Pulsed electron beam processing of boride layer on L6 steel

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The concentrated energy sources, such as intense pulsed electron beams (IPEB), to modify the surface properties of machine parts and tools allows flexible regulation of the structural-phase state of materials in a wide range. The current research aims to create a functional layer on the surface of L6 steel by subsequent processing of a diffusion boride layers by the IPEB of a megawatt power level. The IPEB of a diffusion layer based on boron and aluminum on L6 steel leads to the transformation of the layer by remelting and crystallization of the upper zone of the diffusion layer up to 220 µm deep. Meanwhile the thickness of the whole diffusion layer is 580-620 µm. The microstructure of the layer has become more compact (pores have disappeared) and the roughness has decreased. The maximum microhardness on the surface of the diffusion layer reaches 870 HV. The hardness distribution is uneven, which indicates alternation of hard and soft components in the layer, and lower hardness on the surface indicates predominantly aluminized zone. Microhardness of the modified layer after IPEB has increased to 1400 HV.

Keywords: *surface modification, electron beam, boriding, low alloy steel, microhardness*

1. Introduction

Increasing the strength and wear resistance of machine parts and tools is an urgent problem of modern materials science. Diffusion saturation of the surface of metals and alloys with various chemical elements allows them to be given a number of performance properties that cannot be obtained by heat treatment. Diffusion boriding is one of effective methods of thermal-chemical treatment (TCT) to improve the surface properties of tools [1)]. However, boriding find limited use in industrial production. The main limiting factor is the high fragility of diffusion boride layers produced by common TCT methods. These methods of boriding with furnace heating result in layers with an acicular and saw-like structure. As a rule, the hardest and most fragile phases are formed on the surface of diffusion layer [2)].

It is known, electron beam heating has a wide range of effects: on surface layers, an electron beam (EB) not only increases the temperature, but also initiates diffusion processes in the metal [3,4)]. This leads to the formation of layers primarily based on diffusion processes. By adjusting the parameters of EB heating, it is possible to control the mechanism of formation of the diffusion layer. One of the promising methods of using electron beam processing (EBP) is the combination of EB heating of diffusion layers obtained by TCT for the purpose of their phase transformation and leveling the disadvantages of the latter. The combination of high temperatures and point defects during EBP leads to the development of relaxation and diffusion processes, the formation of layers with a special structure, resulting in properties that cannot be obtained with conventional types of heating [3)].

The purpose of this work is to study the effect of intense pulsed electron beam (IPEB) heating on the diffusion B-Al layer on 5KhNM steel (the analogue to AISI L6 steel). Combined treatment was applied to create B-Al layer on the surface of L6 steel. TCT was performed as a first step to create diffusion layer. Then the surface was heated by IPEB to the to modify previously obtained diffusion layer.

2. Experiments

2.1 Boriding

Diffusion boriding was carried out in treatment pastes containing powders of boron carbide, aluminum and sodium fluoride as an activator, with the following composition: 80% B_4C + 16% Al + 4% NaF (wt) [5)]. The powders were pre-mixed using an organic glue. Aluminum was used to intensify boriding process. This kind of simultaneous boron and aluminum diffusion treatment called boroaluminizing [2)]. To simplify terminology authors will use term boriding instead of boroaluminizing.

Samples made of L6 die steel were placed in rectangular molds along with the paste and compacted. After removing the molds, the briquettes were dried at 373 K for two hours. The resulting briquettes were loaded into a furnace, heated to a processing temperature of 1223 K for two hours. After exposure the samples were cooled in still air at room temperature.

2.2 Electron beam processing

The further EBP of samples with diffusion B-Al layer was carried out using a “SOLO” electron source with a plasma cathode based on a low-pressure arc discharge (Figure 1). The main parts of the installation are electron source (1), electron beam (2), lens (3), quartz glass (4), fiber optic cable (5), sample (6), thermocouple (7), manipulator table (8), multimeter (9), high-speed infrared pyrometer (10), oscilloscope (11) [6,7)]. This source is part of the experimental installation of the same name and is included in the Complex of unique electrophysical installations of Russia “UNICUUM” at the IHCE SB RAS.

EBP was carried out in an argon environment at a pressure in a vacuum chamber of 35 mPa in a leading magnetic field of up to 100 mT. The electron energy during the treatment reached 25 keV, the diameter of the electron beam was 3 cm. The beam current was changed during a pulse with a duration of 950 µs within the range of (20 – 120) A to ensure a temperature on the surface of the treated sample of 1773 K 150 µs after the start of exposure. The surface of the samples was subjected to three pulses, the time interval between which was three seconds. An oscillogram of IPEB modes is shown in Figure 2.

