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FORMATION OF THE STRUCTURE OF A SURFACE LAYER IN MULTIPLE LASER DOPING

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Results of investigations into the influence of multiple laser doping on the structure and properties of the layers formed are given. It is established that repeated treatment enables one to implement the processes of both "laser quenching" and "laser annealing." The possibility of attaining a smooth gradient of the properties in the layer depth is shown.

Among the distinctive features of the structure of coatings formed in laser doping is the high degree of metastability of the phases, which implies a significant supersaturation of solid solutions, the doping of the strengthening phase and a substantial level of residual stresses [1–4]. Furthermore, a large gradient of physicomechanical properties in the layer depth appears, which is due to the presence of a sharp boundary between the doping zone (molten bath) and the base material. However, for a number of components operating under large specific and alternating loads such character of the structure is not necessarily optimum. Stable structures with a smooth gradient of the properties in depth are more preferable. Taking account of the fact that the employment of strengthening laser treatment is expedient only for cases where traditional methods are impossible for structural or technological reasons, it is of interest to study the possibility of repeated heat treatment of laser-doped structures with laser radiation, which is the objective of the present investigation.

To implement the processes of laser doping we employed LGN-702 and Kometa-2 technological laser facilities based on continuously operated lasers. In the experiments with samples of 45 steel, we used two doping compositions: a mixture of equal volumes of boron and chromium carbides ($B + Cr_7C_3$, Cr_3C_2, laser boron chromizing) and a mixture of equal volumes of boron and boron carbide ($B + B_4C$, laser boration) [5]. The thickness of the dope layer was 0.09–0.11 mm and it was monitored by an MT-40NTs thickness gauge.

The x-ray structural investigations were carried out using a DRON-3.0 x-ray diffractometer. The data of the analysis were processed using the application package developed.

We considered different technological variants of doping (Table 1).

In laser boration and boron chromizing, the structure of a strengthened layer has a character classical for laser-doped samples, irrespective of the multiplicity of the doping (Fig. 1). Similarly to the cases investigated earlier, in the strengthening zone one can single out the following parts: the doped surface layer, the heat-affected transition zone, and the base metal.

A distinctive feature of multiple laser treatment is that the doped surface layer is divided into two zones formed under the action of primary and secondary remeltings. The depth of the doped layer corresponding to the lower bound of the primary remelting is equal to 220 to 300 μm. The boundary of the secondary-remelting zone is located at a depth of 170 to 270 μm.

No differences are observed in the structure of the doped zone depending on the regimes of treatment. The results of investigations into the phase composition are presented in Fig. 2.

As is clear from the data presented, the laser heat treatment of laser-doped coatings leads to a variation in their phase composition. The amount of the iron-based solid solution increases, while the content of the carbide component and the unreacted boron (in laser boration) decreases. When a dope with additions of chromium carbide is ap-

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TABLE 1. Technological Variants of Multiple Laser Doping

No. of variant	Type of treatment during the pass			Rate of treatment, mm/min		
	I	II	III	I	II	III
1	LD	–	–	200	–	–
2	LD	LQ	–	200	400	–
3	LD	LQ	–	200	400	–
4	LD	LQ	–	200	900	–
5	LD	LQ	LD	200	400	900

Note: I, II, and III, numbers of passes; LD, laser doping; LQ, laser quenching.

TABLE 2. Estimates of the Nature and the Degree of Doping of the Phase Components

Phase	Probable nature and the degree of doping of the coating depending on the variant of its production, at.%				
	1	2	3	4	5
Amorphous boron + boron carbide					
Fe α	Carbon 0.03	Carbon 0.01	Absent	Carbon 0.02	Carbon 0.03
Fe γ	–	–	–	–	–
Fe_2B	Boron +0.7	Absent	Absent	Absent	Absent
FeB	Absent	Boron +0.9	Boron +0.5	Boron +0.3	Boron +0.25
Fe_3C	Absent	Substitution of boron 5 for carbon	Substitution of boron 6.3 for carbon	Substitution of boron 2.7 for carbon	Substitution of boron 2.3 for carbon
Amorphous boron + chromium carbide					
Fe α	Chromium 0.8	Chromium 0.45	Absent	Absent	Absent
Fe γ	Carbon 0.8	Carbon 0.63	Absent	Carbon 0.8	Carbon 1.0
Fe_2B	Chromium 0.9	Boron –0.45	Boron –0.6	Boron –0.4	Boron –0.3
FeB	Chromium 7	Chromium 7.5	Chromium 6	Chromium 3.5	Chromium 2
Cr_3C_2	Carbon +1.5	Carbon +0.8	Carbon +0.65	Carbon +0.85	Carbon +1.0
Cr_7C_3	Carbon +1.8	Carbon +0.8	Carbon +0.1	Carbon +0.1	Carbon +0.1
Fe_2C	Boron +1.4	Boron +1.15	Boron +1.5	Boron +1.2	Boron +1.35

