Electron-Ion-Plasma Modification of Steel[1]

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Abstract – The phase composition and the defect substructure of preliminary quenched 30CrMnSi steel treated by electron beam were examined using metallography, scanning and transmission electron diffraction microscopy. It is shown that the treatment of the steel by submillisecond low-energy high-current pulsed electron beams in ionized nitrogen leads to nitrogen saturation of a near-surface layer. The saturation causes a considerable increase in the volume fraction of the residual austenite and the formation of particles of the Fe and Cr carbonitride, depending on the mode of electron beam treatment.

1. Introduction

Fundamental researches of mechanisms and physical principles development of the formation of multiphase nano- and submicrocrystalline surface structures by pulse electron beams and plasma flows in a single vacuum cycle and science-based optimization of high-energy treatment to design new technological electron-beam and ion-plasma facilities for treatment of metals, alloys, cermet and ceramics are at the foreground of modern materials science [1, 2]. High rates of quenching and saturation of metal with interstitial elements make it possible to fix the multiphase nano- and submicrocrystalline state of a near-surface metal layer and to considerably improve its physicochemical and exploitation properties [3, 4].

The aim of this study is to develop a method for producing a surface layer in the nano- and submicrocrystalline structural-phase state in low-alloy carbon steel through its irradiation by a submillisecond pulse electron beam in the atmosphere of reactive gas discharge plasma elements.

2. Experimental procedure

The material to be tested was a widely used commercial low-alloy carbon steel 30CrMnSi in the preliminarily quenched state. Pulsed electron beam modification of the steel surface was realized on a “SOLO” setup in the ionized nitrogen atmosphere. The phase composition and the defect structure were examined by optical (OLYMPUS GX71), scanning (SEM-515 “Philips”) and transmission (EM-125) electron diffraction microscopy.

3. Results and discussion

3.1. Phase composition and defect substructure of 30CrMnSi steel before irradiation

The 30CrMnSi steel structure before irradiation was formed by austinization at 1050 °C for 1.5 h and subsequent cooling in oil. Metallographic and electron microscopic examinations show that this treatment results in a formation of quenching structure with a grain size of 50–80 μm. In the grain volume, a martensite structure of mainly lath morphology is formed (Fig. 1, *a*).

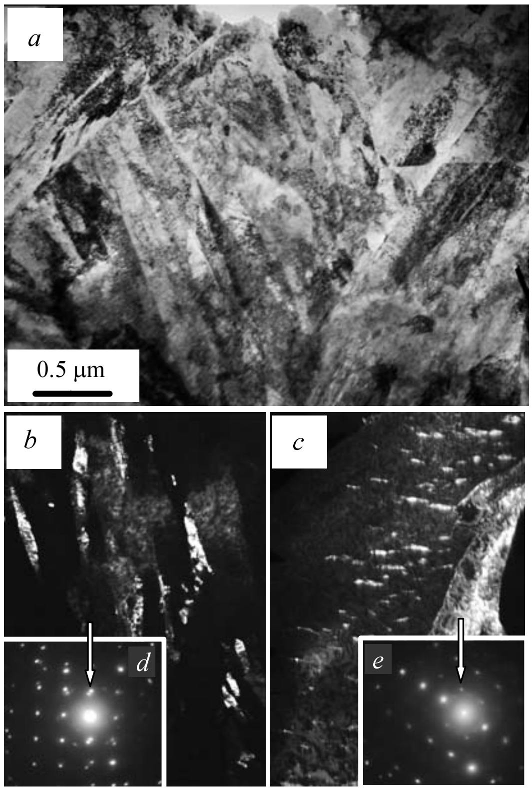

Fig. 1. Structure of 30CrMnSi steel in initial state: *a* – TEM bright field image; *b*, *c* – TEM dark field image obtained in [002] γ-Fe (*b*) and [211] Fe_3C (*c*) reflections; *d*, *e* – diffraction patterns. The arrows mark the dark field reflections

Along the martensite crystal boundaries, a thin interlayer of the residual austenite (γ-phase) is found (Figs. 1, *b* and *d*), and in the martensite crystal volume, self-tempering cementite particles are observed (Figs. 1, *c* and *d*). The defect substructure of marten-

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site crystals is multidimensional dense networks. The scalar dislocation density is ~ 10^{11} cm^{-2}.