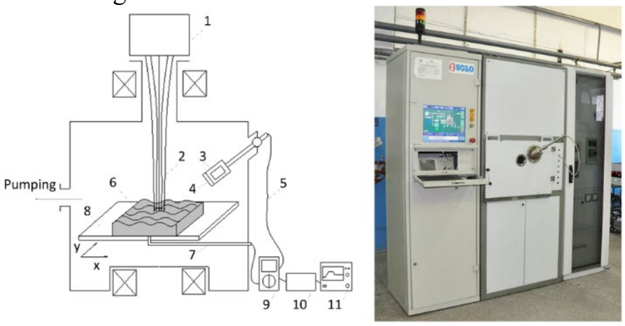

Figure 1. The scheme of processing in a pulsed electron beam installation and appearance of the SOLO installation (IHCE SB RAS) [6,7]

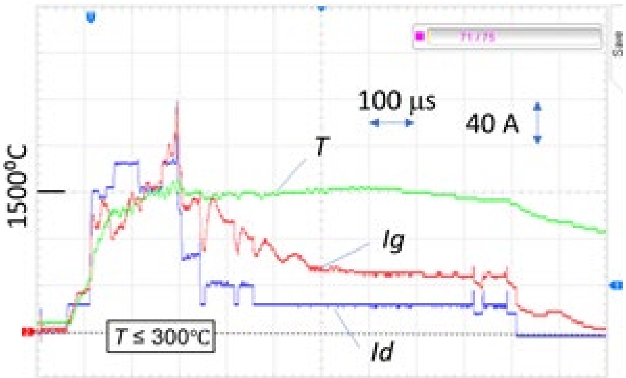

Figure 2. The oscillogram of IPEB parameters: the discharge current of the plasma cathode (Id), the current in the accelerating gap circuit of the electron source (Ig) and the output signal of the high-speed pyrometer (T)

Metallographic analysis was carried out on a METAM RV-34 optical microscope with an Altami Studio digital camera. The elemental composition was studied using a JSM-6510LV Jeol scanning electron microscope with an INCA Energy 350 Oxford Instruments microanalysis system, at the Science Center of the East Siberia State University of Technology and Management. The microhardness of the resulting layers was determined using a PMT-3M microhardness tester at a load of 50 g. XRD analysis was carried out on a D2 PHASER Bruker diffractometer with a LYNXEYE linear detector. The measurement step was 0.02°, the processing time for one step was 1.2 s.

3. Results and Discussion

3.1 Boriding

A diffusion layer of 580-620 µm thick is formed by boriding at 1223 K on the surface of L6 steel (Figure 3). Phase composition can be characterized by presence of iron borides FeB, Fe_2B and iron aluminide FeAl [5]. Deep transition zone is visible below the layer. Table 1 provides distribution of chemical elements in the surface area shown on Figure 3c. The maximum value of aluminum is 8.31 % in Spectrum 2, which corresponds to FeAl. The maximum content of boron is found in Spectrum 3 (8.22 %). It is known, that iron boride Fe_2B contain 8,83 % of boron [3].

Previous study is in the diffusion layer a maximum aluminum content on the surface with a decrease in concentration deep into the layer as a rule.

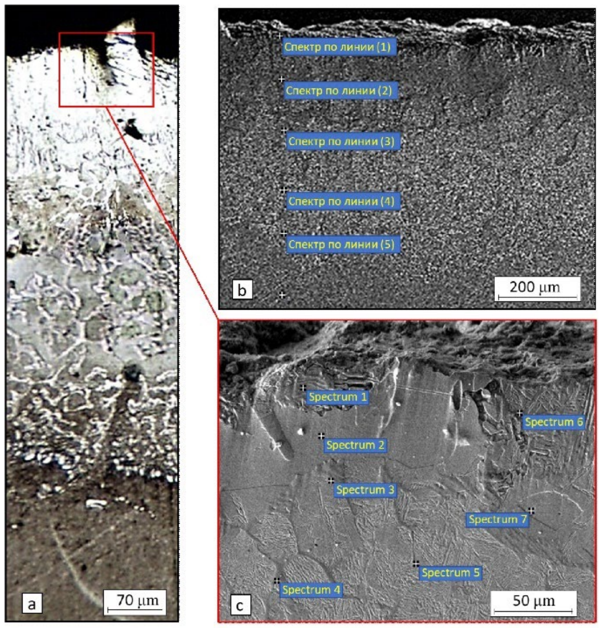

Figure 3. The microstructure of diffusion layer after TCT

Table 1 Elemental composition of the diffusion layer on L6 steel after boriding, wt. %

No spectrum	B	C	Al	Si	Cr	Fe	Ni
1	-	3.88	6.44	0.30	0.85	86.96	1.11
2	-	5.93	8.31	0.52	0.32	83.04	1.52
3	8.22	7.43	0.22	0.12	1.62	81.65	0.19
4	5.44	4.20	0.21	0.12	1.58	87.42	0.48
5	-	13.19	4.01	0.43	0.49	80.09	1.34
6	6.18	2.63	0.82	0.13	1.52	87.41	0.53
7	-	8.92	6.88	0.51	0.26	81.76	1.23

