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LASER-FIELD TECHNOLOGY OF HARDENING

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ABSTRACT

Modern methods of materials laser processing are being actively introduced into production. However, their wide application in engineering is hampered by the high energy intensity of the processes and the unexplored of complex fast processes of such processing technologies. This work is devoted to hybrid laser technologies for material processing, in particular laser-field hardening of metals. A theoretical study of the laser interaction with a metal is carried out, it is shown that the reflection coefficient of laser radiation and the depth of its penetration depend on the electrical conductivity of the skin layer. The main interrelations between the quality parameters of the treated layer and the parameters of the laser-field technological complex are revealed. Investigations on laser hardening in the electrostatic field of steels, widely used in engineering, have been carried out (Steel 10, 45, 65G). It is shown, that the superposition of the electrostatic field on the treatment zone leads to an increase in the depth and hardness of the quenched layer due to the directed motion of electrons in metals.

Keywords: laser radiation, laser-field treatment, hardening, electrostatic field.

1. INTRODUCTION

In the engineering industry, the possibilities of using laser radiation as a universal tool for the processing of various materials are determined by the laws of the passing such processes and phenomena as laser radiation absorption, surface and bulk heating of the material, material melting, its erosion, the formation of heat-affected zones [1, 2], a change in the stress-strain state, the diffusion of elements under thermal conditions, and so on [3, 4]. Hybrid laser technologies in the world practice are mainly represented by laser-arc treatment [5, 6], which is due to the presence of a large number of experimental data and developed technologies [7, 8]. Other hybrid methods of processing have been developed and are being applied: double-beam laser processing, laser-induction processing, laser-plasma processing, laser-light-beam processing, which are also used in industry and have been thoroughly investigated [8]. However, there are practically no scientific papers on laser-field processing. There is no complete theory of the joint action of the laser radiation and the various fields on the processed material.

Science work on the joint effects of various fields and laser radiation, in the world mainly concentrated in Japan. Works on laser-electrostatic and laser-electromagnetic technology, in the field of mechanical pressure, are conducted at Tokai University in Japan [9, 10]. It is worth noting the study of laser-electrostatic technology for graphene modification in Shahid Beheshti University, Iran. [11]

From the brief review, it is clear that there are practically no studies on laser-field technology in the Russian Federation. In this connection, in order to increase the productivity of laser processing and expand the field of laser radiation using, it is necessary to further develop the theory of the interaction of laser radiation with a material taking into account the influence of external perturbing factors, such as electromagnetic, magnetic, and electrostatic fields.

2. THEORETICAL STUDY

Laser hardening of the working surface of a metal product with power close to critical, not allowing reflow, do not give stable and required surface quality indicators [12]. Therefore, in addition to the parameters of the laser-field technological complex, which play the main role in achieving the required technological process, considered as a set of interacting links of a complex system and directly influencing the physics of the interaction of laser radiation with a metal, it is also necessary to take into account the electrical conductivity of the metal on which absorption coefficient depends directly.

The relationship between the absorption coefficient and the conductivity of materials, in particular metals, shows that free electrons in the crystal lattice of a metal increase the fraction of reflected laser radiation. The depth of the skin layer δ, for laser radiation, is determined by the formula:

$\delta=2(2\mu\mu_0\sigma\omega)^{-0,5}$,

here: μ is the magnetic permeability of the material, at frequencies of the optical range for metals is 1; $\mu_0 = 4\pi\times10^{-7}$ H/m; σ is the specific electrical conductivity of the material being processed; ω is the cyclic frequency of the radiation.

The materials reflect the radiation from the surface as a function of the dielectric constant of the medium, as can be seen in the following relationship:

$$R = \frac{Qref}{Q_{fal}} = \left|\frac{\sqrt{\varepsilon}-1}{\sqrt{\varepsilon}+1}\right|^2,$$

where: Q_{ref}, Q_{fal} is the laser radiation energy reflected from the metal surface and falling on it, respectively; ε is the dielectric constant of the medium.

