Numerical Experiments for the Study of the Influence of Wavelength in Laser Impact onto Metals and Alloys

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Abstract – **The program TEMPERATURFELD3D, working in MATLAB, has been used to conduct numerical experiments. The study of the influence of the wavelength of the laser, is pertained to 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 for the same power density and speed. A Graph of the dependence of the maximum temperature of the heating on the surface of the product from the wavelength is built. The obtained results are analyzed.**

Keywords – **Numerical experiments, Software TEMPERATURFELD3D, Laser, Wavelength.**

I. Introduction

Factors that influence the contrast on the laser marking, and hence on the optimization of the process, in general, can be summarized into three groups [1, 2] (see Fig. 1) associated with:

- material properties - optical characteristics (reflectance, absorptivity, depth of penetration) and thermo-physical characteristics(thermal conductivity, thermal diffusivity, specific heat capacity);
- laser source - power density, pulse energy, pulse power, frequency, pulse duration;
- technological process – speed, defocusing, step, number of repetitions.

To these must be added the following factors – the coefficient of overlapping (related to those of the laser source and technological process) and the volume density of the absorbed energy (related to the factors of the three groups).

These basic factors are in certain physical relationships to each other. Relationships and dependencies between them are important for understanding the physical nature of the process and for building its model.

The wavelength is a factor that indirectly influences the research process. Absorptivity (reflection coefficient, respectively) strongly depends on the wavelength of the laser radiation. [3].

On Fig. 1 is represented the dependence $A = A(\lambda)$ for various metals and steel. A trend was observed - the significantly lower absorptivity of the radiation in the far infrared area compared to that of the radiation in the ultraviolet and visible area.

Many authors have studied the dependence of the absorptivity A on the wavelength λ of the laser radiation for Fe [4-8]. On Fig. 2 is presented a summary of the experimental dependence $A = A(\lambda)$. With increasing wavelength λ absorptivity decreases and almost linearly throughout the studied interval. For radiation in the infrared region experimental results are consistent with the formula of Hagen-Rubens [9]

$$A = \left(\frac{4c}{\lambda\sigma}\right)^{\frac{1}{2}}, \tag{1}$$

where c is the speed of light in vacuum, σ - electrical conductance in system CGS.

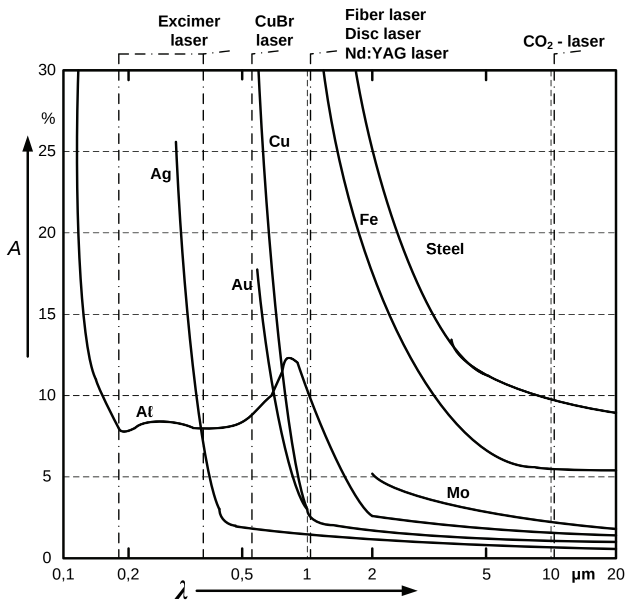

Fig. 1. Dependence of the absorptivity A on the wavelength λ of the laser beam for certain metals and steel