3.2 Electron beam processing

Subsequent EBP according to the previously indicated modes leads to a high energy impact on the steel surface (up to 0.5 MW/cm^2). This results to a high-speed melting and recrystallization of the diffusion layer on L6 steel, which causes a transformation of the diffusion layer to depth up to 220 µm from the surface. The modified layer microstructure is presented in Figure 4. After the EBP the surface becomes smoother without visible cracks or chips compared to initial diffusion layer. EDS analysis shows that boron concentration decreases from 8.22 % to 3.29 % after EBP in spectrum 5 (Table 2). Aluminum content also decreases from 8.31 % to 5.59 % after EBP.

The microhardness on the surface of the initial diffusion layer is 650 HV, and the maximum value reaches 870 HV at 400 µm from the surface (Figure 5). The hardness distribution is complex, which indicates an alternation of hard and soft components in the layer, with lower hardness on the surface indicating a predominantly aluminized zone. The microhardness of the modified layer after EBP on the surface increases to 1200 HV, while the maximum value of

1400 HV is achieved at 150 μm from the surface.

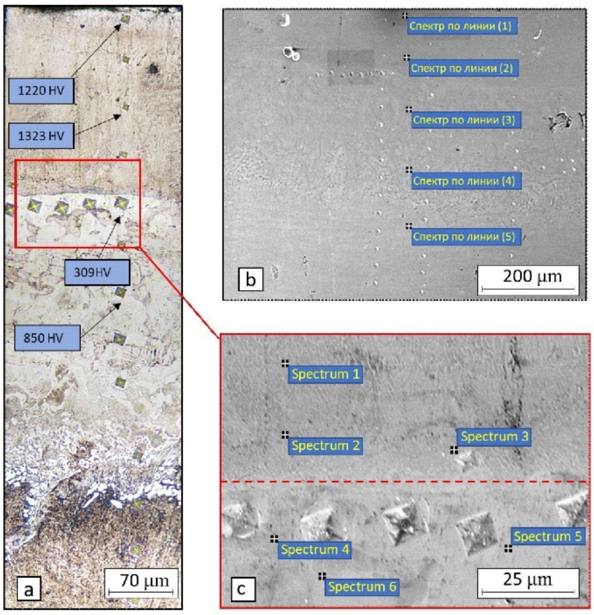

Figure 4. The microstructure of modified diffusion layer after EBP

Table 1 Elemental composition of modified diffusion layer on L6 steel after EBP, wt. %

No spectrum	B	C	Al	Si	Cr	Fe	Ni
1	-	3.10	4.96	0.30	6.50	85.13	2.00
2	2.67	2.50	2.37	0.12	8.19	84.15	1.69
3	-	2.06	4.70	0.43	7.07	85.75	2.86
4	-	3.74	5.59	0.40	5.99	87.71	2.56
5	3.29	3.24	3.61	0.25	5.70	88.36	1.25
6	-	2.50	5.49	0.31	6.69	89.70	2.00

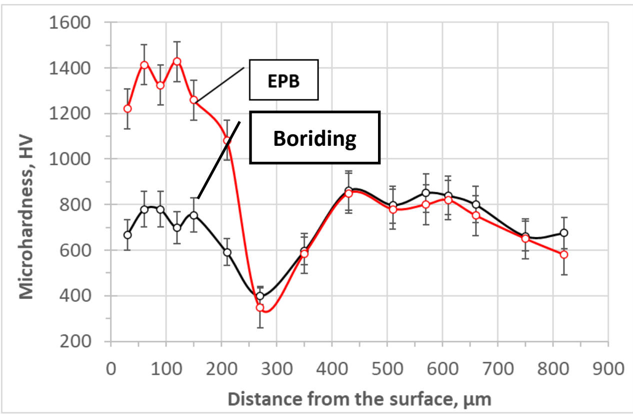

Figure 5. The microhardness of diffusion layer after TCT and EBP

4. Conclusions

EBP of the B-Al diffusion layer on L6 steel leads a transformation of the layer to depth up to 220 μm from the surface. This approach implements thermal effects on a surface with a high energy impact causing rapid melting and recrystallization of the upper part of the layer. The EB pulse duration is several hundred microseconds, which allows the thermal effect to spread to a specified depth without affecting the main volume of the diffusion layer.

As a result, a more favorable surface roughness and higher microhardness of L6 steel surface is obtained. These features allow to propose the combined method of boriding+EBP for strengthening of the working surfaces of dies for hot bending, stamping, forging, and die casting processes.

Acknowledgments

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