

Local Processing of Non-Metal Materials with Concentrated Energy Flow

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Abstract. In the present study, the peculiarities of local heat treatment with a concentrated light energy flow of non-metallic materials are traced. Mathematical dependences are presented for determining the surface density of the absorbed power - $W(r)$, the thermal power - P_0 , and other characteristics in case of local thermal impact on the surface of non-metallic materials with a concentrated light energy flow.

Keywords: concentrated light energy flow, non-metallic materials, surface thermal effect.

I. INTRODUCTION

Electrothermal technological processes are the basis of modern industrial development. By their nature, they are divided into two large groups [6,7,8]:

- Electrothermal physical processes;
- Electrothermal chemical processes.

Physical electrothermal processes include a large group of electroerosion, plasma, electron beam, ion and light (laser) technologies for shaping and shape change.

Electrothermal technologies, together with controlled (by composition) gas environments and vacuum, become the basis for the development of special metallurgy, the production of quartz and optical fibers, the production of metallic amorphous materials, the processing of semiconductor and dielectric materials [2,3].

The development of electrothermal technologies leads to the emergence and possibility of processing new materials (extremely necessary for the development of the electrotechnical industry, electronics, medicine and other branches of the economy) with increased operational properties, extended life and increased reliability [4]. Many of the new materials cannot be processed by existing conventional (casting, plastic deformation, etc.) technologies. In turn, the development of methods for

obtaining new materials leads to the development of new methods of processing and their modification.

The purpose of this publication is to examine the peculiarities of processing non-metallic materials by local thermal impact with a concentrated light energy flow (laser processing).

II. RESULTS AND DISCUSSION

Under the influence of a powerful energy flow on the processed surface of the materials, the absorbed energy is converted almost instantly into heat and creates a secondary (local) source of heat on the surface or in the volume of the material. The dynamics of temperature change, the distribution of temperature fields in the material, as well as the appearance of phase transitions and opportunities for local thermal processing are mainly determined by this secondary heat source [9,10].

The thermophysical task of heating the material under the influence of the secondary heat source during laser processing has no analytical solution [1,11]. Simplifying assumptions are made about the shape of the incident energy pulse, about the thermophysical properties of the medium and their temperature variation, and about the boundary conditions, which at the present time give solutions with satisfactory accuracy.

In this regard, it is appropriate to create a method for local thermal treatment, based on simplified thermophysical considerations related to the local thermal action of pulsed heat sources in the solid body [1].

The controlled thermal (physical) state of the material in the zone of influence of the heat source, by changing the surface density of the absorbed power, by changing the focused energy spot, or by using pulses of different duration and energy is the basis of a wide class of electrophysical technologies and especially the laser ones.

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The thermal impact on the material takes place in the area of action of the secondary source and in the area of action of the heat wave propagating as a result of thermal conduction. In this situation, an increase in the temperature of the material is accompanied by:

- change in the optical, electrical and thermal properties of the material;
- occurrence of thermomechanical stresses;
- phase transitions of the material;
- activation of diffusion processes;
- thermochemical changes in the surface layer

As a result, high heating rates are realized - up to 1010 K/s, and cooling - up to 108 K/s, which determines the large temperature gradient - 106 K/s [7].

Local laser processing of the material is the result of the appearance and use of powerful light fluxes that act on the surface of the processed product. It can be considered as localization to the maximum extent of the thermal impact along the radius - r , of the beam (most often according to the Gaussian distribution of the surface power density) and in the depth of the material - along the z axis - fig.1.

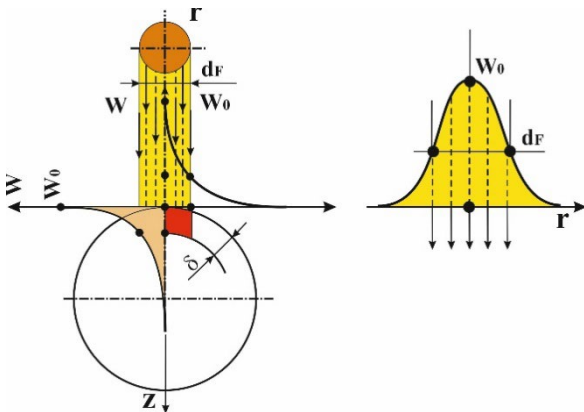


Fig.1. Schematic diagram of local surface laser thermal impact on non-metallic materials depending on the penetration depth - δ and the size of the workpiece - R .

