Nb-C-N-Fe surface layers synthesis in high speed steel by compression plasma impact

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High energy particle beams such as laser, electron, ion, and laser beams are widely used to modify properties of different materials. The effect of such flows in a mode with melting on heterogeneous systems containing the structure which ensureы certain properties of such systems leads to, as a rule, to dissolution of functional structures and deterioration of the system properties. Thus, a high energy impact on high speed steels results in structure homogenization, namely, dissolving of Fe_3W_3C type carbides /1-3/ and softening of the surface layer. In spite of surface properties worsening such treatment can be used as high temperature quenching. Subsequent annealing allows recovering the structure and obtaining more homogeneous distribution of hardening carbides /3/ than carbide distribution formed by traditional thermal treatment, thus preventing microchipping cutting tools made from high speed steels.

High energy particle beams treatment of the “coating/substrate” system can be used for alloying the substrate material with the coating elements. In particular, treatment of this system by compression plasma flows led to melting of the coating and substrate surface layer, liquid phase mixing and subsequent crystallization under conditions of high speed cooling. The investigation of the phase and element composition of the high speed steel surface layer alloyed by niobium atoms under the action of compression plasma flows was the main aim of this work.

AISI T1 steel samples (Fe 73,9-76,5%, W 17.0-18,5%, Cr 3,8-4,4%, V 1,0-1,4%, Mo 1,0%, C 0,7-0,8%, wt. %) were investigated. Combined treatment was carried out in the following way. At the first stage Nb coating was deposited using the vacuum arc vapor deposition technique with the following operating parameters: the arc current was 190 A, the negative bias voltage on the steel substrates was – 120 V, the deposition time was 10 minutes. The thickness of the coating was ~ 4 μm.

At the second stage the samples were treated by compression plasma flows (CPF) generated in the magneto-plasma compressor of compact geometry. The experiments were performed in the “residual gas” mode, i.e. the vacuum chamber was filled with nitrogen at the pressure of 400 Pa. The distance between the electrodes and the treated surface of the samples changed from 12 to 8 cm, which corresponded to the energy density of heat flux absorbed by the sample (Q) of 14 and 23 J/cm^2 per pulse, respectively (registered by calorimetric measurements). Treatment was carried out by three or six pulses (n) at the interval of ~ 5 s.

The element composition of the samples modified surface layers was determined by means of the Auger electron spectroscopy (AES) using PHI-660 spectrometer combined with sputtering by Ar ions. Only five elements (C, N, O, Nb, Fe) were taken into account for the concentration determination due to the spectrometer limitations. Therefore AES data can be mainly used for the analysis of elements distribution behavior under different CPF treatment regimes. The determined concentration of the elements does not reflect their real atomic concentration because W atoms (~ 18 %) were not taken into consideration. The phase composition was investigated by means of the X-ray diffraction (XRD) method with the Ultima IV RIGAKU diffractometer in Bragg-Brentano geometry with parallel beams in Cu Kα radiation (λ=0.15418 nm).

The AES data showed the formation of two main sublayers in the analyzed layer after CPF treatment (Fig. 1). The first sublayer is a thin film containing mainly Nb and C. The second sublayer is a steel surface layer alloyed with Nb atoms. The Nb atoms concentration in the steel surface layer decreased with the growth of Q due to the increase of the melted layer thickness and redistribution of the alloying element in it and due to increase or erosion intensity during plasma impact.

One can see that the film contains C, N, O, Nb and Fe atoms. The presence of thin ZrN, TiN or ZrO_2 films on the surface of steel alloyed by Zr or Ti atoms under the action of CPF was observed earlier /4/. The formation of such a film took place due to the interaction of vacuum chamber residual atmosphere gases with alloying elements at the stage of cooling, nitride or oxide formation and subsequent film growth due to diffusion of alloying elements to the surface. Carbon was also observed earlier at the surface but as contamination. In these experiments one can see that carbon is one of the main constituents of the formed film. The ratio of the Nb and C concentration in the surface film (in case of CPF treatment with Q=14 J/cm^2) allows one to assume niobium carbide formation in it (Fig. 1 a and b). Nitrogen and oxygen had diffusion-like profiles in the surface film. Thus, diffusion of these elements took place in carbon-containing film formed earlier. At the same time the cause of the carbon-containing film formation is not clear. The presence of Fe atoms in case of CPF treatment with Q=14 J/cm^2 could be explained by large surface roughness of the sample that appeared after plasma impact.

