

Structure and Phase Compound of 0.38C–Cr–3Ni–V Steel Implanted by Mo and B Ions¹

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Abstract – Research of structure and phase composition of martensitic 0.38C–Cr–3Ni–V steels implanted by ions Mo and B carried out by TEM and X-ray analysis. Quantitative estimations of volume fractions of formed phases were executed and the size of particles of these phases was determined.

1. Introduction

One of methods of improvement of properties of constructional materials is ionic implantation [1, 2]. She allows modifying physical and mechanical properties practically any surfaces. Ionic implantation as a management method is superficial-sensitive properties of metal materials intensively develops last three decades and now is widely used in industrial production already enough. Ionic implantation – a highly effective method of technological processing of the materials, based on interaction of operated fluxes of high-energy ions with a surface of solid for the directed change of its properties connected with atom structure. The method of ionic implantation is universal way of enter of alloying elements as allows to enter into any alloy practically any element in controllable quantity up to 20–50 at. %. In most cases, such concentration cannot be reached using methods of traditional alloying owing to the limited equilibrium solubility of alloying elements in a matrix.

In [3] it is shown, that wear resistance of TiN coating obtained by a magnetron method then implanted by ions of Al and B essentially raises. This effect is reached as result of change of phase composition, morphology and microstructure of a coating. Amorphous area is formed in separate region of coatings at ionic implantation of aluminium and boron in the TiN coating [3]. In a surface layer of coating is formed precipitating of stable and metastable phases, lattice rearrangement of a coating, i.e., solid solutions of penetration on the basis of initial crystal structure are formed, radiating defects are simultaneously generated, dislocation structures of high density are formed [4]. Recently there was a considerable quantity of the works describing change of a structurally-phase state at ionic implantation not only on a surface of a material, but also in layers of deeper, than length of free run of the implanted ions [1, 2, 5–7]. The phenomenon of change of structure and properties on the distances

considerably exceeding a thickness of the implanted layer at ionic implantation of surface layer is called as effect of long-range action [2]. It is interesting to investigate this effect at treatment of 0.38C–Cr–3Ni–V steel by a method of ionic implantation.

The purpose of the present work is research of structure and phase composition of 0.38C–Cr–3Ni–V steels surface modified by Mo⁺ and B⁺ ion beams.

2. Experiment

Ionic implantation of Mo and B ions carried out on installation of “DIANA-2” with energy of 80 kV on a 0.38C–Cr–3Ni–V steel. Two-component beams of Mo and B ions directed on samples of 0.38C–Cr–3Ni–V steel 6×6×15 mm in size after oil quenching and tempering on air at 500 °C. The working sides of samples intended for coating deposition, grind and polished to within $R_a = 0.08 \mu\text{m}$.

X-ray investigation carried out using diffractometer DRON-3. The phase composition and the crystalline structure parameters of the surface were examined by the X-ray using the FeK_α radiation. Using of main diffraction reflections allow to do qualitative phase analysis and to receive values of parameter of crystalline lattice of main phase [8, 9].

Transmission electron microscopy (TEM) has been used to investigate the microstructure and phase composition of the surface layer of samples using selected area diffraction. It has allowed spending identification of phases, to measure the grains sizes of a composite coating, average scalar density of dislocations.

3. Results and discussion

By X-ray method, a steel 0.38C–Cr–3Ni–V was investigated in an initial state and after implantation by Mo and B ions. Implantation of this ions leads to change of crystalline lattice parameter of the basic phase. In the Table, values of lattice parameter, the size of blocks of coherent scattering (D), amplitude of internal stress ($\Delta d/d$) are resulted. Difference in lattice parameter of an initial steel and implanted by Mo and B ions is essential: 2.8666 and 2.8713 Å, accordingly. In an initial state α -phase has the lattice parameter is a close to tabulated value.

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Table. Phase composition and structural characteristics of 0.38C–Cr–3Ni–V steel in an initial state and implanted by Mo and B ions

State	Phases	a , nm	D , nm	l , nm
Initial	α -Fe, Fe ₃ C	0.28666 ± 0.00004	≥ 100	50
Implanted	α -Fe, B Fe ₃ (BC), MoB ₂	0.28713 ± 0.00005	30÷50	60

By our estimations, the thickness of half layer of weakening of X-rays is about 10 m μ [9]. The thickness of the ionic-alloyed layer, as a rule [2] does not exceed 200 nm. Nevertheless, change of crystal lattice parameter in the second sign is observed. It testifies that the implanted ions get on the big depth, than free length of ions.