3.2. Structure of 30CrMnSi steel after electron beam treatment in the ionized nitrogen atmosphere (pulse duration τ = 50 μs)

Electron beam treatment of the quenched steel in ionized nitrogen results mainly in the following types of structures:

1. Structures formed by thermal transformation of the martensite of the initial steel state: 1) martensite packets with partially retained martensite crystal boundaries (Fig. 2, *a*) or with martensite crystals of cross-sectional dimensions (3–4) equal to those of the initial martensite crystals. The transformation of a packet is by scattering of low angle boundaries of martensite crystals. In the packet volume, high dislocation density (~ $6 \cdot 10^{10}$ cm^{-2}) is retained; 2) grain-type structure. The boundaries of martensite crystals are not observed, the scalar dislocation density is ~ $2.5 \cdot 10^{10}$ cm^{-2} (Fig. 2, *b*).

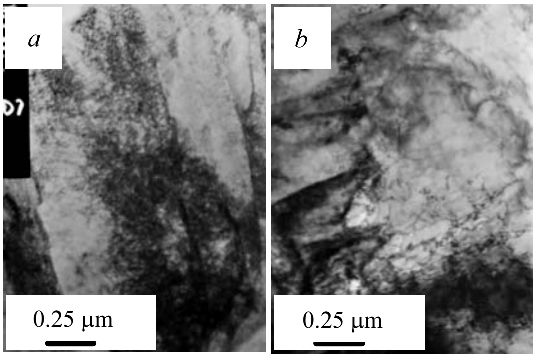

Fig. 2. Structure of 30CrMnSi steel surface layer after electron-beam treatment: transformation of lath martensite

2. Structures formed by the polymorphous $\alpha \Rightarrow \gamma \Rightarrow \alpha$ transformation: 1) packet martensite with thick interlayers of the γ-phase (Fig. 3).

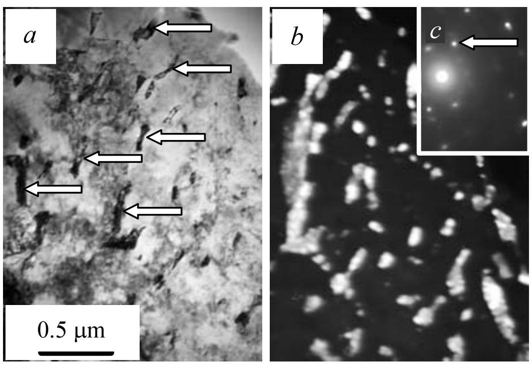

Fig. 3. Structure of 30CrMnSi steel surface layer after electron-beam treatment: the stage of $\alpha \Rightarrow \gamma$ transformation: *a* – TEM bright field image; *b* – TEM dark field image obtained in [002] γ-Fe reflection; *c* – diffraction pattern

In the martensite crystal volume, a rather high dislocation density (~ $4.5 \cdot 10^{10}$ cm^{-2}) is retained; 2) a two-phase subgrain structure in which the α- and γ-phases show up both in the form of subgrains and in the form of the interlayers separating subgrains (Fig. 4).

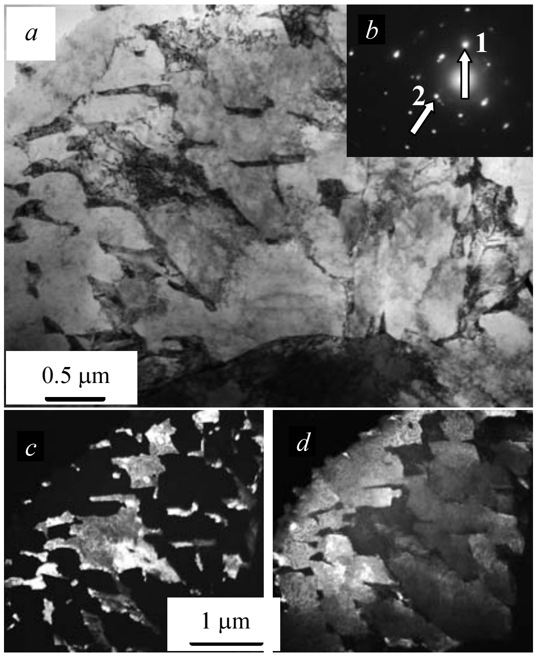

Fig. 4. Structure of 30CrMnSi steel surface layer after electron-beam treatment: the stage of $\alpha \Rightarrow \gamma$ transformation: *a* – TEM bright field image; *b* – diffraction pattern; *c*, *d* – TEM dark field image obtained in [002] γ-Fe (*c*) and [110] α-Fe (*d*) reflections. The arrows 1 and 2 mark the dark field reflections to (*c*) and (*d*), correspondently