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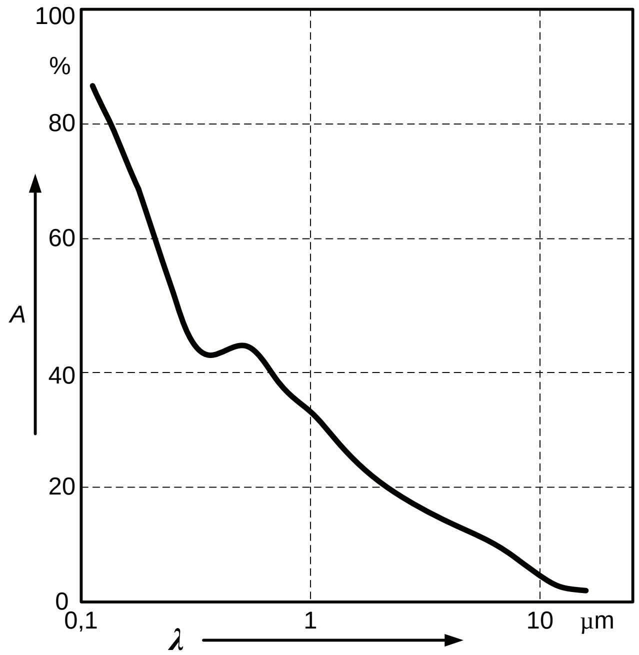

Fig. 2. Experimental dependence of absorptivity A on the wavelength λ of the laser radiation for Fe

II. PRESENTATION

The objective of this report was to investigate the influence of the wavelength on the process of laser marking of articles made of metals and alloys. Lasers operating in the visible, near and far infrared areas are used.

A. Numerical experiments

There have been a series of numerical experiments for calculation of the temperature field in the zone of impact on laser marking by melting on metals and alloys. In Table. 1 are given the used lasers and their wavelengths.

Calculations refer to stainless steel, copper and aluminum. Their main parameters are presented in Table 2 [10, 11].

TABLE 1
USED LASERS AND THEIR WAVELENGTH

Laser	Wavelength λ, nm	ℓog [λ]
CuBr laser	511	2,708
Ruby laser	694,3	2,842
Diode laser	940	2,973
Fiber laser	1060	3,025
CO_2-laser	10600	4,025

TABLE 2
BASIC PARAMETERS OF THE STUDY MATERIALS

Material Magnitude	Steel 12X17	Cu	Aℓ
Thermal conductivity k, W/(kg.K)	24	401	236
Density ρ, kg/m^3	7720	8920	2700
Specific heat capacity c, J/(kg.K)	462	380	830
Thermal diffusivity a, m^2/s	$7{,}01.10^{-6}$	$1{,}18.10^{-4}$	$1{,}15.10^{-4}$
Temperature of melting T_m, K	1750	1357,6	933,47

The numerical experiments were performed with the program TEMPERATURFELD3D [12], specialized in studying of the temperature fields by laser impact. It requires four types of input parameters:

- program;
- geometric;
- of the laser;
- of the material.

At the end are realised the following options:

- 3D and 2D profile of the maximum temperature on the surface of the sample.
- 3D and 2D temperature profile of the sample in depth (layer by layer).
- Dependence of the temperature on the depth in various time points.
- Determination of the speed of heating and cooling in different parts of the product when there is laser impact.
- Animation of the process.

Constant technological parameters in the calculations are given in Table. 3. The speed is typical for an industrial laser marking on products from the studied materials.

TABLE 3

CONSTANT TECHNOLOGICAL PARAMETERS DURING THE CALCULATIONS

Parameter	Value
Power density q_S, W/m^2	
Speed v, mm/s	
Number of repetition N	1
Defocusing	0

The samples are in the shape of a rectangular plate with a thickness h = 500 μm. Its upper surface lies in the plane OXY. The movement of the laser beam is in a direction parallel to the OY axis and starting from a point with coordinates ($8{,}0.10^{-5}$; 0) m.

B. Results

In fig. 3, 4 and 5 are presented 3D temperature fields in the area of the laser impact for stainless steel 12X17. At impact with the given in Table. 3 parameters, the maximum surface temperature of the specimen is T_1 = 2250 K for laser CuBr (fig. 3), T_2 = 1790 K for fiber laser (fig. 4) and T_3 = 555 K for CO_2-laser (fig. 5).

