Modification of Structure and Properties of AiSi M2 High-Speed Steel by Pulse Electron Beam[1]

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Abstract – By optical microscopy, SEM, TEM, X-ray diffraction methods and microhardness measurement the investigations of phase composition, defect substructure and mechanical properties of surface layer of AiSi M2 high-speed steel samples treated by pulse electron beam were carried out. It is revealed that treatment of preliminary quenched and tempered AiSi M2 steel samples by electron beam with energy density 6…12 J/cm^2 leads to decrease of surface layer microhardness. The analysis of mechanisms of steel softening observed at pulse electron beam treatment was carried out.

1. Introduction

AiSi M2 high-speed steel is widely used for production of cutting tool due to high thermostability in the presence of high hardness and wear resistance. The implementation of the automated systems of material treatment makes high requirements to cutting tool. At the present moment, there are many methods (mechanical, thermal, chemicothermal, etc.), allowing increasing the exploitation characteristics of AiSi M2 high-speed steel tool. Previously it was shown that treatment of high-speed steel by laser or intense ion beam allows increasing of its wear resistance in some times in comparison with untreated steel. The last is connected with formation of quenching structure characterized by a high dispersion of martensite crystals and carbide phase particles, high defects density [1, 2].

One of perspective methods of exploitation characteristics increase of AiSi M2 high-speed steel tools is treatment by pulse electron beam with submillisecond pulse duration. In the present work the results of investigation of pulse electron-beam irradiation influence on structure, phase composition and mechanical properties of surface layer of high-speed steel samples are analyzed.

2. Experimental procedure

The investigations were realized on AiSi M2 high-speed steel samples (0.82–0.9% C; 3.8–4.4% Cr; 5.5–6.5% W; 5.0–5.5% Mo; 1.7–2.1% V). Samples were preliminarily quenched in oil from 1210 °C and then tempered during 1.5 h at 560 °C. The pulse electron beam treatment was carried out on setup "Solo" [3] with following electron beam parameters: electron energy 18 keV, pulse duration 50 μs, energy density of electron beam 6, 8, 10, and 12 J/cm^2. Structure and phase composition formed in the near-surface layer of untreated and treated samples were investigated by optical microscopy (OLYMPUS GX71), scanning electron microscopy (SEM-515 "Philips"), transmission electron microscopy (EM-125), X-ray diffraction analysis (diffractometer Shimadzu XRD, Cu K_α radiation) methods. The thin foils for the TEM observation were obtained by electrolytic thinning of plate removed from a sample surface treated by electron beam. The microhardness measurements were done using the PMT-3 microhardness tester at normal load of 0.5*N*.

3. Results and discussion

In initial state the AiSi M2 high-speed steel has the structure of tempered martensite (mainly, lath martensite) (Fig. 1, *a*).

In small quantities (~ 7%), there are grains of δ-ferrite (Figs. 1, *b* and *c*). In some case on the boundaries of martensite crystals the residual austenite in the form of thin layers was revealed. The second phase on the occupied bulk of investigated steel is carbide phase. M_6C, V_8C_7, and V_4C_3 carbides are revealed. The main carbide is M_6C. The size of M_6C particles changes in the range of 0.2–8 μm.

The average size of M_6C particles is 0.91 μm. The volume fraction is ~ 19% (Fig. 1). The average sizes of particle of vanadium carbide are d = 9 nm (particles are located on dislocations), and d = 10 nm, L = 24 nm (d is cross section; L is the linear sizes of particles; particles are located along boundaries of martensite crystals). The volume fraction of vanadium carbide particles is ~ 1%.

By the optical and scanning electronic microscopy methods the visible changes of surface morphology of steel samples treated by electron beam with energy density E_S = 6–8 J/cm^2 are not observed. The further increase of electron beam energy density (E_S = 10…12 J/cm^2) leads to melting of a thin surface layer of the sample. The last fact results in disappearance of scratches and formation of a wavy relief of a surface (Fig. 2).

