INVESTIGATING THE INFLUENCE OF THE NUMBER OF REPETITIONS AND VOLUMETRIC ENERGY DENSITY ON LASER MARKING OF PRODUCTS

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Abstract: The basic factors affecting the laser marking of products – volumetric density of the absorbed energy and the number of repetitions, were studied. Experiments were conducted of marking the samples of stainless steel with fiber laser. The dependence of the contrast of marking from the power density for different number of repetitions, and also the volumetric density of the absorbed energy from speed was obtained and the experimental results analyzed.

Keywords: laser marking, fiber laser, contrast, number of repetitions, volumetric density of absorbed energy, power density, marking speed.

1. INTRODUCTION

Laser marking is a complex technological process [1–4]. One of the basic criteria for assessing the quality of marking is its contrast on product. Factors that influence the contrast in the laser marking, and hence optimization of the process in general, can be combined into three groups, associated with:

– the properties of material – optical characteristics (reflection coefficient, absorption ability, absorption coefficient, penetration depth) and thermo-physical characteristics (heat conduction, thermal conductivity, heat diffusion length);

–laser source – power, power density, pulse energy, frequency, pulse duration, wavelength, beam quality;

– technological process – speed, step, defocusing, number of repetitions.

The complex factors such as the coefficient of overlap (related to those of the laser source and technological process) and volumetric density of absorbed energy (related to factors of three groups) must be added to the above [5].

These basic factors are related in certain physical dependencies between them. They are important for understanding the physical nature of the process and build of its model.

The aim of this paper was:

– To investigate the influence of volumetric energy density and the number of repetitions on the process of laser marking;

– To analyze the experimental dependence of the contrast of marking from the power density for different numbers of repetitions;

– To analyze the experimental dependence of the volumetric energy density from the speed.

A. Theoretical studies

To carry out the marking, the power density of the laser radiation should be sufficient to cause structural changes in the product of structural steel, melting the material in the treatment zone and/or its partial evaporation. As far as the studies are concerned, it must be taken into account that with its increase the absorption ability of steel increases.

The power density is defined by the formula

$$q_S = \frac{P}{S}, \qquad (1)$$

where P is power, S – the surface of the working area.

Taking into account that

$$S = \frac{\pi d^2}{4}$$

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$$q_S = \frac{4P}{\pi d^2} , \qquad (2)$$

was obtained, where d is the diameter of the working area.

The volumetric density of absorbed energy is given by the expression

$$E_\rho = \frac{AE}{V} , \qquad (3)$$

where A is the absorption ability, E – fallen energy of laser radiation, V – volume of the impact area .

Volumetric density of the absorbed energy can be practically determined by the formula

$$E_\rho = \frac{Aq_S}{v} , \qquad (4)$$

where v is speed.

Volumetric density of absorbed energy is the quantity that the most complete renders an account the energetic impact of laser radiation on the sample. It determines the heating temperature of the sample and the method of marking. It indirectly influences the contrast of marking.

The upper limit of the power (and thus of the power density) of each laser source is preset and is necessary to determine an optimum interval of amendment of q_S to achieve the good quality of marking. Sometimes it is necessary to mark the products made of a particular material for a technological system whose power density is not sufficient to carry out the process. In this case, one of possible solutions is to use different number of iterations N of the marking, to obtain the desired result.

B. Experimental studies

Experimental studies were performed with laser technological system for marking with fiber laser [6−8]. They included the products from stainless steel 10H14AG15. It is intended for non-magnetic components operating in slightly aggressive environments; household items; lightweight structures, joined by spot welding. Its basic characteristics are given in [9].

1) Investigating the influence of the number of repetitions N

Experimental plan

The experiments that included the study of the influence of the number of repetitions N on the con-

trast of marking k^*, were carried out on cut samples of steel 10H14AG15 on raster marked fields with measuring 5 mm x 5 mm with fiber laser. 40 squares with different processing speeds v were raster marked on the studied samples of steel, in the interval $v \in [30; 130]$ mm/s and with a number of repetitions $N = 1; 2; 3, 7$, respectively.

Certain parameters of laser system, which are kept constant during the experiments, are presented in table 1.

Graphics of the resulting experimental dependence $k^* = k^*(v)$ for different number of repetitions of the marked squares are shown in Fig. 1. The following conclusions can be drawn from their analysis:

– The contrast of laser marking increases by increasing the number of repetitions;

– When changing the speed in the interval $v \in [30, 130]$ mm/s in double raster marking of the lines contrast k^* increased $1,4 – 1,5$ times compared to their single marking. The explanation of this experimental result confirms the theoretical studies of [5]. As a result of the first processing increases the absorbance in the area of impact. Thus, in case of repeated impact on the target area the greater part of the fallen laser radiation was absorbed.

– When the number of repetitions $N = 3$ produces a higher contrast k^* of the marked area in comparison to that for $N = 2$. It should be noted that the increase in contrast is not significant, about 10%.

– In number of repetitions $N = 7$, the marking contrast is almost the same as with the number of repetitions $N = 3$. Furthermore, the method of marking by evaporation is obtained. The quality of marking is slightly reduced.