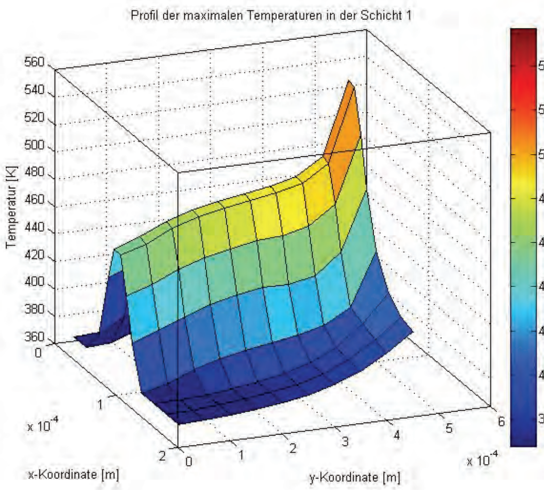

Fig. 3. Temperature profile of the surface of a sample of stainless steel 12X17 when there is an impact with a CuBr laser

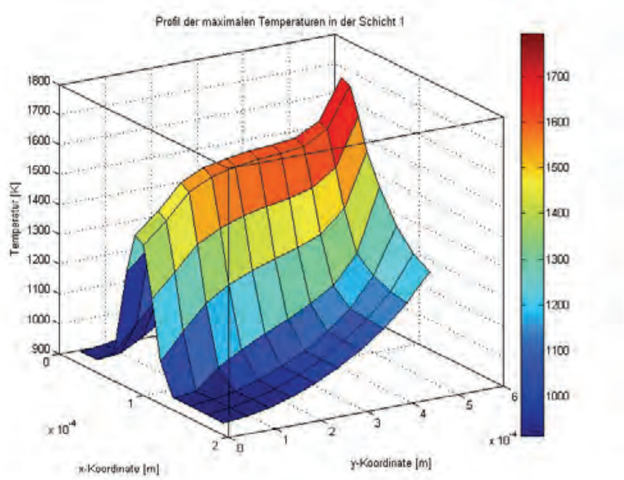

Fig. 4. Temperature profile of the surface of a sample of stainless steel 12X17 when there is an impact with a fiber laser

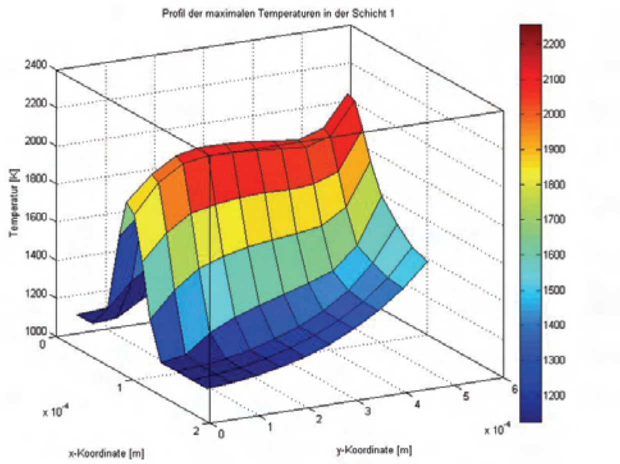

Fig. 5. Temperature profile of the surface of a sample of stainless steel 12X17 when there is an impact with a CO_2 laser

In fig. 6, 7 and 8 are presented graphs of the dependence $T = T(\ell og\ [\lambda])$ for samples of steel 12X17, copper and aluminium. From their analysis can be made the following conclusions:

For samples of steel 12X17

- With the increase of the wavelength decreases the temperature of the heating on the surface of the sample in the zone of impact.
- In the studied parameters the temperature is above the melting temperature when there is an impact with the lasers in the visible and near infrared area. With a laser in the far infrared area it is 550 K, i.e. considerably lower than the melting temperature.
- For laser marking of samples are suitable lasers, working in the visible and near infrared areas.

For samples of copper

- With the increase of the wavelength sharply reduces the heating temperature on the surface of the sample in the area of impact.
- In the studied parameters the temperature is above the melting temperature when there is an impact with a CuBr laser and with lasers in the near and far infrared areas in the interval $T \in [450, 700]$ K. This is explained with the significantly lower absorbency of radiation with wavelengths in the near and far infrared areas as compared to that of the visible region.

For samples of aluminium

- The radiation is absorbed best in the near infrared region and in the upper part of the visible region.
- The radiation in the far infrared area is slightly absorbed by the samples and it slightly increases the temperature on the surface within the area of impact. It is not suitable for laser marking by melting.