In accordance with the equilibrium diagram of state the Fe and Mo forms the bcc solid solution [10, 11]. Here the simplest demonstration of effect of long-range action – superdeep penetration of an impurity which is caused radiating and thermostimulated diffusion [2, 12] is observed. The elastic stress, which takes place in an ionic-implanted layer [13], can be one more reason of the radiationally high-speed carry interstitial atom at ionic implantation. Formation of solid solution leads to generation of dislocations and reconstruction of defect structure of α -phases. Formation of dislocation structures leads to occurrence disorientation and material fragmentations, to change of areas of the coherent scatterings obtained by X-ray method.

On the average in α -Fe it can be dissolved to 7 at. % Mo. It is known, that at ionic implantation quite often there are solid solutions with limiting concentration [2]. Such concentration of Mo is achieved in the implanted layer. It confirms experimentally measured value of lattice parameter of a crystal lattice of α -phases by X-ray method. To determine a Mo content in an implanted layer, used dependence of lattice parameter of iron on concentration of molybdenum [10]. An increase of a lattice parameter occurs at implantation and formation of solid solution Fe–Mo and is caused by that the radius of Mo atom is more than Fe radius.

The sizes of areas of coherent scattering in implanted by ions Mo and B steels considerably decrease in comparison with an initial state of steel (Table). A material of a substrate under ionic implantation is fragmented (Fig. 1).

The sizes of fragments in lath and plates differ. On Fig. 1, *a* TEM image of structure implanted by Mo and B ions steel and the scheme of fragments in martensitic plates and lath is presented. Fragments in laths are extended along rod boundary borders (Fig. 1, *b*). It is interesting, that in martensitic plates amount of fragments it is a little. Their sizes on average 400×200 nm in plates and 300×50 nm in laths. The size of fragments and the size of blocks of coherent scattering differ 10 times. The size of area of coherent scattering is controlled by dislocations. The simple

calculations executed under the formula $l = 1/\sqrt{\rho}$: where l is the distance between dislocations; ρ is the scalar density of dislocations justify this fact (Table). We see that region of coherent scattering (X-ray) and distance between dislocations (TEM) has close values (D and l).

The typical 0.38C–Cr–3Ni–V steel represents is plate-lamellar martensite with precipitation of Fe₃C cementite of the needle form inside martensite crystals. The sizes of Fe₃C phase are 56×8 nm in an initial state of steel. Its volume fraction is 0.29%. It is necessary to notice, that after ionic implantation the cementite precipitation, characteristic for an initial state practically disappear from a body of martensite crystals. Boron forming in the implanted steel the Fe₃(BC) phase together with Fe₃C cementite will be transformed in complex borocarbide of iron with the same a crystal lattice. Borocarbide go off a body of martensite plates and allocate on lath boundary. The sizes of this phase are 34×240 nm and a volume fraction is about only 0.7% (Fig. 1, *c*). According to [14], the boron can replace carbon with 83%.

Penetration of boron in a crystal lattice of iron, in view of small solubility boron of both on interstitial and on substitutional causes considerable changes of a crystal lattice. These distortions relax by formation of dislocation and dislocation loops [14]. The scalar density of dislocations is proportional to concentration of a solid solution [4]. When the defects form, the diffusion rate of boron increases. At first, it occurs on dislocations, then – on small-angle and large-angle boundaries. The last become the basic channels of penetration of boron in steel and on them the basic part of borocarbides formed. Besides these processes there is an accelerated diffusion on interphase boundaries α /Fe₃C in perlite with the subsequent transformation in carbocementite.

Everywhere there is other phase MoB. This phase has orthorhombic lattice Cmcm. Sizes of particles of this phase is about 32 nm. At last, smaller phase giving halo (characterizing quasiamorphous phase) about the central ring can concern to MoB₂ or Mo_{0.8}B₃ (Fig. 1, *d*). Both these phases have hexagonal close-packed structure of P6/mmm type and to distinguish them it is not obviously possible.

The sizes of this phase changes from 5 to 20 nm. The further crushing of particles of this phase leads to its amorphisation.

The phenomenon amorphisation in separate local places of a surface of the implanted material is characteristic for ionic implantation. In Figs. 1, *c* and *d*,

