STRUCTURE – PHASE STATES EVOLUTION IN 100-M DIFFERENTIALLY HARDENED RAILS AT LONG-TERM OPERATION

Gromov V.E.[1], Yuriev A.A.[2], Ivanov Yu.F. [3, 4], Glezer A.M. [5], Konovalov S.V.[6], Semin A.P. [1], Sundeev R.V. [5, 7]

[1] *Siberian State Industrial University, Novokuznetsk, Russia, gromov@physics.sibsiu.ru*
[2] *LTD Company «EVRAZ – Integrated West Siberian Metallurgical Combine», Novokuznetsk, Russia, ant-yurev@yandex.ru*
[3] *Institute of High Current Electronics, Tomsk, Russia, yufi55@mail.ru*
[4] *National Research Tomsk Polytechnic University, Tomsk, Russia, yufi55@mail.ru*
[5] *National University of Science and Technology "MISIS", Moscow, Russia, a.glezer@mail.ru*
[6] *S.P. Korolev Samara National Research University, Samara, Russia, ksv@ssau.ru*
[7] *Moscow Technological University, "MIREA", Moscow, Russia*

In the modern conditions of high loads on the axis and movement speeds the surface layers of rails undergo the intensive plastic deformations leading to the damages in long-term operation, it may be the cause for the withdrawal of rails [1,2]. Even at a comparatively small operating load – 100–500 mln. t brutto – in the surface layers of rails the structural phase states with anomally high microhardness and ultrafine grain size in the interval from 20 to 500 nm are formed. The plates of cementite are either arched or fractured and on the interphase boundaries the extremely high density of dislocations is determined, and the cementite dissolution takes place as well [1, 2].

One of the most important directions of development of notions of structural phase transformations is the determining of corresponding quantitative regularities along the rail cross-section. In this relation, the data on fine structure analysis, dislocations' substructures and extinction contour enabling to assess the level of internal long-range stress fields may be useful. For the initial state of bulk and differentially rails it is done in Refs. [3–5] and for bulk hardened rails after long-term operation it is done in Refs. [6–8].

The multi-stage process of dissolution of cementite particles of the initial state is observed in steel in operation. As the production of 100-m differentially hardened rails by compressed air began comparatively recently the determination of nature and evolution regularities in long-term operation of fine structure in the head of these rails is of current concern and has the scientific and practical importance. The purpose of the research is the analysis of defect substructure being formed in long-term operation of DT 350 rails by methods of layer-by-layer transmission electron diffraction microscopy.

The test materials were the samples of differentially hardened rails DT 350 from steel grade E76CrV manufactured at LTD company «EVRAZ-WSMC» after passed tonnage of 691.8 mln. t brutto in the process of testing on proving ground at experimental ring LTD «VNIIZhT» (Table 1). The investigation of phase composition and defect substructure of rails was carried out by methods of diffraction electron microscopy. The tests foils were manufactured by methods electrolytic of thinning of plates cut by electrospark method at 0, 2 and 10 mm distance from the tread surface along the central axis.

The following structure components were detected in the rail head along the central axis: the colonies of lamellar pearlite (fractional content ≈ 0.7), the grains of ferrite-carbide mixture (≈ 0.25), the grains of structurally free ferrite (≈ 0.05). The similar values of structural components were obtained in bulk-hardened rails [1, 3–5].

The operation of rails is accompanied by the transformation of material's defect substructure. The value of dislocation density reaches the maximum magnitude in the surface layer. As the distance from the tread surface increases the dislocation density decreases insignificantly, in this case the type of dislocation substructure is practically unchangeable. The structure of dislocation chaos or ball-cellular dislocation substructure is present in the ferrite component of pearlite colonies, in the grains of structurally free ferrite and in the grains of ferrite-carbide mixture.

The steel structure formed in the process of long-term operation is in the elastic-stressed state. This fact is detected by the presence of bend extinction contours on the structural images [6–8]. The presence of bend extinction contours in electron microscope images is indicative of the elastic-stressed distorsions of the material's crystal lattice and it may be caused by the mechanical effect on the rail metal in the process of operation [1]. The stress concentrators of the test steel are the intraphase (the interphase of ferrite grains and pearlite grains belong to them) and the interphase (interphase of ferrite and cementite) interfaces.

All morphological constituents of steel (the lamellar pearlite grains, the ferrite-carbide mixture grains and the grains of structurally free ferrite) undergo the essential transformation in longterm operation of rails. At 10 mm distance from the tread surface the relative content of grains of structurally free ferrite amounted to 5% (note that the relative content of ferrite grains is practically independent of the distance to the tread surface); the grains of ferrite-carbide mixture – 5%; the balance-pearlite grains. At 2 mm distance from the tread surface the relative content of ferrite-carbide mixture grains increased up to 10%; in the surface layer (the layer adjacent to the tread surface) measured 35%. It is evident that these transformations of steel structure take place at the expense of failure of lamellar pearlite grains. The performed studies of morphology of rail surface layer structure showed that the relative content of pearlite grains where the lamellar structure retained amounted to 25%; the balance – the pearlite grains in which the cementite plates are cut by gliding dislocations into separately located particles. These particles have globular shape, with their average dimensions being 30–50 nm.

For bulk hardened rails the formation of nanodimentional particles of carbide phase in steel ferrite constituent is observed after long-term operation. They are detected both in pearlite grains and in ferrite-carbide mixture grains and in grains of structurally free ferrite.

The analysis of the microelectron diffraction patterns is indicate of the two main transformation mechanisms of cementite plates taking place in rail steel operation. First, the mechanism of plate cutting by the moving dislocations. In this case some quantity of cementite particles of globular morphology is formed Second, the mechanism of cementite plate dissolution caused by the departure of carbon atoms from cementite crystal lattice to dislocations (to Cottrell atmospheres and dislocation nuclei). Note that these mechanisms of pearlite structure transformation were considered in detail earlier in [1].

The studies of fine structure phase state of differentially hardened rail metal depending on the distance to tread surface along the central axis of the head after passed tonnage of 691.8 mln. t brutto in the process of field testings were carried out by methods of electron transmission diffraction microscopy.

When analyzing the deformation transformations of lamellar pearlite structure, it was shown that the failure of cementite plates of pearlite colonies proceeded mainly by two mechanisms: the cutting by glide dislocations and as a result of carbon atom departure from cementite crystal lattice to dislocations. The comparison with the data for bulk hardened rails was carried out.

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