The volume fraction of the γ-phase in this structure can reach 50% of the material volume. In the volume of subgrains of the α- and γ-phases, chaotically distributed dislocations are found; the scalar dislocation density decreases about ten times (~$1 \cdot 10^{10}$ cm^{-2}), compared with the initial structure. In austenite subgrains larger than ~ 0.5 μm, lamellar martensite crystals are observed, i.e., during the high-speed cooling, a polymorphous martensite type $\alpha \Rightarrow \gamma \Rightarrow \alpha$ transformation occurs in the surface layer.

The formation of the lamellar martensite is untypical of this steel grade and the large volume fraction of the residual austenite are apparently indicative of saturation of the surface steel layer with nitrogen present as the working gas in the working chamber of the electron-beam setup. Hence, the electron beam treatment of the 30CrMnSi steel specimen in the ionized nitrogen atmosphere involves its nitriding. The absence of nitride phases in the surface layer may be indicative of the short duration of thermal e-beam action.

3.3. Structure of 30CrMnSi steel after electron beam treatment in the ionized nitrogen atmosphere (pulse duration τ = 150 μs)

Like in the previous case, the electron beam treatment of the quenched steel in the ionized nitrogen atmosphere involves the formation of the following structures in the surface layer:

Structures formed by thermal transformation of the martensite of the initial steel state: 1) a grain structure with a grain size of 3–7 μm formed by recrystallization of the α-phase. In the grain volume, chaotically distributed dislocations of scalar density ~ $1.5 \cdot 10^{10}$ cm^{-2} are found (Fig. 5).

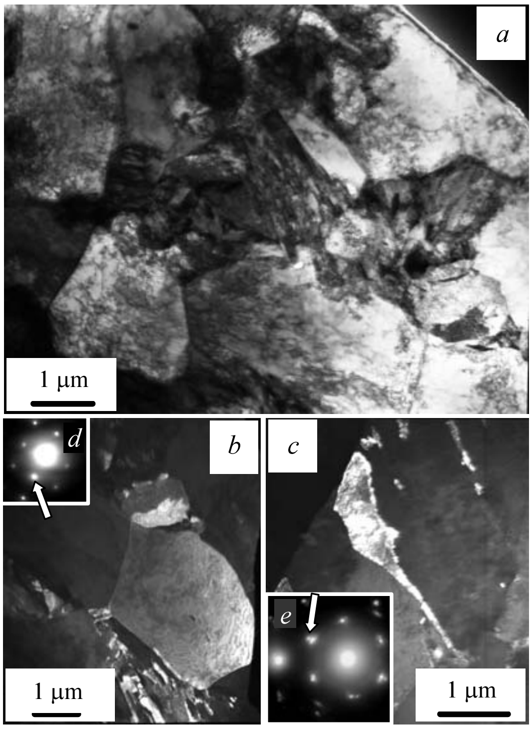

Fig. 5. Structure of 30CrMnSi steel surface layer after electron-beam treatment: *a* – TEM bright field image; *b*, *c* – TEM dark field image obtained in [110] α-Fe (*b*) and [002] γ-Fe (*c*) reflections; *d*, *e* – diffraction patterns. The arrows mark the dark field reflections

In grains larger than 1–2 μm, packet and lamellar martensite structures are observed (Figs. 5 and 6). Along the boundaries of grains with a size of 3–7 μm and along the martensite crystal boundaries, residual austenite in the form of interlayers and islands are found (Figs. 5, *c* and 6, *b*).

The electron-beam treatment in the nitrogen atmosphere with this pulse duration is accompanied by the formation of nitride and carbonitride particles.

The particles are formed mainly along the interphase boundaries (boundaries of grains, martensite packets and crystals). The particles formed along and at the junctions of the grain boundaries are globules. The particles formed along the boundaries of martensite crystals and packets are thin interlayers (Fig. 7).

Thus, the electron-beam treatment of 30CrMnSi steel in the ionized nitrogen atmosphere at a pulse duration τ = 150 μs involves nitriding of the specimen, which is evidenced by the presence of nitride phases in the surface layer.