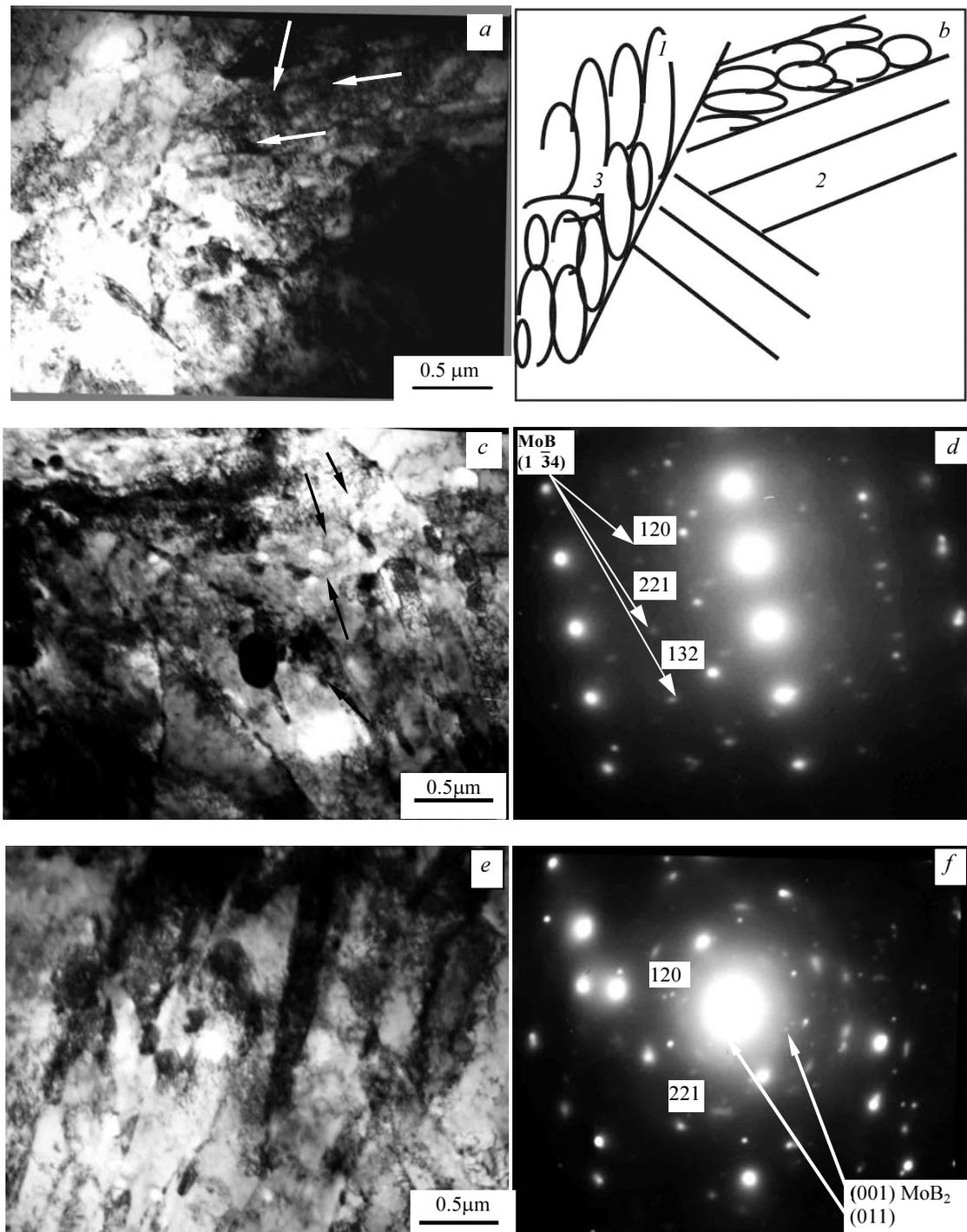


Fig. 1. TEM image of 0.38C–Cr–3Ni–V steel implanted by Mo and B ions: *a* – light field image (arrows are shown bending extinction contours); *b* – the scheme of an arrangement of fragments; *c* – light field image; *d* – microdiffraction pattern. On microdiffraction pattern the reflexes of a plane (1 34) of the MoB phases is shown by arrows; *e* – light field image; *f* – microdiffraction pattern and the scheme of indexing of quasi amorphous MoB₂ phases

the structure of implanted by ions Mo and B and the scheme of indexing of this phase is shown. In microdiffraction pattern (Fig. 1, *d*), it is possible to see some planes of MoB phase. In Fig. 1, *f*, the pattern showing halo relating to MoB₂ or Mo_{0.8}B₃ amorphous phases is shown. At thermal processing of 0.38C–Cr–3Ni–V steel (quenching and temper) forms defect structure.

The scalar density of dislocations ρ in implanted and initial steels differs lightly and is equal in lath $3.5 \cdot 10^{10} \text{ cm}^{-2}$, in plates $2.0 \cdot 10^{10} \text{ cm}^{-2}$.

4. Conclusion

Implantation Mo and B ions essentially modifies a surface of 0.38C–Cr–3Ni–V steel. A matrix of the

implanted steel is fragmented. There are phases of Mo–B system: nanocrystalline MoB phase, quasi amorphous MoB₂ or Mo_{0.8}B₃. The crystal lattice parameter of implanted by ions Mo and B steels considerably increases, blocks of coherent scattering decrease. The effect of long-range action in structure of the implanted steel is traced.

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