The growth of *Q* led to the decrease of the film thickness (Fig. 1c) while the *n* increase almost did not influence it.

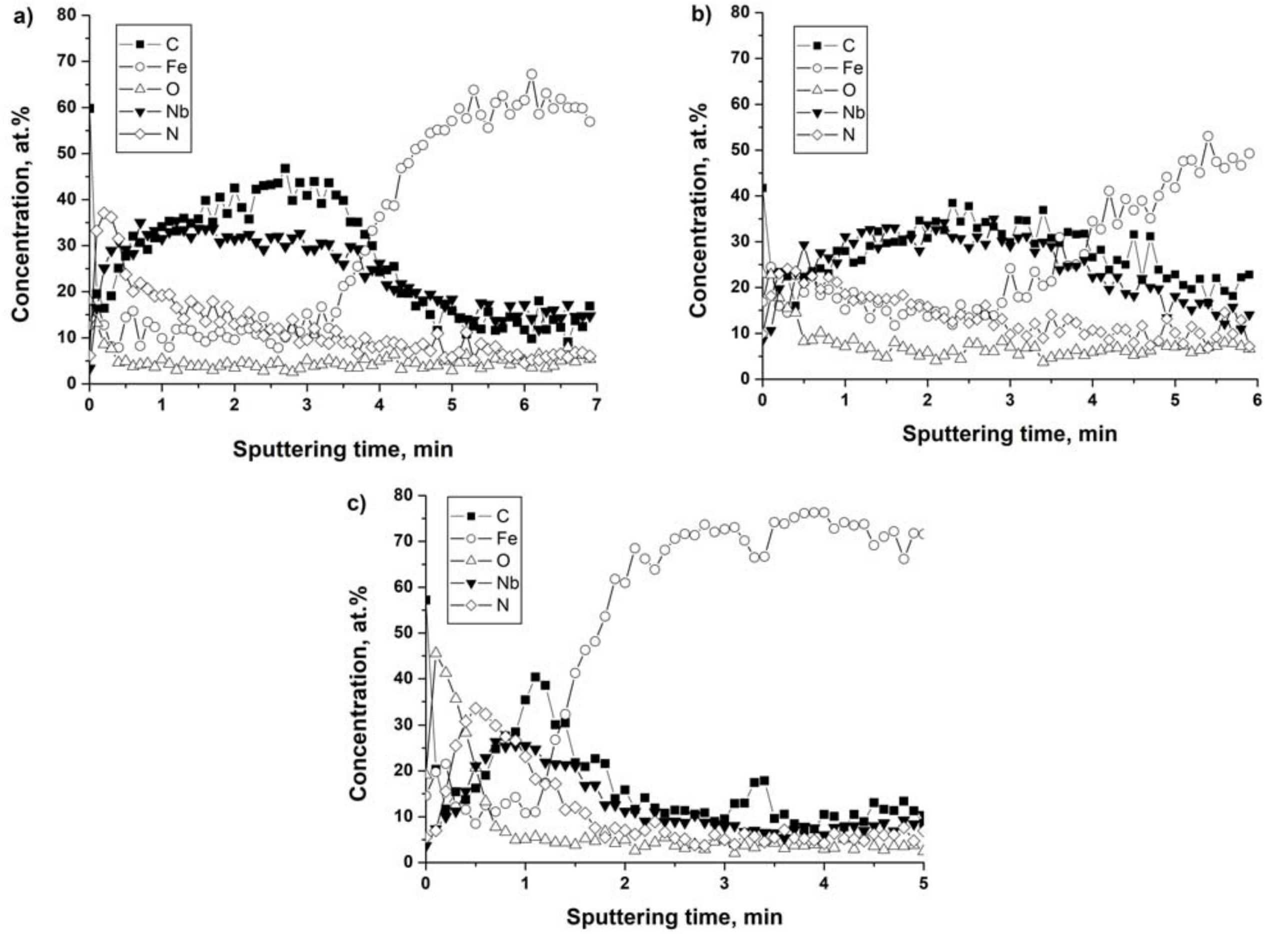

Fig. 1 - AES profiles of elements in the surface layer of the Nb/steel system after CPF treatment with *n*=3 and *Q*=14 J/cm^2 (a), *n*=6 and *Q*=14 J/cm^2 (b), *n*=3 and *Q*=23 J/cm^2

The results of the phase composition analysis are presented in Fig. 2. The XRD data showed that CPF impact on the Nb/steel system led to the dissolution of Fe_3W_3C type carbide and formation of a solid solution (with the alloying elements) on the basis of α-Fe and γ-Fe. The diffraction lines of the α-Fe solid solution are shifted to the area of smaller diffraction angles indicating the presence of interstitial atoms or atoms with a greater radius. The XRD analysis revealed a new phase formation. The position of this phase diffraction lines better corresponds to the position of δ-NbN diffraction lines than to the position of the NbC diffraction lines in spite of the AES data. Both of