In a metal, the conduction electrons can be considered completely free, then the reflection coefficient will be calculated in accordance with the formula:

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$$R = 1 - \sqrt{\frac{2\omega}{\pi\sigma}} \ .$$

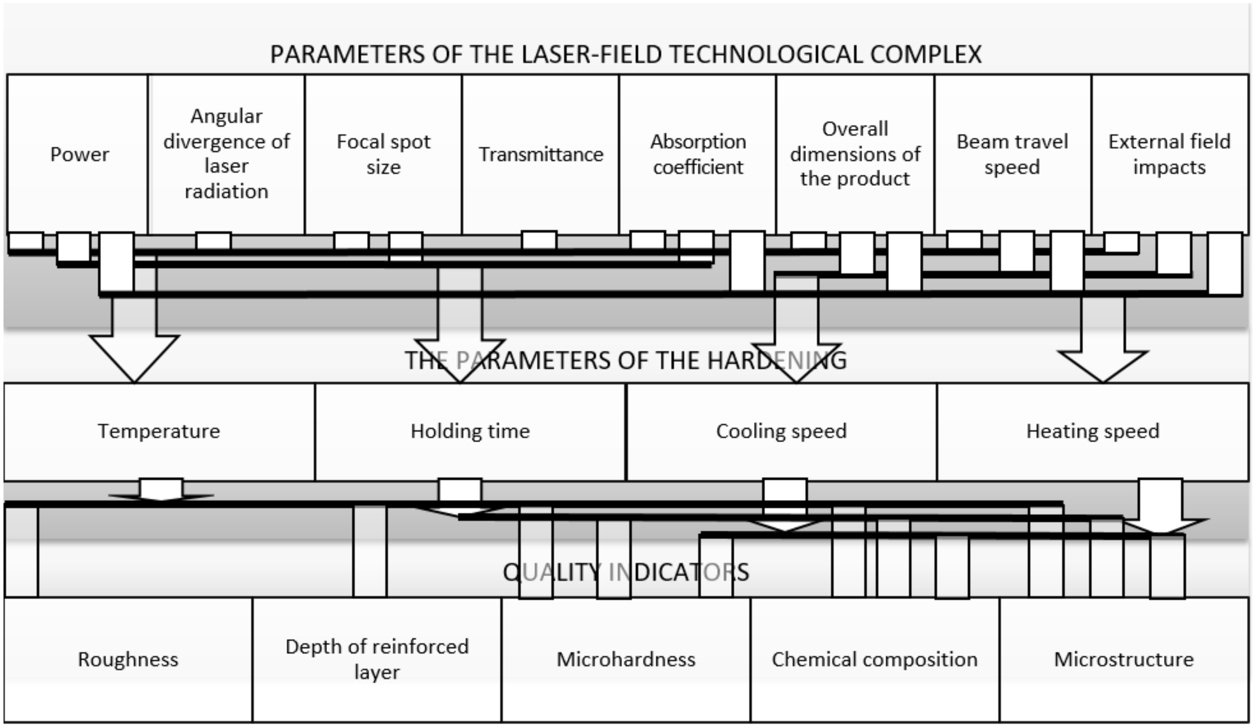

Figure-1. Dependence of the quality parameters of the treated layer on the parameters of the laser-field technological complex.

Studies conducted on laser heat treatment of metals, incl. and other authors, reflect the instability of the quality indicators of the technological process. Such indicators of the quality of the technological process include: the depth of the laser exposure zone, microhardness, the roughness of the treated surface, the chemical composition and homogeneity of the microstructure [1].

Analysis of the relationship between the parameters of the laser-field technological complex, the laser hardening process, and the quality of the processed area showed that the laser-field technological complex itself has a major influence on the temperature in the hybrid processing zone, and all the process quality parameters depend on it, in turn (Figure-1).