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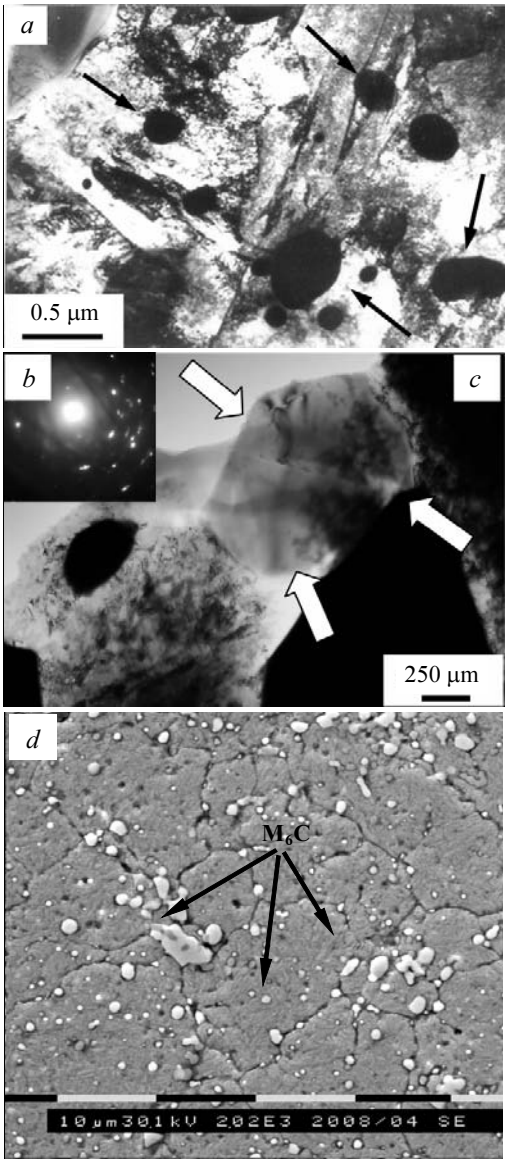

Fig 1. Structure of AiSi M2 high-speed steel before the electron-beam treatment. Arrows show carbide phase particles (*a*, *d*), grain of δ-ferrite (*c*). *a*–*c* – TEM images; *d* – SEM image

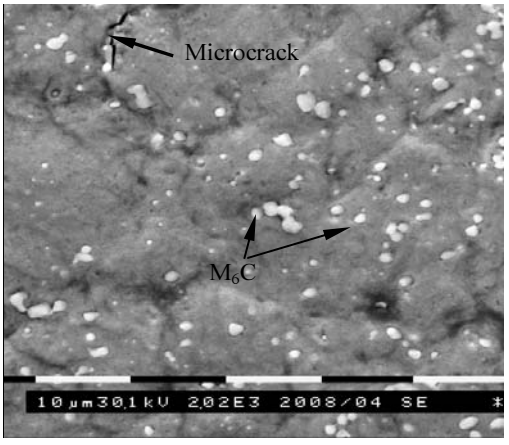

Fig. 2. SEM image of AiSi M2 high-speed steel sample surface after electron beam treatment with energy density of 10 J/cm^2

The electron-beam treatment is accompanied by formation of microcracks in a surface layer. Usually microcracks are formed along carbide/matrix interface or in the bulk of carbide phase particles with sizes in range of 3…8 μm. At increase of energy density of electron beam the number of microcracks decreases. It is probably connected with decrease of thermal stresses due to increase of bulk temperature and decrease of cooling rate of steel surface layer.

Simultaneously with cracking process, the electron beam treatment of steel samples leads to dissolution of carbide phase particles which located in the surface layer. The quantitative analysis of sizes of carbide phase particles indicates that with increase of energy density of electron beam from 6 to 10 J/cm^2 the particles with size less than 1 μm are dissolved (Fig. 3, curves *1* and *2*).

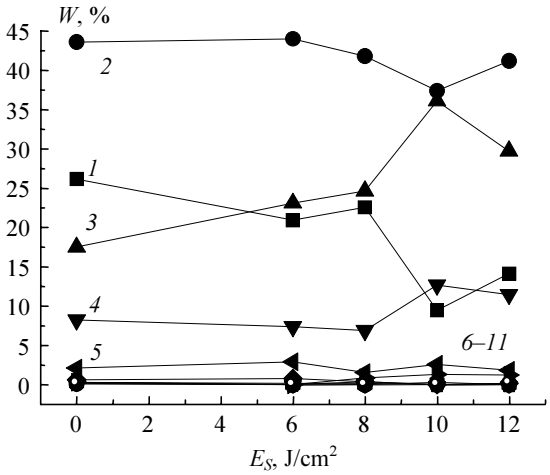

Fig. 3. Dependence of number of carbide phase particles from energy density of an electron beam. The intervals of particle size: *1* – 0–0.5; *2* – 0.5–1; *3* – 1–1.5; *4* – 1.5–2; *5* – 2–2.5; *6* – 2.5–3; *7* – 3–3.5; *8* – 3.5–4; *9* – 4–4.5; *10* – 4.5–5; *11* – 5–5.5 μm

Simultaneously with that the number of particles with sizes in the range of 1…2 μm is increased (Fig. 3, curves *3* and *4*). Treatment of steel samples by electron beam with energy density E_S = 12 J/cm^2 results in dissolution of particles with size of 1…2 μm.