Note: + or – signs show a possible deficiency or excess of one component of the given phase; the figures without a sign show a possible degree of doping of the given phase with the indicated element.

plied, the dissolution of the carbide component contributes to the increase in the content of the retained austenite. Furthermore, the amount of oxides increases since the technology provides for laser treatment without employing a protective atmosphere. With the aim of eliminating this negative effect we assumed it expedient to carry out laser treatment of the doped layers as repeated doping with application of a layer of the same dope serving protective functions as well.

As follows from the data given in Fig. 2, in double laser doping the amount of oxides does not increase when the dope with additions of boron carbide is used and they disappear when the dope with additions of chromium carbide is used. Similarly to the laser quenching, the amount of the solid solution of iron increases. Both slurries are characterized by the appearance of the retained austenite, which is attributable to the high degree of doping of the solid solution. In all probability, the increase in the degree of doping of the solid solution is due to the dissolution of the carbide phase whose content is compensated for by introduction of an additional amount of doping components.

The variation in the phase composition with increase in the velocity of the second pass with boron-carbide-based dopes implies the appearance of a small amount of the retained austenite; when the slurry with chromium-carbide additions is employed, the increase in the rate of treatment leads to a decrease in the carbide component. This is

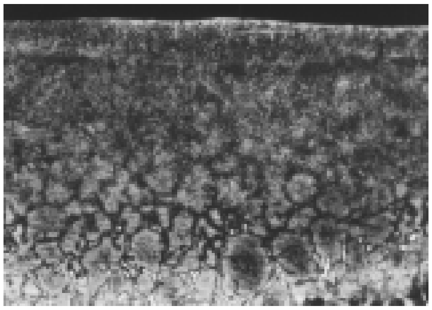

Fig 1. Characteristic microstructure of a doubly doped layer. × 200.

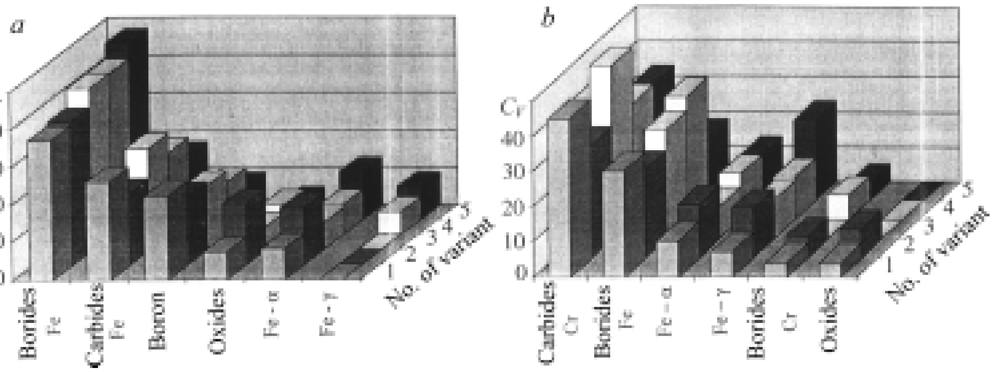

Fig. 2. Results of a semiquantitative analysis of the phase composition upon different variants of treatment in doping with the following dopes: a) $B_{am} + B_4C$; b) $B_{am} + Cr_7C_3$, Cr_3C_2.

attributable to the fact that the increase in the rate of laser treatment causes an increase in the cooling rate of the molten bath and accordingly an increase in the degree of metastability of the structure formed. In the presence of boron-containing components in the laser-remelt bath, crystallization of the carbide component follows the formation of boride phases. The foregoing is confirmed by the results of an analysis of the phase composition of a coating produced by triple laser doping, in which an increase in the velocity of travel of the laser beam from pass to pass results in a structure with an even larger amount of the solid solution and a corresponding decrease in the amount of the strengthening phase.

The results of evaluations of the degree of doping of the phase components are given in Table 2.

It should be noted that the nature of the component doping for a given phase was evaluated by the compatibility of the phases, by the value of the atomic radii, and by the form of the crystal lattice, and this nature is probabilistic.