These arguments lead to a logical conclusion: to increase the depth of the zone of thermal action at a constant laser radiation power, it is necessary to reduce the conductivity of the skin layer. Using external influences on charged particles in a material, in particular an electrostatic field, it is possible to redistribute electrons in metals.

3. EXPERIMENTAL STUDY

On the basis of theoretical data, an experimental laser-field technological complex has been developed (Figure-2).

The laser-field technological complex includes such elements as laser processing complex on the basis of fiber laser LS-2, focusing system Precitec; microprocessor system; controlled source of electrostatic field, connected with an additional electrode.

Electrons, under the action of the force from the side of the positively charged electrode, accumulating on the surface of the metal, from the side opposite to the laser hardening zone, reduce the conductivity of the skin-layer of the part in the required heat-affected zone, which will increase the penetration depth of laser radiation and increase its absorption coefficient.

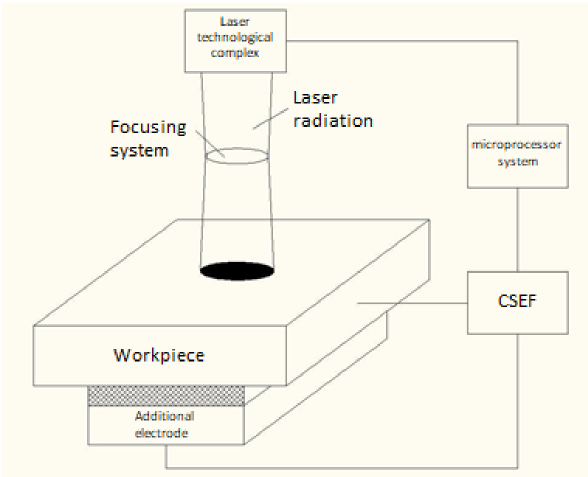

Figure-2. Scheme of the laser-field technological installation.

For the development of the technological process and testing of laser-field exposure regimes, it is necessary to control the main parameters of the process and their effect on the quality indicators (depth of the strengthened layer, microstructure, chemical composition, microhardness, surface roughness, etc.) of the technological process [13, 14].

Laser radiation power density, exposure time, laser beam positioning accuracy, electrostatic field intensity, etc. are the main parameters of the laser-field technological complex having a direct impact on the quality indicators of the technological process. The microstructural analysis of steels subjected to treatment with concentrated energy flows in conditions close to critical, without the use of additional external influences, shows a significant increase in the microhardness and depth of the quenched material region, but the probability of failure to achieve the required surface quality in the form of its reflow increases, which leads to a change geometric parameters, as well as to a possible increase in roughness by 3 to 5 classes [15].

By changing the power of laser radiation, the focal length and the intensity of the electrostatic field, are the necessary to achieve the required quality parameters of the technological process, set the parameters of the laser-field technological complex. Experimental testing of the technological process was carried out on samples of steel 10, 45 and 65G. Such a choice of sample materials is due to the analysis of the use of steel grades in the production of KAMAZ [1].

The analysis of thermal treatment zone of the laser-field technological complex (Figure-3) indicates an increase in the depth of the hardened zone for all metal samples, with a constant laser radiation power, which is relevant for parts that work on abrasion. On the obtained graphical dependences, the nonlinear increase in the depth of the zone of thermal action from the intensity of the electrostatic field is noticeable. Considering the areas of field strength from 4 MV/m and above, the intensity of the increase in the depth of the heat-affected zone decreases with a similar increase in the applied voltage to the additional electrode for all the materials under consideration.

An additional effect in processing under the influence of an external field is an increase in the hardness of the hardened layer from 100 $HV_{0.05}$ for Steel 65G and to 240 $HV_{0.05}$ for Steel 10. The average values of the obtained data allow us to conclude that the harder the metal hardened by simple laser radiation, the lower the increase in hardness in hybrid laser-field processing. This effect is explained by the more intensive removal of thermal energy when cooling into the depth of the material, due to the directional motion of the electrons, while it is worth noting that there is a critical velocity of electrons in the material under the action of an external electrostatic field, which limits the intensity of this type of cooling. The hardening of steel 10 is explained by the change in the chemical composition of the treated layer under laser action [16].