– The results of the graphics (1) and (2) show that the efficiency of the raster marking with double processing of the operating zone is significantly higher than that for a single processing.

Table 1. Basic parameters of laser system with fiber laser, which are kept constant during the experiments.

Parameter	Value
Power density q_S , W/m^2	$7{,}75.10^9$
Frequency v, kHz	30
Pulse duration τ, ns	250
Diameter of work spot d, μm	35
Step Δx, μm	50
Defocusing Δf, mm	0

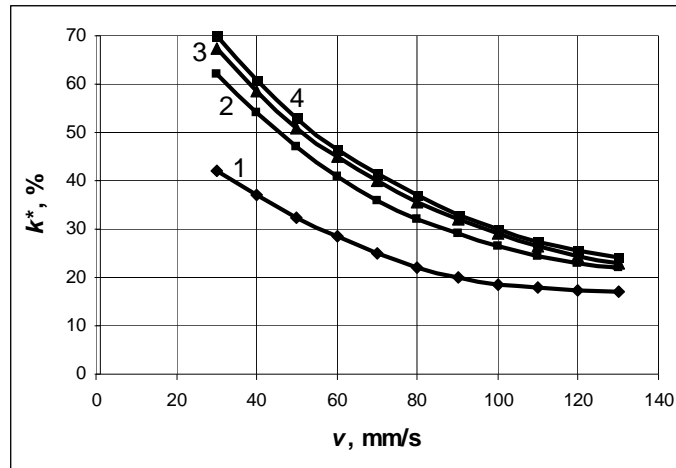*Figure 1. Graphics of the experimental dependence k* = k*(v) for laser marking with number of repetitions:*
1 – N = 1; 2 – N = 2; 3 – N = 3; 4 – N = 7.

2) Determining the volumetric density of absorbed energy

Experimental plan

For different speeds of marking the power density of the laser radiation is determined, for which a certain contrast of the laser marking is obtained. Then the ratio q_S/v for these speeds was calculated.

The parameters of laser system, which are kept constant during the experiments, are presented in Table 2.

Table 2. Basic parameters of laser system with fiber laser, which are kept constant during the experiments.

Parameter	Value
Frequency v, kHz	30
Pulse duration τ, ns	250
Diameter of work spot d, μm	35
Step Δx, μm	50
Defocusing Δf, mm	0

The analysis of experimental results

The graph of dependence $q_S/v = f(v)$ – Fig. 2 was made from the obtained results. The volumetric density of the absorbed energy according to (4) is proportional to the ratio q_S/v. The proportionality factor is equal to the absorbance A of the material. It is considered to be constant.

− The following conclusions can be drawn from the graph:

− With increasing velocity v it has been was observed that a decrease of the attitude q_S/v as dependence is almost linear;

− When changing the speed in the interval $v \in$ [30; 120] mm/s ratio q_S/v is in the interval $q_S/v \in$ [30.1; 27,4] GJ/m³ decreasing by about 10%. The reason is that with increasing the speed of the marking the impact time in the treatment zone is reduced. This leads to the reduction of energy loss [10]. In these cases, the process is realized with less volumetric energy density.
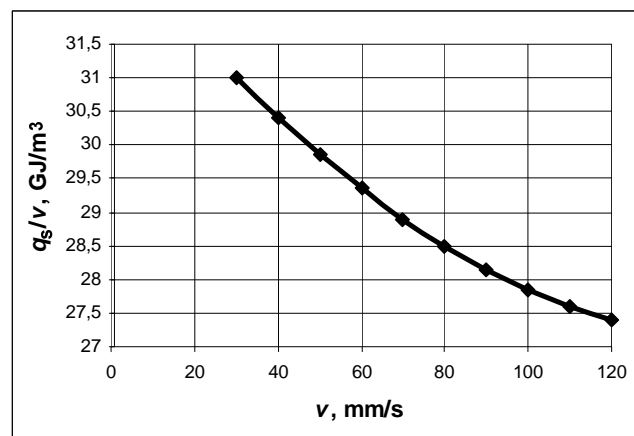

Figure 2. Graphics of the experimental dependence $q_S/v = f(v)$ for marking with fiber laser

3. CONCLUSION

The experimental results support the carrying out of the process of laser marking of stainless steel products in industrial conditions. They provide various choices of operating parameters of the operator of laser systems. Studies can be extended to disc laser, Nd:YAG laser and CuBr laser, which are suitable for laser marking.

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ПРОУЧАВАЊЕ УТИЦАЈА БРОЈА ПОНАВЉАЊА И ОБИМА ГУСТИНЕ ЕНЕРГИЈЕ НА ЛАСЕРСКО ОБИЉЕЖАВАЊЕ ПРОИЗВОДА

Сажетак: Анализирани су главни фактори који утичу на ласерско означавање производа − волуметријска енергетска густина и број понављања. Експериментална истраживања обухватила су обиљежавање узорака нерђајућег челика фибер ласером. Добијена је зависност контраста обиљежавања од густине енергије за различит број понављања, као и булк густина апсорбоване енергије од брзине. Анализирани су добијени експериментални резултати.

Кључне ријечи: ласерско обележавање, фибер ласер, контраст, број понављања, волуметријска енергетска густина, густина снаге, брзина обележавања.

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