eff} with laser treatment.

TABLE 3 PARAMETERS OLYMPUS OLS5000

Parameters	Value
Total magnification	54× ÷ 17,280×
Field of view	16 µm ÷ 5.120 µm
Display resolution	1 nm
Measurement accuracy	± 1.5%
Maximum number of measuring points in a single measurement	4096 × 4096 pixels
Maximum number of measuring points	36 megapixels
Wavelength of laser light source	405 nm
Power of laser light source	0.95 mW

Table 3: Basic parameters of a microscope OLS5100 – EAF

III. RESULTS

The results from the experiment representing the graphical dependencies of the change of the roughness from the power $R_q = R_q$ (P) are shown in Fig.3.

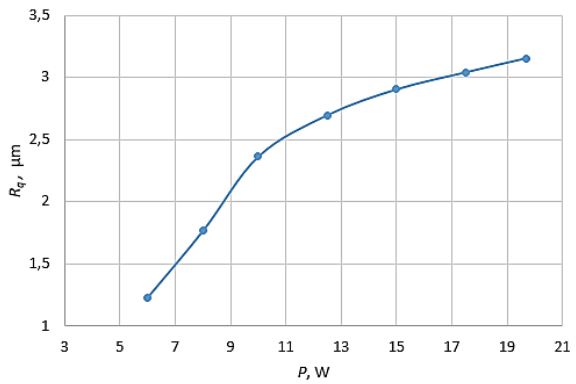

Fig.3 Experimental dependence of roughness variation on mean power.

The following conclusions can be made from the analysis of the graph:

With increasing power in the range $P \in [6, 19.7]$ W, the processing roughness increases non-linearly;
The increase in roughness is described by the equation

$$y = 9\times10^5\times x^4 - 0.004\times x^3 + 0.0478\times x^2 + 0.0986\times x - 0.3393. \qquad (4)$$

For powers in the range $P \in [6, 10]$ W the rate of growth of the roughness as a function of the power $\Delta R_q / \Delta P$ is 0.28 µm / W
For powers in the range $P \in [10, 19.7]$ W the speed of increase of roughness as a function of power $\Delta R_q / \Delta P$ is 0.05 µm / W.

For powers in the range $P \in [6, 10]$ W, the speed of change of roughness is 5 times greater than that in the range $P \in [10, 19.7]$ W.

The results from the experiment representing the graphical dependencies of the change of the roughness from the speed $R_q = R_q(v)$ are shown in Fig. 4.

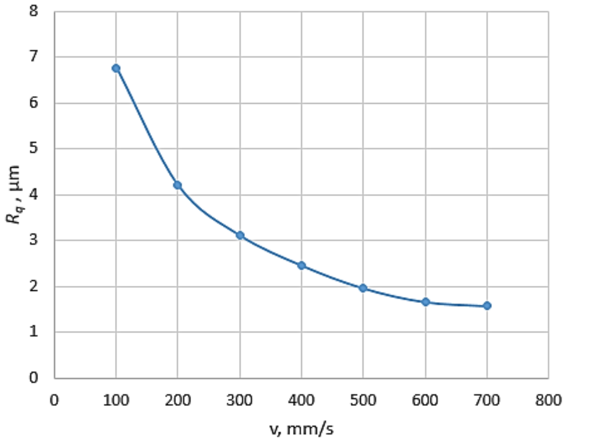

Fig. 4. Experimental dependence of roughness variation on marking rate.

The following conclusions can be made from the analysis of the graph:

When the speed increases in the range $v \in [100,700]$ mm/s a nonlinear decrease in roughness is observed.

For speeds in the range v $\in$[100, 400] mm/s the rate of roughness reduction as a function of speed $\Delta R_q/\Delta v$ is 0.014 µm/(mm/s)

For speeds in the range $v \in$[500, 700] mm/s the rate of roughness reduction as a function of speed $\Delta R_q/\Delta$v is 0.003 µm / (mm/s) , which is 4.8 times less than that in the range v $\in$[500, 700] mm/s

The results from the experiment representing the graphical dependences of the roughness change from the step $R_q = R_q(\Delta x)$ are shown in Fig. 5

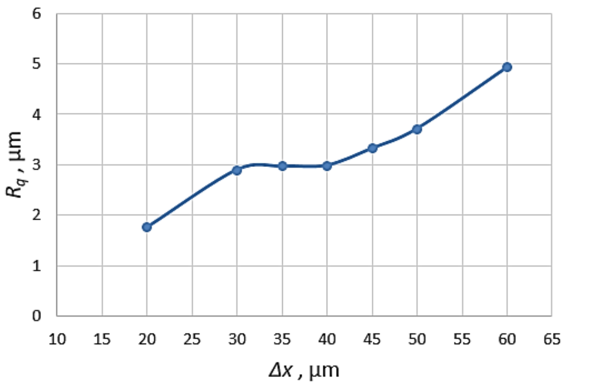

Fig. 5. Experimental dependence of roughness variation on raster marking step.

The following conclusions can be made from the analysis of the graph:

When the step increases, a logarithmic increase in roughness is observed;

For step in the range $\Delta x \in$[20, 30] µm the speed of growth of the roughness as a function of the step $\Delta R_q/\Delta x$ is 0.114.

For step in the range $\Delta x \in$[30, 40] µm roughness has minimal changes

For step in the range $\Delta x \in$[40, 60] µm the speed of growth of the roughness as a function of the step $\Delta R_q/\Delta x$ is 0.001.

The results of the experiment, representing the graphical dependence of the variation of the roughness as a function of the energy density $R_q = R_q(E_{eff})$ are shown in Fig. 6.

