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Nanosize Carbides Formation and Fatigue Life Increase of Stainless Steel by Electron Beam Treatment

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Electron – beam treatment with 20 J/cm² energy density of Fe-0.20C-23Cr-18Ni stainless steel increases fatigue life up to 2.1 times. Fracture surface investigations have been carried out by the methods of scanning and transmission diffraction electron microscopy and layer-by-layer analysis of structural phase states and defect substructure of steel subjected to the multicyclic fatigue tests, has been made as well. Nanosize $(Cr,Fe)_{23}C_6$ carbides formation and physical reasons of steel fatigue life increase by electron – beam treatment have been found out.

Keywords: Fatigue, Electron – beam treatment, Defect substructure

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1. INTRODUCTION

Much material, obtained by the modern structural methods of investigations, demonstrates complex nature of fatigue, dependence on various factors. Fatigue life increase of stainless steels is connected with concentrated energy flux application, modifying materials surface.

The aim of our work is the comparative, layer–by–layer analysis of a structure, phase composition and defect substructure of Fe-0.20C-23Cr-18Ni austenite steel, subjected to multicycle fatigue up to fracture, and the mechanism detection of fatigue life increase after high – intensive electron – beam treatment.

2. MATERIALS AND METHODS

Fe-0.20C-23Cr-18Ni steel is an investigation material. Electron – beam treatment conditions: eU electron energy = 18 keV; duration of pulse electron – beam action τ=50 μs; quantity of pulses N=3; frequency of pulses f = 0.3 s^{-1}; electron beam energy density Es=20J/cm².

The fatigue tests were carried out with special installation usage according to the scheme of cycle asymmetrical cantilever bend. Cycle loading stress–20MPa, frequency loading – 20 cycles/s, testing temperature – 296 K, the number of cycles before steel fracture ~$3.3 \cdot 10^5$. Electron beam non – treated steel samples (initial state) were fractured after ~ $1.5 \cdot 10^5$ cycles loading.

The investigations of steel structure – phase state were carried out by the methods of scanning and transmission diffraction electron microscopy.

3. RESULTS AND DISCUSSION

In the initial polycrystal state of the investigated steel there's a dislocation substructure like networks (Fig. 1, a) with ~ $4 \cdot 10^{10}$ cm^{-2} scalar density in the grain volume. The other element of a grain structure is microtwins (Fig. 1, b) of the one twinning system, rarely-of two systems.

The second phase particles carbide $(Cr, Fe)_{23}C_6$ in the form of longitudinal interlayers with the longitudinal sizes of 0.2 – 1.0 μm and transversal sizes 40-100 nm are revealed along the grain boundaries (Fig. 1,c). They have the round form 0.5 μm (Fig. 1, d) in the grains volume.

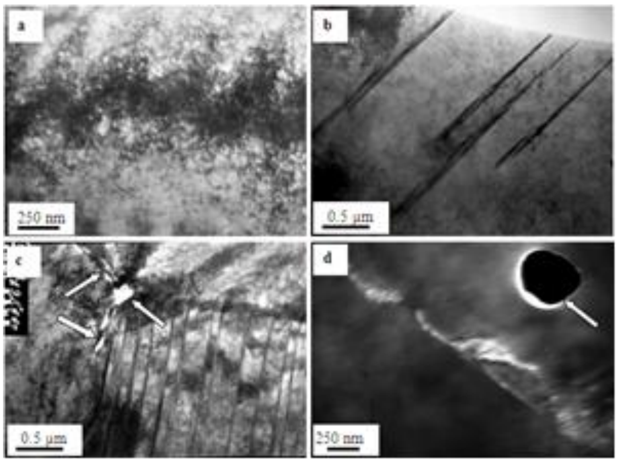

Fig. 1 – Electron microscope image of Fe-0.20C-23Cr-18Ni steel structure in the initial state; a-c – light fields; d – dark field obtained in the (111)γ–Fe reflection. Second phase particles, located along the boundary (c) and in the grain volume (d), are shown by the arrows in (c) and (d)

High level of inner stress field, being formed near the interface boundary of particle/matrix, points out some potentially dangerous places in the initial state material structure, that can cause fatigue cracks formation with its following fracture.

The images of steel surface fracture, after ~ $1.5 \cdot 10^5$ cycles loading, obtained by the methods of scanning electron microscopy, show that the maximum effect of a structure transformation develops in the pre-surface layer of a 10…12 μm thickness. The forming layer has got small sizes (0.5…1.0 μm) of fracture crystallites and is separated from the basic sample volume by the clear boundary, along which there are a lot of micropores.

There were many changes in a structure phase state of the given layer while experimenting. First, the junction of two microtwins systems leads to steel volume formation with nanoscale structure (Fig. 2). Crystallite sizes vary from 25 to 80 nm.