It is accompanied by increase of particle number with the smaller sizes. The number of particles with size of > 2 μm practically does not change at all used modes of electron beam treatment of steel samples (Fig. 3, curves *5–11*).

The modification of a phase composition of AiSi M2 steel subjected to electron beam treatment was analyzed by X-ray diffraction methods. The investigations were shown that the electron-beam treatment is accompanied by $\alpha \Rightarrow \gamma$ polymorphous transformation. The volume fraction of a γ-phase based on relative intensity of diffraction peaks is increased with increase of energy density of electron beam (Fig. 4).

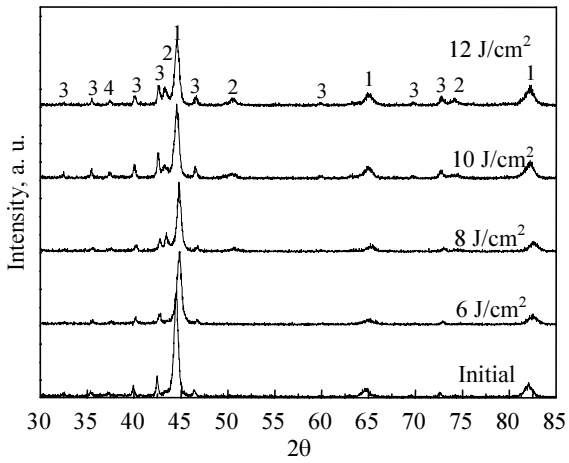

Fig. 4. XRD patterns of AiSi M2 high-speed steel samples before and after the HCPEB treatment. The numerals show α-Fe (*1*), γ-Fe (*2*), M_6C (*3*), V_4C_3 (*4*)

Simultaneously the intensity of diffraction peaks of carbide phase such as M_6C decreases. This fact shows that there is dissolution of carbide phase particles (6–8 J/cm^2). The increase of electron beam energy density (10–12 J/cm^2) results in both dissolution and segregation of carbide phase particles.

Detail analysis of a phase composition and defect substructure of steel samples before and after electron-beam treatment was carried out by TEM method. It is determined that the electron-beam treatment with energy density E_S = 6–8 J/cm^2 is accompanied by steel tempering processes (the scalar dislocation density is reduced, the boundaries of lath martensite are destroyed, the average sizes of vanadium carbide particles are increase).

The typical TEM images of tempered martensite structure formed at this mode of electron-beam treatment are presented in Figs. 5 and 6.

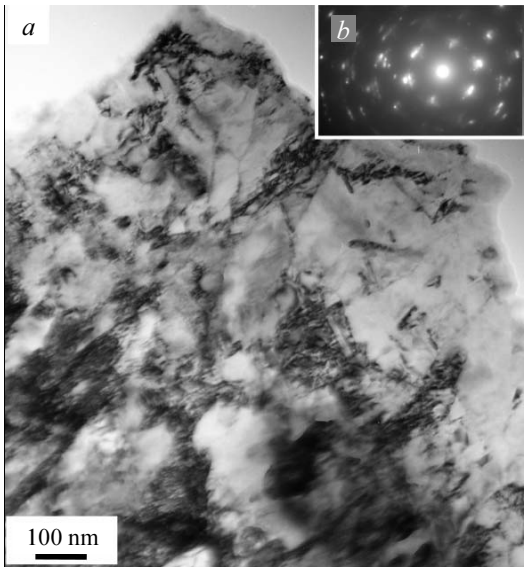

Fig. 5. Structure of AiSi M2 high-speed steel after electron-beam treatment with E_S = 8 J/cm^2: *a* – TEM bright field image; *b* – diffraction pattern to (*a*)

