INFLUENCE OF HIGH-INTENSITY Zr ION BEAM TREATMENT ON STRUCTURE AND MECHANICAL PROPERTIES OF HIGH STRENGTH 30CrMnSiNi2 STEEL

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ВЛИЯНИЕ ОБРАБОТКИ ВЫСОКОИНТЕНСИВНЫМ ПОТОКОМ ИОНОВ Zr НА СТРУКТУРУ И МЕХАНИЧЕСКИЕ СВОЙСТВА ВЫСОКОПРОЧНОЙ СТАЛИ 30ХГСН2А

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Аннотация. *Исследование структуры модифицированного поверхностного слоя высокопрочной стали 30ХГСН2А проводили с помощью оптической просвечивающей электронной микроскопии, а так же методов рентгеновской дифракции. Испытания на статическое и циклическое растяжение проводили для стальных образцов в состоянии поставки, а так же после модификации поверхностного слоя потоком ионов Zr.*

Introduction. The service life time of machine parts and structure elements, in many respects depends on in their ability to resist nucleation and propagation of fatigue cracks. One of the most effective and widespread methods of the surface modification that allows increasing the strength characteristics of metal surface layers, resistance to fatigue fracture and increase of corrosion resistance is ion beam treatment. The use of advanced engineering solutions makes it possible to realize modification of the subsurface layers accompanied by the formation of new phases at the depth of up to several micrometers on the basis of this method. A similar approach with the use of zirconium ion beam was previously used by the authors for the treatment of heat-resistant 12Cr1MoV steel [1, 2]. Thus, the modification of subsurface layer with the use of Zr^{+} ion beam irradiation can be accompanied by the nucleation of high strength fine dispersed phases there. At the same time, this treatment is conducted at high temperatures that must be accompanied by local heating of the subsurface layer up to the temperature of 700°C which, in turn, can lead to high-temperature tempering (softening).

The special regime of irradiation, which combines the rotation of specimens relative to the ion source, has been realized that allows reducing the temperature of the specimen to localize possible structural changes within relatively thin subsurface layer. It is assumed that it will allow to preserve the initial structure in the core of the specimens under treatment, and respectively, to minimize lowering of their mechanical properties. The purpose of this paper is to study the modified subsurface layer structure of high-strength 30CrMnSiNi2 steel realized by Zr+ ion beam treatment and its effect on the fatigue life time.

Experimental material and procedure. The size of the specimens for the fatigue tests was 65×8×1 mm. A central hole with a diameter of 2 mm was drilled in the specimens as the stress concentrator. The specimens were subjected to quenching and subsequent normalization according to the standard regime. The ion beam modification of the specimen subsurface layer was conducted with the aid of the high-current vacuum-arc source of metallic ions based on UVN -0.2 “Qvant” [3]. The specimens were tested under high cyclic fatigue with the asymmetry ratio R_a=0.1 (peak load – 270 MPa). The structural-phase composition was determined with the help of the X-ray diffractometer Shimadzu XRD-6000. Auger spectroscopy of the specimens was performed with the use of the device "Shuna-2". Authors appreciate help of Research-Analytical Center of TPU and Center for shared use of equipment “Nanotech” of ISPMS SB RAS.

Structural study of the modified subsurface layer. The Auger spectroscopy data has allowed to reveal the dependence of chemical elements concentration through the surface layer depth (Fig. 1, a). It was found that penetration depth of the Zr^+ ~ does not exceed 0.4 μm which agrees well with the measurement data of the modified layer carried out by the friction track (0.37 μm). Compounds with the Zr ions were also registered with the help of inclined X-ray beam technique that makes it possible to study thin subsurface layers. The intermetallic compound phases such as Zr_3Fe, $FeZr_2$, and so ZrC are revealed.

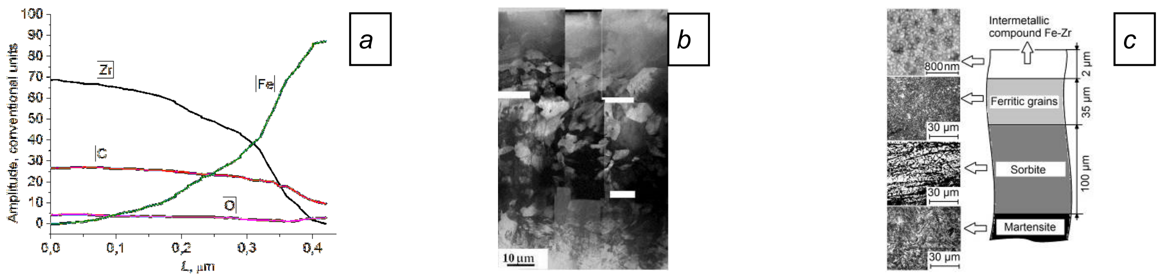

Fig. 1. Dependence of chemical elements concentration through the surface layer depth (a); TEM image of the subsurface layer cross section of the specimen after the irradiation (b); layered macrostructure scheme (c)