these phases possess a face centered cubic (fcc) lattice, therefore, the formation of the Nb(C,N) solid solution with fcc lattice can be supposed. One can also see that the position of these phase diffraction lines depends on treatment regimes. In case of CPF treatment with *Q*=14 J/cm^2 and *n*=3 diffraction lines shifted to the position of NbC diffraction lines that could be associated with the carbon increase in the Nb(C,N) phase which correlates with the AES data.

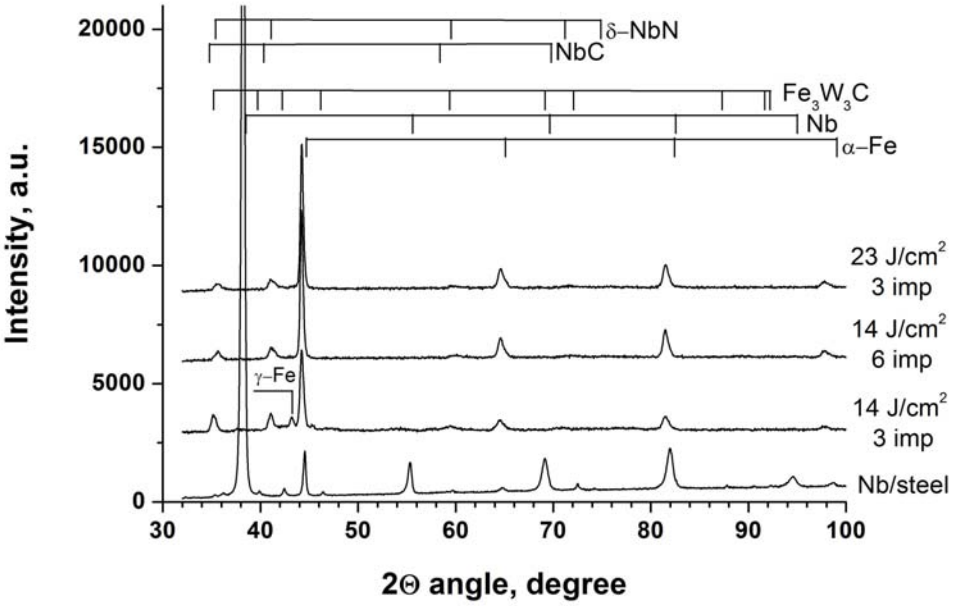

Fig. 2 - XRD patterns of the untreated Nb/steel sample and samples treated by CPF

The findings showed that compression plasma flows impact on the Nb/high speed steel resulted in the formation of two main sublayers in the steel modified layer: the surface film containing the Nb(N,C) phase and the steel surface layer alloyed with Nb atoms. Both the film thickness and Nb concentration in the alloyed steel surface layer were dependent on plasma treatment parameters.

References

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