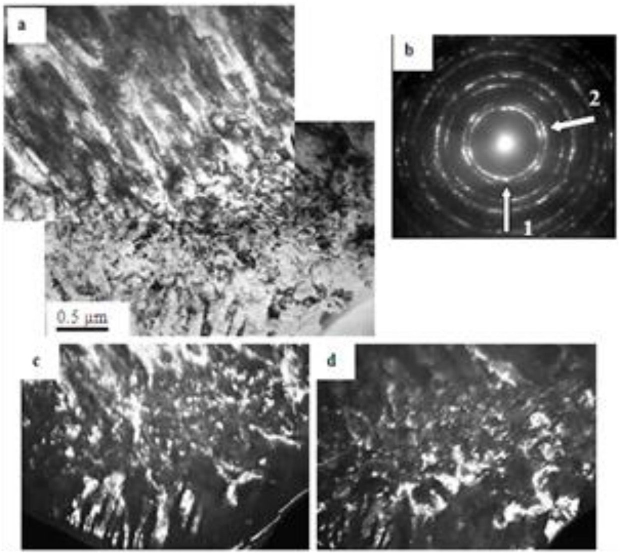

Fig. 2 – Nanocrystal structure, forming in the surface layer the fractured steel; a – light field; b – microelectron diffraction pattern, reflections, where dark zone 1 –(c), 2 – (d) is obtained, are shown by the arrows; c, d – dark fields, obtained in (111)γ–Fe, (111)γ–Fe+(002)γ–Fe diffraction rings reflections

4. PROCEEDING PAPER STRUCTURE AND CORRESPONDING STYLES

Second, there're some longitudinal microcracks along the grains boundaries containing the second – phase interlayers.

Third, fatigue tests form a band substructure in the grains volume, that don't contain microtwins. The bands were fragmented; the sizes of fragments vary from 50 nm to 80 nm.

Fourth, fatigue fracture is accompanied by γ→ε martensite transformation in the steel surface layer. ε-martensite crystals were found along the grains boundaries. ε – martensite formation is connected with cracks formation. There are some microcracks along the grains boundaries where ε – martensite plates were detected. This allows to suppose that the martensite transformation has been initiated by the elastic stresses, being formed the grains interface boundaries under fatigue.

Fifth, steel fatigue failure leads to multimicrotwinning and consequently to the complex curvature-torsion of a steel crystal lattice and a big number of bending extinction contours of a different form and size indicates about it.

In a result of a steel fatigue loading there are some material zones with the critical structure, unable to the following evolution in the sample surface layer of a ~ 10 μm thickness. This should lead to microcracks appearance and growth and, consequently, to the sample fracture as a whole. The second factor, that can lead to the fatigue life decrease of the investigated steel, is the presence of (Fe, Cr)$_{23}$C$_6$ carbide particles in it. Incompatibility of particles and matrix deformation is accompanied by the internal stress fields formation leading to the cracks appearance under critical substructure generation.

It has been established that steel electron-beam treatment of 20 J/cm^2 energy density increases its fatigue life up to 2.1 times owing to the processes suppression, allowing critical structure zones formation, being the potential location of micro cracks generation.

Samples fatigue loading, subjected to the preliminary electron-beam treatment, is followed by the formation of the second phase precipitates (Fig. 3, a). The particles have got round form; the particle sizes vary from 20 to 40 nm. Micro-electron diffraction pattern indexing, obtained from the material volume, containing the second phase precipitates (Fig. 3, b) allows to say that given particles are carbides on the basis of (Cr, Fe)$_{23}$C$_6$ chromium composition.

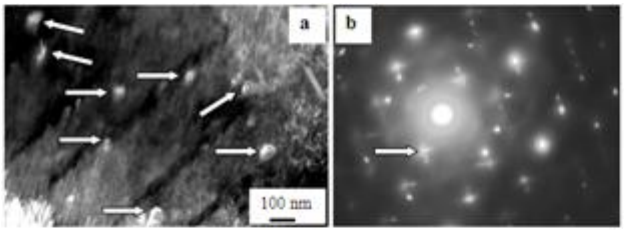

Fig. 3 – Electron-microscope image of carbide-phase particles, detected in the grain volume of steel surface layer, treated by electron beam and followed fracture; a – dark field, obtained in (002)γ– Fe + (006)Cr$_{23}$C$_6$ coincidence reflections; b – microelectron diffraction pattern, the reflection is shown by the arrow where the dark field has been obtained; carbide-phase particles are shown by the arrows in (a)

The investigations of an irradiation and fracture surfaces are showed, that one of the possible reasons of steel samples fracture was microcraters generation on the irradiation surface. Microcraters, being stress concentrators, tended to micro – and macrocracks formation, and their development led to the sample fracture. One of the ways of the following steel fatigue life increase is the suppression of craters generation on the surface.

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