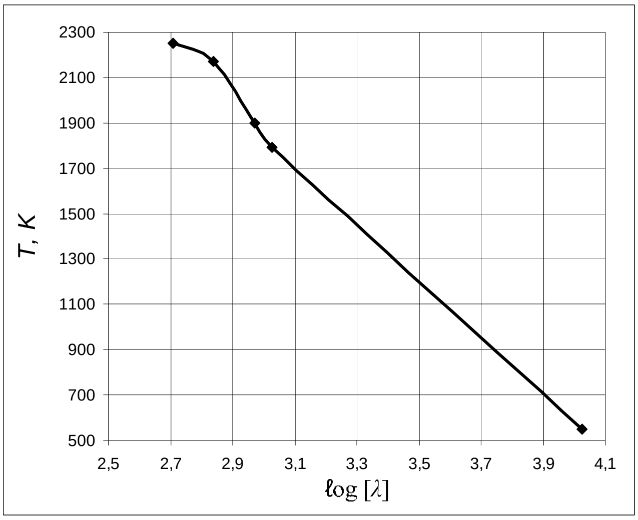

Fig. 6. Graphs on the experimental dependence of the temperature on ℓog [λ] for a sample of steel 12X17

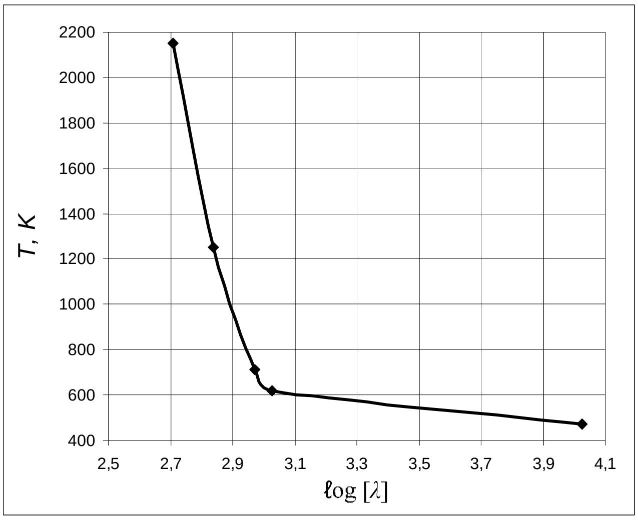

Fig. 7. Graphs on the experimental dependence on the temperature on ℓog *[λ]* for a sample of copper

According to the experimental studies can be summarized that the radiation wavelength λ = 10,6 µm is not suitable for marking of steel and metals. From an energetic point of view, the radiation in the visible range is the most suitable for the studied process. For lasers in the near infrared area the absorptivity is relatively good. They possess a very good quality of radiation and a high efficiency coefficient. They are also suitable for marking these materials.

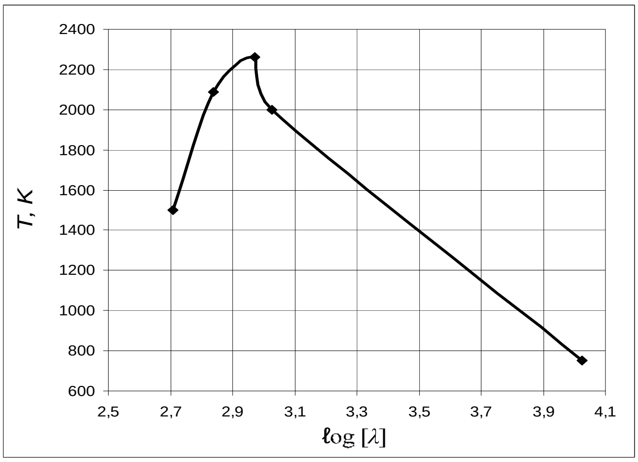

Fig. 8. Graphs on the experimental dependence on the temperature on ℓog [λ] for a sample of aluminium

III. Conclusion

In the study of the laser marking of metals and alloys should be determined the importance of the various factors affecting the process. The application of numerical experiments leads to faster attainment of optimum results. Thus, it speeds up the attainment of greater efficiency in production and the better quality of the marking.

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