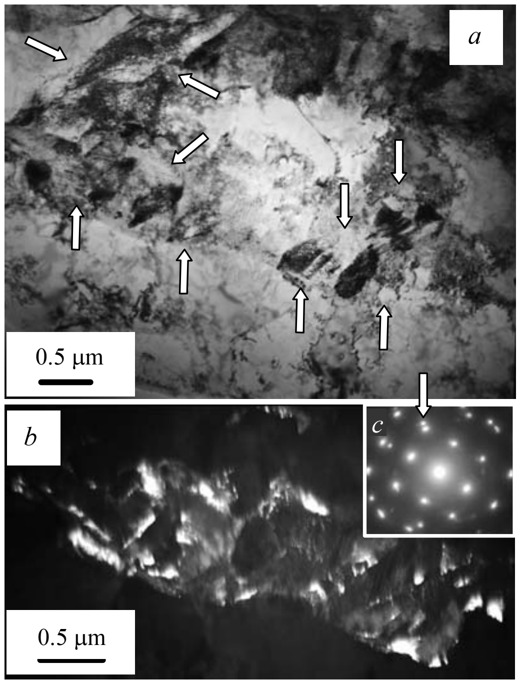

Fig. 6. Structure of 30CrMnSi steel surface layer after electron-beam treatment: *a* – TEM bright field image; *b* – TEM dark field image obtained in [002] γ-Fe reflection; *c* – diffraction pattern (the arrow marks the dark field reflection). The arrows show the grains with martensite structure

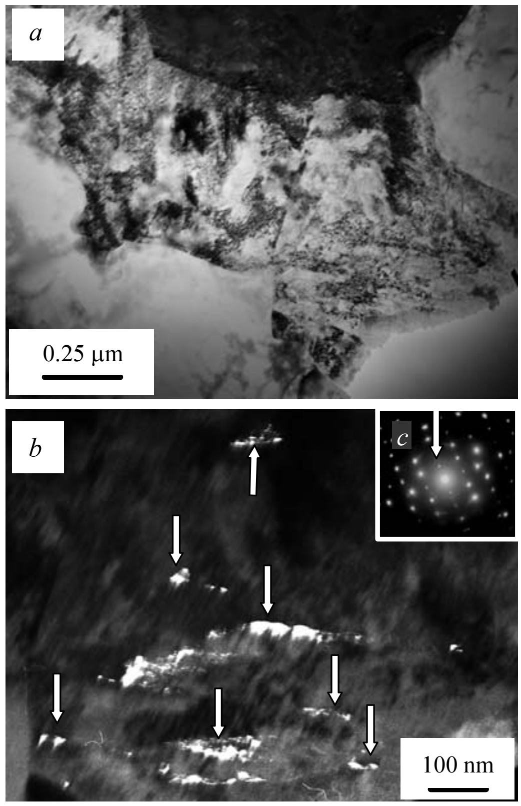

Fig. 7. Structure of 30CrMnSi steel surface layer after electron-beam treatment: *a* – TEM bright field image; *b* – TEM dark field image obtained in [122] $(Fe,Cr)_2N_{1-x}$ reflection; *c* – diffraction pattern. The arrows show the particle of nitride phase (*b*) and dark field reflection (*c*)

4. Conclusions

Electron-beam treatment of the preliminary quenched 30CrMnSiN steel in the ionized nitrogen atmosphere was realized. Along with effects of thermal beam action on the surface layer structure, effects of structural modification through nitrogen saturation of the surface layer are revealed.

References

[1] V.A. Gribkov, F.I. Grigoriev, B.A. Kalin, and V.L. Yakushin, *Promising radiation-beam technologies for material treatment*, Moscow, Kruglyi God, 2001, p. 528.

[2] J. Pouta, G. Foti, and D. Jacobson, *Surface modification and laser, ion and electron beam doping*, Moscow, Mashinostroenie, 1987, p. 424.

[3] V. Rotshtein, Yu. Ivanov, and A. Markov, *Materials surface processing by directed energy techniques*, Paris, Elsevier, 2006, pp. 205–240.

[4] S.V. Grigoriev, Yu.F. Ivanov, N.N. Koval, Yu.A. Kolybaeva, A.V. Teresov, and P.V. Moskvin, Izv. Vyssh. Ucheb. Zaved. Fiz., Special issue **50**, 47 (2007).