As is clear from the data presented, in single laser doping one observes a rather high degree of doping of the structural components which is preserved in the subsequent laser quenching, although its level decreases for all the phases. The repeated laser doping with a rate of treatment of 400 mm/min results in the equilibrium of the ion component — the effect of "laser annealing" of the strengthened layer is attained. At the same time, when the rate is 900 mm/min, the degree of doping of the structural components of the coating increases in the case of both double treatment and triple treatment. Noteworthy is the nonequilibrium of the strengthening phase for all the variants of laser treatment; the cementite is enriched with boron and represents boron cementite.

Graphs of the microhardness distribution in the depth of the strengthened layer for the investigated regimes of laser boration and boron chromizing are presented in Fig. 3.

Analysis of the data presented shows that:

(1) all the curves have three characteristic portions of hardness: the doping zone, the heat-affected zone, and the base material;

(2) repeated laser treatment ensures a smoother microhardness gradient in the layer depth;

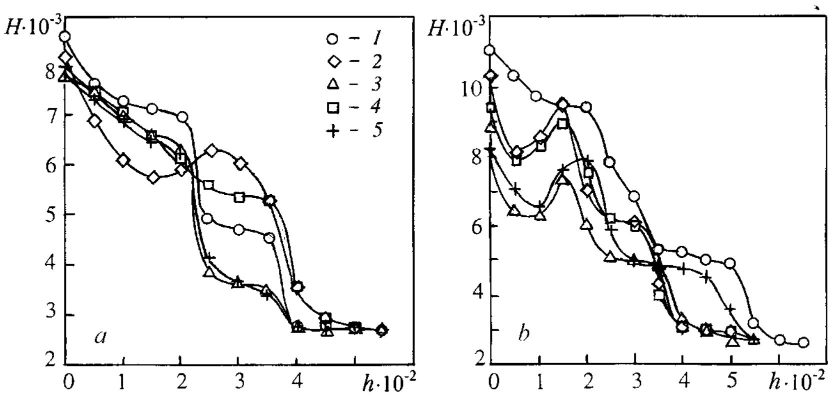

Fig. 3. Distribution of the microhardness in the layer depth in different variants of laser doping: a) $B_{am} + B_4C$ dope; b) $B_{am} + Cr_7C_3$, Cr_3C_2 dope. (1–5) variants of treatment.

TABLE 3. Character and Level of Residual Stresses in Solid-Solution Phases

Phase	Residual stresses in variants of treatment, MPa			
	1	2	3	4
Amorphous boron + chromium carbide				
α phase	–295	–202	+12	–26
Austenite	+126	+16	+801	–658
Amorphous boron + boron carbide				
α phase	–44	–196	–105	–213

Note: + or – signs correspond to tensile and compressive stresses respectively.

(3) of interest is the point of inflection of the microhardness curves which is more characteristic of the chromized layers, which is due to a partial recrystallization of the portions of singly laser-doped zones adjacent to the molten zones in secondary doping.

The level of residual stresses in the phases of a coating, i.e., stresses of the second kind, was determined by comparing the parameters of the lattice of the doped layers and the parameters of the lattice of chips produced in grinding the doped layer and screening through a sieve with a mesh of 0.3 mm. The described procedure in itself provides for a rather high error (of the order of ±50 MPa). However both the sign of the stresses and their value can be evaluated at a qualitative level (high or low stresses). The results of evaluations of the stresses in solid-solution phases for double treatment are given in Table 3.

The analysis of the data obtained demonstrates that compressive stresses are formed in the α phase while tensile stresses are formed in the retained austenite. A correlational analysis of the stresses in the α and γ phases has shown the presence of a statically significant regression of the form $y = A + B/x$, where x are the residual stresses in the α and y are the residual stresses in the austenite. In other words, the residual stresses in the α phase and the austenite are in inverse proportion.

Thus, the investigations into the implementation of the process of multiple laser treatment have shown that:

(1) in repeated laser doping, we have a quantitative change in the phase composition;

(2) control over the regimes of repeated treatment enables one to adjust the degree of metastability of the solid solution in a wide range and to change the gradient of physicomechanical properties in the layer depth.

NOTATION

C_V, volume content of the phases, vol.%; H, microhardness, MPa; h, depth, μm; y and x, levels of residual stresses in the α phase and the austenite respectively, MPa; A and B, coefficients in the regression equation. Subscripts: am, amorphous.

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