Determination of Critical Power Densities in Laser Marking of C30 Steel Samples

Nikolay Angelov[1], Georgy Stoyanov[2]

[1]Technical University of Gabrovo, Department of Physics, Chemistry and Ecology, 4 Hadzhy Dimitar str., Bulgaria,

[2]Technical University of Gabrovo Department of Electric Power Supply and Equipment, 4 Hadzhy Dimitar str., Bulgaria

Abstract. Experiments were carried out to determine critical power densities in laser marking of samples of structural steel C30. Fiber laser was used. Critical power dependence on melting density and of evaporation on velocity were studied and corresponding graphics were drawn. The obtained results were analyzed and summarized.

Keywords: laser marking, fiber laser, steel C30, critical power density, speed.

1. INTRODUCTION

A fast and clean technology, laser engraving is rapidly replacing older marking methods like dot peen and chemical etching. A key factor for its widespread adoption is the exponential increase in the use of direct part marking to enable tracking and traceability across many industries, most notably machine building, automotive manufacturing, airplane building, ship building, electronics, food industry, medical device and others. Easy and flexible automation, the fact that it is a non-contact process, its improved environmental profile and low cost of ownership add to the benefits of purchasing and using laser marking equipment or laser etching equipment.

Types of markings include alphanumeric characters, bar-codes, 2D matrix codes, serial numbers, logos and graphics. Materials which can be laser marked include metals, semiconductors, plastics, ceramics etc. (www.amadamiyachi.com/products/laser-marking).

The type of applied marking is dependent on the characteristics of the used laser (wavelength, power density, frequency, pulse duration, pulse energy, pulse power beam quality); material properties (optical and thermos-physical characteristics) and technological parameters (speed, number of repetition, defocusing, step; Veiko, 2007; Dinev, 1993; Grigoryanc et al., 2006; Sobotova et al., 2015; Angelov, 2011).

The purpose of this work is to determine the critical power densities of melting and evaporation power for marking on samples of steel C30 steel for different marking speeds.

2. THEORETICAL BASIS

In the optimization of the laser marking process, a large part of the experiments directly or indirectly examine the influence of the power density on the quality of the marking and primarily on the contrast. This necessitates the use of methods for determining the critical power density of evaporation q_{Scrv} and melting q_{Scrm} and for measuring the contrast.

3. DATA

Material

Experimental studies refer to structural steel C30. It is widely used in the industry. Traction axes, cylinders, discs, bolts, nuts, screws and others are produced from it. The chemical composition of the steel is presented in Table 1. It is low carbon steel with a content of alloying element manganese from 0.50% to

0.80%. The temperature dependence of some physical parameters of steel is shown in Table 2 (www.splav-kharkov.com). It is characterized by high value of coefficient of thermal conductivity and coefficient of thermal diffusivity.

TABLE 1. Chemical composition of structural steel C30

Chemical element	C	Mn	S	Cr	As
Content, %	0,27 ÷ 0,35	0,50 ÷ 0,80	< 0,04	< 0,25	< 0,08
Chemical element	Si	Ni	P	Cu	
Content, %	0,17 ÷ 0,37	< 0,30	< 0,035	< 0,30	

TABLE 2. Temperature dependence of basic physical parameters of structural steel C30. Legend: T - temperature; k – coefficient of thermal conductivity; ρ - density; c – specific heat capacity, a – coefficient of thermal diffusivity.

T, K	k, W/(m.K)	ρ, kg/m^3	c, J/(kg.K)	a, m^2/s
293	52	7850	460	1,44.10^{-5}
373	51	7820	470	1,39.10^{-5}
473	49	7790	483	1,30.10^{-5}
573	46	7760	546	1,09.10^{-5}
673	43	7730	563	7,28.10^{-6}
773	39	7700	764	6,63.10^{-6}
873	36	7670	824	5,70.10^{-6}
973	32	7640	884	4,74.10^{-6}

Laser system

The experiments were conducted by applying a laser marking technological system with a fiber laser (www.spilasers.com). Some basic parameters are shown in the Table 3. The laser emits in pulse mode. The fiber optic laser works in the near infrared area. It is distinguished by a high repetition rate of the pulses and has a relatively high efficiency. The laser system has very high positioning accuracy, good repeatability and provides high speed laser beam movement.