Depending on the transparency of the material at $\delta \ll d_F$, a surface heat source is formed with a different distribution of the absorbed power density $W(r,z)$ - fig.2.

When processing non-metallic materials, the normal (Gaussian) distribution is the most common power density distribution law - $I(r)$, in the normal section of the energy beam (or in the contact spot). Its corresponding local heat source is also characterized by a normal distribution of the surface density of the absorbed power - $W(r)$, and can be calculated by formula 1:

$$W(r) = W_0 \exp(-k \cdot r^2) = A \cdot I_0 \cdot \exp(-k \cdot r^2) \quad (1)$$

where: k - flow concentration coefficient characterizing the shape of the normal distribution curve.

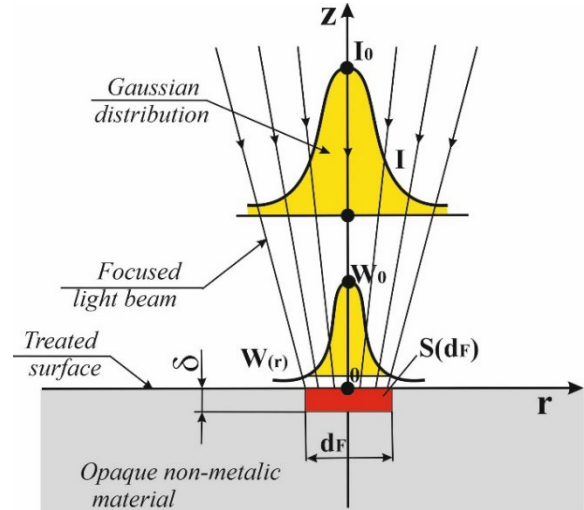


Fig.2. Formation of surface secondary heat source depending on the transparency of the material.

The thermal power of the local heat source - P_0 . we can obtain by integrating the surface power density $W(r)$ over the surface of the contact spot - $S_F = \pi \cdot r_F^2$ (formula 2).

$$P_0 = \int_{(s)} W(r) \cdot d_F = (\pi/k) \cdot W_0 \quad (2)$$

With a uniform distribution of the surface power density - $W(r)$ along the radius of the contact spot or with $W = W_0 = \text{const}$ the thermal power - P_0 can be determined by expression 3:

$$P_0 = S_F \cdot W_0 = \pi \cdot r_F^2 \cdot W_0 \quad (3)$$

In this situation, with the same heat power - P_0 , the two distributions have the same surface power density - W_0 , if the flow concentration coefficient is $k = 1/r_F^2$ (or $r_F^2 = 1/k$), we can take the radius r_F as the radius of the contact spot - fig.3

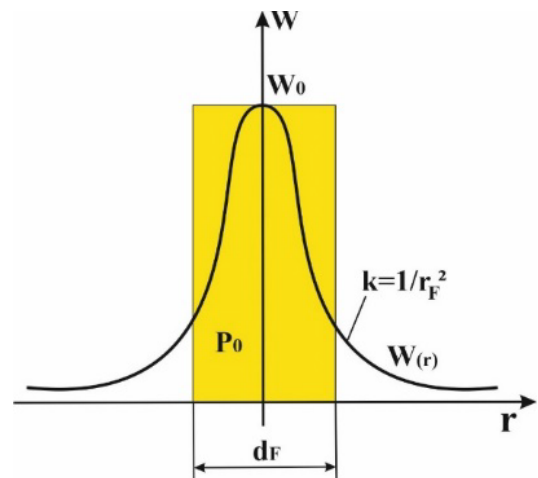


Fig.3. Power equivalence of Gaussian and uniform surface distribution of power density at $d_F = 2r_F$.

