Laser surface hardening of steel parts

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Abstract. The hardness of steel parts after laser treatment depends on a number of factors. In this paper, attention is focused on the surface heating temperature. The aim of the study is to make a reasonable choice of heating temperature. The results of physical modeling are presented. It is established that the temperature of the phase transformation decreases by 150 ... 200 K. This is due to thermal stresses. The kinetics and mechanism of transformation during laser processing affect the formation of the structure. Heating to a temperature 200.250 K below the melting point leads to an increase in hardness by 10-15 HRC units.

1. Introduction
Laser surface hardening (LSH) has advantages in terms of productivity and technical and economic indicators compared to other processes. The development of LSH is taking place in the direction of increasing the volume of processed metal products, as well as improving automated control systems. Poorly studied and debatable issues remain related to structural-phase transformations in steels under intense laser heating. Until now, theoretical provisions on hardening follow from the concepts of the Fe-Fe3C system equilibrium states diagram.

2. State of the LSH theory
If we consider steel with a carbon content of 0.40% C, then, following the recommendations [1-3], the temperature during laser heating should be adjusted to a value close to the melting point. It worked out and it was confirmed presentation, what happens with laser scanning heating temperature click on the source link structures in austenitic status on 200...300 K above the equilibrium value. When this approach final result put in the dependency from two thermodynamic parameters – temperature control and time. Time manifests itself in speed heating and cooling.

But when using a laser heating in volume material in the surrounding area the focal point spots appear thermal properties voltage drop, which, given the Le Chatelier’s effect, temperature control polymorphic transformations they reduce it. The problem is that what is the reduction experimentally is not installed.

3. Assessment steel States during the LSH process
In terms of automation, as a control object of the LSH should consider converting process material from the source state in final software the specified trajectory.

Input parameters are:

\( X_1 \) - power density;
\( X_2 \) - the pulse time;
\( X_3 \) - focal length;
\( X_4 \) - hardness up to the LSH.
Output parameters:
\( Y_1 \) - surface hardness;
\( Y_2 \) - the depth of the hardened zone;
\( Y_3 \) - the depth of the weakened zones;
\( Y_4 \) - hardness of the weakened zone.

Accepting note direct and indirect costs links provided appropriate transmission lines functions, mathematical model LSH model as follows multidimensional the object can be submitted next:

\[
Y_1 = W_{11}X_1 + W_{12}X_2 + W_{13}X_3 + W_{14}X_4;
\]
\[
Y_2 = W_{21}X_1 + W_{22}X_2 + W_{23}X_3 + W_{24}X_4;
\]
\[
Y_3 = W_{31}X_1 + W_{32}X_2 + W_{33}X_3 + W_{34}X_4;
\]
\[
Y_4 = W_{41}X_1 + W_{42}X_2 + W_{43}X_3 + W_{44}X_4.
\]

In particular, gear ratio function \( W_{11}X_1 \) defines dependency hardness from temperatures, and through the medium of gear ratios functions \( W_{12}X_2, W_{13}X_3, W_{14}X_4 \) puts hardness in dependency from other parameters at the entrance. However, install development structural and phase changes transformations directly during the LSH process not represented possible in view of omissions necessary tools funds.

4. Assessment steel States during the LSH process
Laser treatment by its physical nature is a thermal shock combined with mechanical action from thermal stresses. Fundamental importance with a simulation of thermomechanical action is imitation of high-speed heating of the test sample surface.

According to the scheme shown in Fig. 1, heating of the contact surface of the heater 1 made of ZhS-6K alloy with samples 2 and 3 made of 4X5MFS steel occurs at a speed of 1000 K/s by passing an electric current from a 100 KW transformer. The pressure on the heated surface varied in the range of 200-400 MPa. The temperature on the contact surface was measured using a platinum-rhodium-platinum thermocouple with an electrode diameter of 0.5 mm. The thermocouple was calibrated using the melting temperature of the aluminum wire, which was heated at the same rate.

![Fig. 1. Scheme for simulating intensive surface heating.](image)

The parameters of the imitative thermomechanical cycle are shown in Fig. 2.
The dependence of the surface hardness on the heating temperature is shown in Fig. 3.

![Graph showing the dependence of hardness on temperature](image)

The regularity revealed during the simulation of surface heating at a rate of 1000 K / s is that at the temperature $t_r$, the hardness decreases, at the temperature $t_n$, the hardness increases, at the temperature $t_k$ reaches the maximum value, and with a further increase in temperature it decreases.

When the $t_r$ - temperature of the beginning of weakened is reached, diffusion processes are activated in the metal structure, and there is a coagulation of the strengthening dispersed carbide phases are coagulated. At the temperature $t_n$, the $\alpha \Rightarrow \gamma$ - transformation occurs, at the temperature $t_k$ it ends. Overheating above $t_k$ leads to a decrease in hardness.

5. Conclusion
The efficiency of the LSH can be increased if it is heated not to a temperature close to the melting point, but to a temperature 200...300 K below the melting point. LSH is a special type of processing, it's not
correct to identify it with heat treatment and call it laser thermal hardening, since changes in the structure of the processed metal occur under conditions that are not comparable with heat treatment. In the process of intensive heating, a complex stress state occurs in the processed material. Under the influence of compressive thermal stresses, the crystal lattice of the metal is distorted. It is possible that a mating plane appears between the $\alpha$ and $\gamma$ phases, which results in a crystal-geometric relation the $\alpha \rightarrow \gamma$ phases, in which the $\alpha \rightarrow \gamma$ transformation begins at a lower temperature and proceeds intensively through a non-diffusion mechanism in the temperature range $(T_n - T_k) = \sim 200$ K.

There can be no question of the formation of austenite grains and equalization of the C concentration. Under the influence of unavoidable plastic deformations in the $\gamma$-Fe-based phase, the dislocation density increases, which is probably why the structure that occurs during cooling acquires an abnormally high hardness. If the heating occurs above the temperature $T_k$, the hardening achieved due to plastic deformations will disappear.

References

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