TABLE 3. Basic parameters of laser marking system with a fiber laser

Parameter	**Value**
Wavelength λ, nm	1 064
Power P, W	30,0
Diameter of working spot d, µm	35
Frequency ν, kHz	80
Pulses duration τ, ns	100
Pulse energy E_p, mJ	0,38
Pulse power P_p, kW	3,80
Speed of the beam, mm	0 ÷ 7000
Beam quality M^2	< 1,1
Positioning accuracy, µm	2,5
Efficiency, %	40

4. METHODOLOGY

The following methodology is used to determine q_{Scrm} and q_{Scrv} (Angelov, 2011):

- Lines are plotted on the samples at constant speed, as the power density is changed by a certain step;
- Sandings are prepared and the impact areas are visually observed under the microscope marked lines;
- The impact zone where the melting process is terminated (the marked line is not noticeable), is needed and located;
- The critical power density for melting q_{Scrm} is calculated by the formula

$$q_{Scrm} = \frac{4P}{\pi d^2}, \tag{1}$$

where P is the power at which the marked line disappears, d - the diameter of the working spot;

- The impact area where the evaporation process starts (a channel appears on the surface of the material), is needed;

- The critical power density for evaporation q_{Scrv} is calculated by the formula

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

where P' is the power at which a channel appears at the surface of the material.

5. EXPERIMENTAL RESULTS

Experiments were carried out according to the described methodology with a fiber laser to determine the critical values of the power density of melting q_{Scrm} and evaporation q_{Scrv}. C30 steel samples were used. The power density intervals for the different marking methods can be determined by means of the critical power density values for melting and evaporation.

Graphics of dependence of the critical value of power density of melting q_{Scrm} on speed v of the marking are given in Fig. 1. From the results obtained, the following conclusions can be drawn:

- The critical power density of melting increases almost linearly with increment speed;
- The rate of amendment of the critical power density value of melting is

0,965.10^8 (W/m^2)/(mm/s) in the interval v Є [20, 60] mm/s;
0,668.10^8 (W/m^2)/(mm/s) in the interval в v Є [60, 100] mm/s.

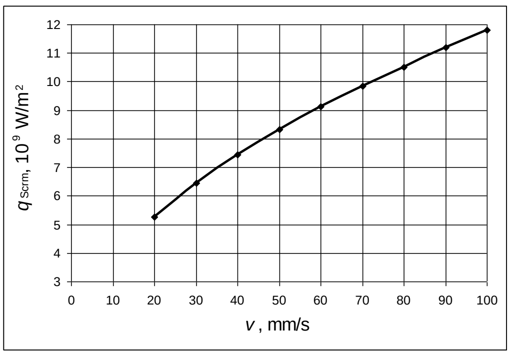

Fig. 1 Graphics of dependence of the critical power density of melting q_{Scrm} on speed v

Graphics of dependence on the critical value of power density of melting q_{Scrv} on speed v of the marking are shown in Fig. 2. From analysis of the graphics one can see that:

- The critical power density of melting increases with increment speed for the entire investigated interval;
- The rate of increase of the critical power density value of evaporation is

1,45.10^8 (W/m^2)/(mm/s) in the interval v Є [20, 60] mm/s;
1,05.10^8 (W/m^2)/(mm/s) in the interval v Є [60, 100] mm/s.

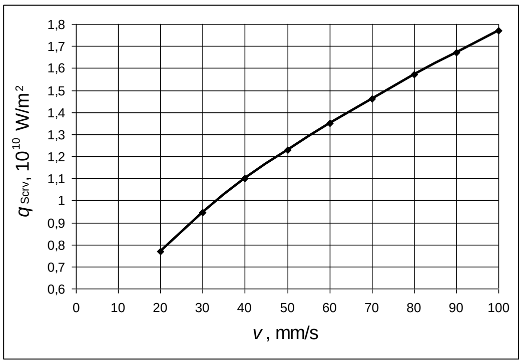

Fig. 2 Graphics of dependence of the critical power density of evaporation q_{Scrv} on speed v

6. CONCLUSIONS

Experimental research helps to clarify the laser marking process by melting C30 structural steel products. The following results were achieved:

- The dependency of the critical power density of melting on speed for fiber laser was obtained;
- The dependency of the critical power density of evaporation on speed for fiber laser was obtained;
- The results make it possible to determine the power density variation interval for laser marking by melting for this material.

REFERENCES

Angelov, N., 2011, *Optimization of the Laser Marking Process of Instrumental Steel Samples,* PhD thesis, Technical University – Gabrovo, p.23 – 48 (in Bulgarian)

Dinev, S., 1993, *Lasers in Modern Technology*, Publishers Alfa, 51-110 (in Bulgarian)

Grigoryanc, A., Shiganov, I. & Misyurov, A., 2006, *Technological Processes in Laser Pprocessing*, Publ. MGTU N. Baumana, Moscow (in Russian)

Sobotova, L. & P. Demec, 2015, Laser Marking of Metal Materials, *MM Science Journal, December*, 808-812

Veiko, V., 2007, *Technological Lasers and Laser Radiation*, Publishers SPB GU ITMO, Sankt-Peterburg, 24, 33, 44 – 46 (in Russian)

www.splav-kharkov.com

www.spilasers.com

www.amadamiyachi.com/products/laser-marking