The composite picture composed of transmission electron microscope micrographs of the surface layer of in the irradiated specimen is presented in Fig. 2, b. It is seen that in the subsurface layer at the depth of ~35 μm the grain ferrite-cementite structure has formed that is related to the thermal impact under the irradiation. Further, the formation of the transition structure was determined (up to the depth of no more than 150 μm) consisting of ferrite grains with the characteristic size of 5 ... 10 μm as well as sorbite one (the latter or secondary sorbite is typical for high temperature tempering). In the lower layers of the specimen (at a depth of more than 150 μm) the (initial) martensite structure is remained.

The measurements of microhardness were carried out at the top (flat) face for all types of specimens. The lateral face to characterize the changes taking place through the specimen cross section was additionally analyzed for the coupons subjected to the irradiation. It is revealed that the treatment by the high-intensity Zr ion beam resulted in softening of a surface layer at the depth of 150 μm.

On the basis of obtained data the scheme of the layered macroscopic structure formation is proposed to illustrate the impact of changes taking place under 30CrMnSiNi2 steel processing by the high-intensity Zr ion beam (Fig. 1, c.). It consist of: i) the layer of ferrite grains to spread at the depth of 35 μm; ii) the thin surface layer comprising intermetallic compounds of iron with zirconium and Zr-based carbides; iii) the transition layer to have the structure being most similar to the sorbite one; iv) the core that possesses initial martensite structure.

Static and cyclic tension. It was shown under the static tension that non-treated specimens have the ultimate strength of σ_U=1640 MPa; the specimens subjected to the ion beam modification have the ultimate strength σ_U=1495 MPa. Thus, as a result of the ion beam treatment of the 30CrMnSiNi2 steel specimens the ultimate strength was lowered by 9 %; in doing so no changes of elongation at failure were revealed (Fig. 2, b).

During the fatigue tests the average number of cycles prior the failure were determined. For the specimens without the treatment this value made N_f=76 000±22 000 cycles while for the specimens after the irradiation it is equal to N_f=107 000±36 000. Thus, the surface modification by the Zr^+ ion beam irradiation of 30CrMnSiNi2 steel specimens ensures increasing the fatigue life-time by 30 %. The graph of the fatigue crack length vs the number of loading cycles was built being based on analysis of the surface image captured during the tests (Fig. 2, c). It is seen that the crack nucleates substantially later and develops slower in the specimen after the ion beam treatment.

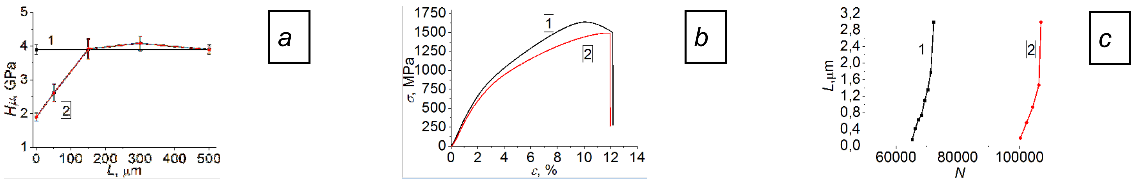

Fig. 2. Graph on microharnes through the specimen cross section as function of the distance from the surface of 30CrMnSiNi2 steel (a); loading diagrams at specimen tension with central hole (b); crack growth diagram as the function of the number of cycles (c); 1) in as-supplied state; 2) after the treatment

Summary. The characterization of the subsurface layer structure modified by the Zr^+ ion beam irradiation was carried out. In the subsurface layer as a result of the high-temperature thermal affect martensite structure was transformed into the ferrite-pearlite one. According to the data of auger spectroscopy zirconium does not penetrate deeper than 0.6 μm. It was shown that the nanohardness of the specimens was reduced noticeably after the ion beam treatment. Under static tension tests the ion beam modification of the 30CrMnSiNi2 steel specimens resulted in the ultimate strength reduction by 145 MPa (9 %). During the fatigue tests it was shown that the number of cycles prior to failure in the irradiated specimens is 30% larger in contrast with the untreated ones. In doing so the modified subsurface layer contributed to the delay of origination and propagation of the fatigue crack. The main reason for the revealed changes was the certain softening of the subsurface layer while the hardened specimens were extremely sensitive to the nucleation of microscopic cracks that was completed by the fast nucleation and the growth of the main fatigue crack.

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