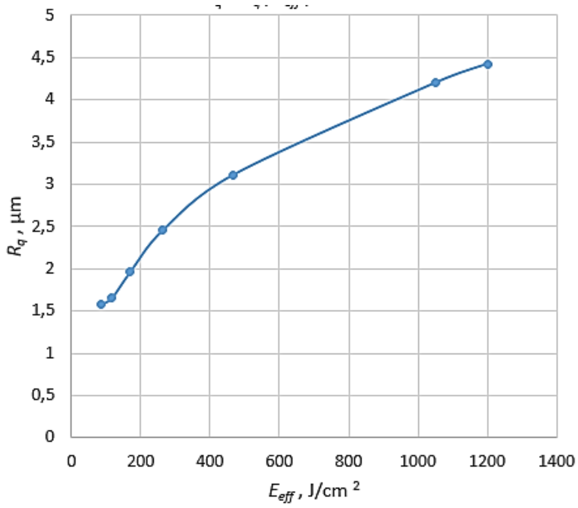

Fig. 6. Experimental dependence of roughness change on energy density.

The following conclusions can be made from the analysis of the graph:

For energy density in the range $E_{eff} \in$[116; 1200] J/cm ^{2} an increase in roughness is observed, the dependence being non-linear;

In the interval $E_{eff} \in$ [116; 262] J/cm ^{2} the rate of growth of the roughness as a function of the energy $\Delta R_q / \Delta E_{eff}$ is 0.0054 µm / J/ ^{cm2} ;

In the interval $E_{eff} \in$ [226; 1200] J/cm ^{2} the rate of growth of the roughness as a function of the energy $\Delta R_q / \Delta E_{eff}$ is 0.0021 µm / J/cm ^{2} which is 2.5 times less than that in the range $E_{eff} \in$ [116; 262] J/cm ^{2} ;

In the interval $E_{eff} \in$ [250,350] J/cm ^{2} a rapid increase in roughness is observed, which increases the efficiency in rubbing systems.

From the measurements made, the highest value of the roughness R_q = 6.763 µm was observed at the speed v = 100 mm/s and R_q = 4.925 µm at the step Δx= 20 µm

IV. Conclusion

The present study analyzes how roughness is modified by laser processing parameters: average power, speed, step and energy density. For the selected range of study, an increase in roughness is observed. The increase in roughness for some treated areas is 10 times greater than that of the substrate. The correct choice of parameters makes it possible to achieve a certain class of roughness, which is necessary in machine building.

Research is planned on the effect of the number of repetitions on the roughness of carbon steel workpieces.

V. Acknowledgment

The authors gratefully acknowledge financial support by the European Regional Development Fund, Postdoctoral research aid Nr. 1.1.1.2/16/I/001 research application "Analysis of the parameters of the process of laser marking of new industrial materials for high-tech applications, Nr. 1.1.1.2/VIAA/3/19/474".

References

[1] K. Rafiee, H. Naffakh-Moosavy and E. Tamjid, “The effect of laser frequency on roughness, microstructure, cell viability and attachment of Ti6Al4V”, Materials Science and Engineering: C, 2020, 109, 110637. doi:10.1016/j.msec.2020.110637

[2] S. Shaikh, S. Kedia, D. Singh, M. Subramanian and S. Sinha, “Surface texturing of Ti6Al4V alloy using femtosecond laser for superior antibacterial performance.”, Journal of Laser Applications, 31(2), 02.2011, doi:10.2351/1.5081106

[3] J. Walker, C. Murray, M. Nie, B. Cook, and Clare, “The effect of large-area pulsed electron beam melting on the corrosion and microstructure of a Ti6Al4V alloy”, Applied Surface Science, A. T. 2014, 311, 534–540, doi:10.1016/j.apsusc.2014.05.105

[4] Лазер форум, „Промышленная лазерная маркировка и гравировка металлических и неметаллических изделий“, URL: http://laser-form.ru/technologies/tehgravirovka.html, дата обращения: 13.02.2023

[5] A. Lamikiz, J. Sánchez, López de Lacalle, D. del Pozo, and J. M. Etayo, “Surface Roughness Improvement Using Laser-Polishing Techniques.”, Materials Science Forum, 2006 526, 217–222, doi:10.4028/www.scientific.net/msf.526.217

[6] D. Przestacki, and M. Jankowiak, “Surface roughness analysis after laser assisted machining of hard to cut materials”, Journal of Physics: Conference Series, 2014, 483, 012019, doi:10.1088/1742-6596/483/1/012019

[7] Angelov, N., Numerical Experiments for the Study of the Influence of Wavelength in Laser Impact onto Metals and Alloys, ICEST 2013, 26-29 June 2013, Ohrid, Macedonia, pp. 603-606, 2013, http://rcvt.tu-sofia.bg/ICEST2013_2_37.pdf

[8] E. Ukar, A. Lamikiz, L. López de Lacalle, D. del Pozo and J.L. Arana, “Laser polishing of DIN 1.2379 tool steel with CO2 laser and high-power diode laser”, Int. J. Machine Tools Manuf, 2010, 50, 115–125.

[9] A. Gisario, A. Boschetto, and F. Veniali, “Surface transformation of AISI 304 stainless steel by high power diode laser”, Optics and Lasers in Engineering, 2011, 49(1), 41–51, doi:10.1016/j.optlaseng.2010.09.01

[10] T. Perry, D. Werschmoeller, X. Li, F. Pfefferkorn, N.Duffie, “The effect of laser pulse duration and feed rate on pulsed laser polishing of microfabricated nickel samples”, 2009, J. Manuf. Sci. Eng. 131, 030995–031002.

[11] U. Bögli, A. Blatter, S. Pimenov, A. Smolin and V.I. Konov, “Smoothening of diamond films with an ArF laser”, Diamond Relat. Mater, 1992, 1, 782–788