Experimental studies show that the quality indicators of processed products and their stability depend on the parameters of the process and the type of material being processed [6, 8, 17]. Hybrid laser processing with an electrostatic field of direct polarity leads to an increase in the microhardness and depth of the thermal exposure zone simultaneously with a decrease in the probability of reflow of the processed zone of the product, and at the limiting values of the field strength equal to 5 KV/m, its almost complete absence [10, 11].

4. CONCLUSIONS

Analysis of the laser-field hardening zone showed that the application of an electrostatic field of direct polarity leads to an increase in such a parameter as the depth of the quenched layer, under all treatment regimes of metals, simultaneously with an increase in hardness. The width of the metal layer hardened by means of laser-field technology remains unchanged under all treatment regimes. The developed technological scheme of realization of laser-field processing technology allow to study the dynamics of hardening process and increase its efficiency.

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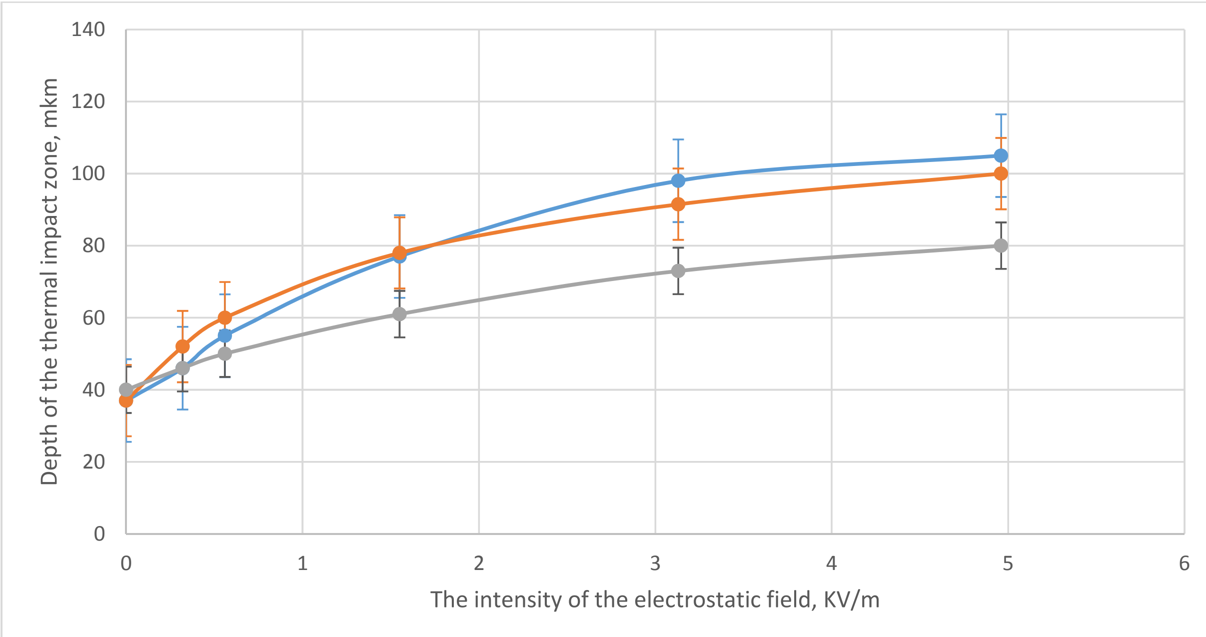

Figure-3. Dependence of the hardened zone depth on the strength of the electrostatic field (1 - Steel 10, W = 3 KJ; 2- Steel 65G, W = 4,5 KJ; 3 – Steel 45, W = 3,8 KJ).

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