Therefore, we can refer to the case of a normal distribution and calculate with equation 4 all the solutions derived for a uniform distribution of the surface power density:

$$W(r) = W_0 \exp(-r/r_F)^2 \quad (4)$$

Depending on the way of absorbing the energy of the incident light beam, we can distinguish two typical cases:

- continuous absorption during the penetration of the light beam into the material;
- penetration of the light beam into the material at a certain depth - δz , without absorption, after which the absorption is distributed uniformly in all directions with continuous weakening with distance from the center (isotopic diffusion scattering).

When processing non-metallic materials with radiant heat transfer in laser processing, there is a continuous absorption of energy deep into the material.

Therefore, we can determine the depth of penetration with equation 5:

$$\delta = 1/\alpha \quad (5)$$

where: α – attenuation coefficient of the light wave.

The dependence of absorption on the depth of penetration (Bouguer-Lambert law) is valid for a uniform distribution of the power density - W_0 , in the energy spot of interaction with a diameter d_F - fig.4.

$$W/W_0 = \exp(\alpha z) \text{ или } W/W_0 = \exp(-\delta \cdot z) \quad (6)$$

where: $\delta^2 = \rho / (\pi \cdot \mu \cdot f)$

Therefore, in the case of beam machining of non-metallic materials and a Gaussian distribution of the surface density of absorbed power in the contact spot, the depth distribution of the machined zone can be determined by the expression 7:

$$W/W_0 = \exp\{-[2r/d_F]^2 + (z/\delta)\} \quad (7)$$

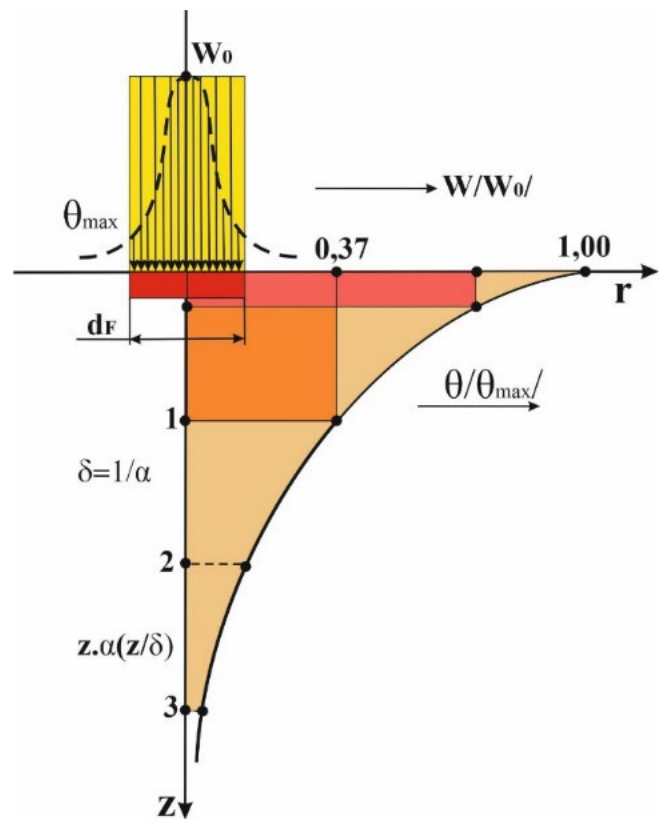


Fig. 4. Distribution of surface energy (relative power density W/W_0 and relative overheating θ/θ_{max}) during laser processing of non-metallic materials.

III. CONCLUSIONS

From the conducted experiments and the results obtained, it is proved that the local heat sources during laser processing of non-metallic opaque materials are characterized by a temperature distribution field that follows the distribution of the absorbed energy density - $W(r,z)$.

In practice, when processing non-metallic materials with a laser-type heat source, the maximum temperature is registered on the surface of the material.

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