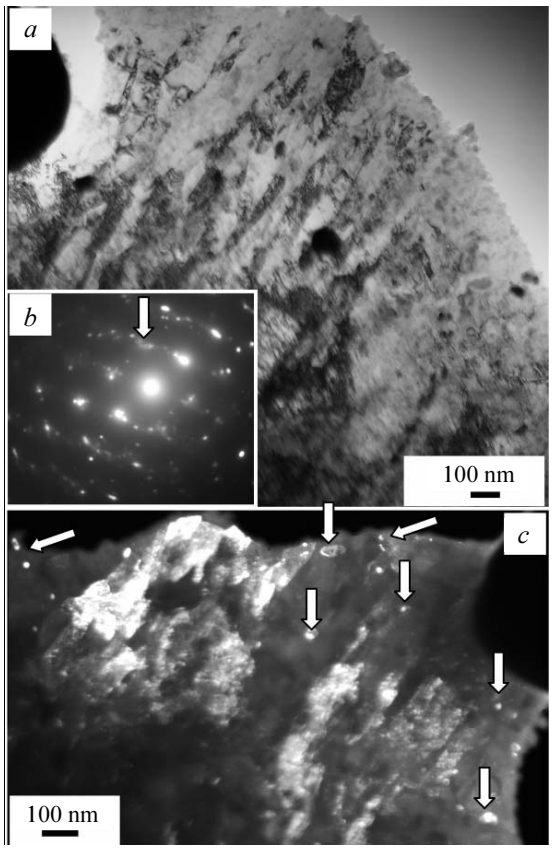

Fig. 6. Structure of AiSi M2 high-speed steel after electron-beam treatment with E_S = 8 J/cm^2; *a* – TEM bright field image; *b* – TEM dark field image obtained in [110] α-Fe + [121] $MoC_{0.54}$; *c* – diffraction pattern to (*a*), the arrow marks the dark field reflection. Carbide phase particles are shown by arrows (*c*)

Parallel with decomposition of martensite structure, electron-beam treatment leads to $\alpha \Rightarrow \gamma$ transformation. Formed austenite is situated in junctions and along boundaries of packet and martensite crystals in the form of island region and thin layers.

As it was mentioned above the electron-beam treatment with E_S = 10–12 J/cm^2 leads to melting of surface layer. The high-speed quenching results in formation of quenching structure which contains martensite grains and grains of residual austenite. One of the reasons of formation of similar structure is high speed of thermal effect on steel structure at which the processes of carbon and alloying elements diffusion are overpowered. Consequently, volumes of melting formed around of M_6C particles become enriched by atoms of carbon and alloying elements. The last fact and high speeds of cooling, promote formation of grains and island region of residual austenite in structure of surface layer. Volumes of melting depleted by atoms of carbon are quenched with formation of martensite crystals (mainly, lath morphology). The features of formed martensite are the small sizes of packets (hundred nanometers) and martensite crystals (the cross-section size of crystals changes within the limits of 50…80 nm).

Thus, as a result of the analysis of structure and phase composition of AiSi M2 steel samples treated by electron beam it is established that at all investigated irradiation modes the structure with reduced strength properties in comparison with that of initial structure is formed. Really, the microhardness measurements of steel samples before and after treatment by electron beam showed essential softening of material. The average values of surface microhardness before and after electron-beam treatment are presented in Fig. 7.

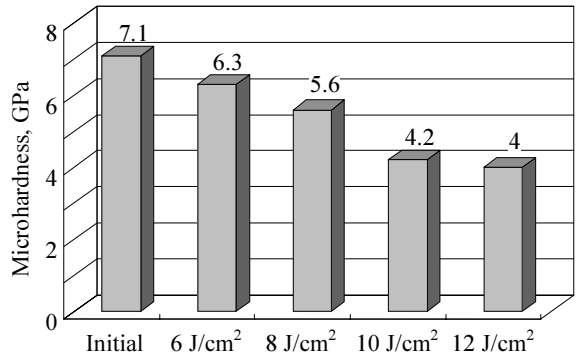

Fig. 7. Surface microhardness of AiSi M2 steel samples before and after electron-beam treatment

The increase of energy density of electron beam results in decrease of surface microhardness reducing in ~ 1.8 time at E_S = 12 J/cm^2 in comparison with initial microhardness.

4. Conclusions

1. Treatment of AiSi M2 steel by electron beam at the chosen modes of irradiation is accompanied by softening of samples surface layer.

2. The reasons of steel softening are: a) the processes of steel tempering (E_S = 6–8 J/cm^2); b) formation of structure with the increased contents of residual austenite (E_S = 10–12 J/cm^2).

References

[1] P.A. Leontev, N.T. Chekanova, and M.G. Khan, *Laser surface treatment of metals and alloys*, Moscow, Metallurgiya, 1986, p. 142.

[2] X.X. Mei, W.F. Sun, S.Z. Hao, T.C. Ma and C. Dong, Surface and Coatings Technol. **201**, 9–11, 5072 (2007).

[3] V.N. Devyatkov, N.N. Koval, and P.M. Shanin, Izv. Vyssh. Uchebn. Zaved. Fizika **37**, 76 (1994).

[4] N.N. Koval, N.S. Sochugov, V.N. Devyatkov, S.V. Grigoryev, I.R. Arslanov, A.V. Mikov, V.G. Podkovyrov, and K. Uemura, Izv. Vyssh. Uchebn. Zaved. Fizika **8**, 51 (2006).