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# Nanostructure Formation in Superior Quality Rails

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Using transmission electron microscopy methods the layer by layer analysis of the bulk hardened superior quality rails is carried out and the quantitative parameters of structure, phase state and defect substructure gradients are established. The gradient character of changing of structure-phase states and dislocation substructure along the cross section of rail head is revealed.

The oil bulk hardening of superior quality rails is accompanied by the formation of morphologically different structure, being produced according to the shear and diffusion of γ-α transformation. The base structure volume is formed by the diffusion mechanism and is consisted of plate pearlite grains, free ferrite grains and grains of ferrite-carbide mixture. The presence of the bend extinction contours testifying to curvature-torsion of crystal lattice is revealed on electron microscope images. The analysis of far acting internal field stresses created by interfaces of cementite plates of pearlite grains and interfaces of pearlite and ferrite grains is carried out. It is shown that the interface boundaries globular cementite particles-matrix are the possible places of microcracks initiation.

**Keywords:** Rails, Structure, Phase composition, Dislocation substructure.

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## 1. INTRODUCTION

The interest to structure-phase states and defect substructure of rails after thermo mechanical processing is traditionally high, as they define the mechanical and operational properties. The bulk-hardened rails usually used at the Russian railways are exposed to oil hardening with the subsequent high tempering. The researches of structure, phase composition and dislocation substructure formed in rails' section as a result of thermo mechanical effects are very important for understanding of the physical nature of transformations as they allow to form the operational parameters of products purposefully. For revealing of the nature and mechanisms of formation of structure, phase composition and defect structure and, as consequence, for establishment of the optimum treatment regimes, the clarifying of quantitative regularities of formation of gradients of structure-phase states and parameters of fine structure of rails gets the fundamental importance [1-3].

The purpose of the present paper is the analysis of structure-phase states and defect substructure being formed in the bulk-hardened rail steel.

## 2. MATERIAL AND METHODS OF RESEARCH

Samples of rail steel of the category "B" (heat-strengthened rails of the superior quality) were used as a research material in accordance with Russian standard GOST 51685-2000 (C – 0.77; Mn – 0.87; Si – 0.34; S – 0.022; P – 0.081; Cr – 0.08; Ni – 0.06; Al – 0.08; V – 0.08; N – 0.01 wt %). Rails have passed traditional heat treatment after rolling: a bulk oil hardening with the subsequent high tempering.

The structure-phase state of steel was investigated by the transmission electron microscopy (TEM) methods of thin foils in the layers located at the distance of 2 mm and 10 mm from a rail head surface on the central axis and on round corner.

## 3. RESULTS OF RESEARCH AND DISCUSSION

According to morphological character the following structural components of rail steel have been defined: lamellar pearlite (the relative content of 0.68), grains of ferrite-carbide mixture (0.28) and grains of structurally free ferrite. The lamellar pearlite of rail steel is structurally and morphologically imperfect. Structural imperfections of ferrite plates of pearlite colonies are related to the presence of dislocation substructure in them.

It has been defined that the dislocations in ferrite plates can be distributed chaotically (fig. 1a) or can form a net substructure (fig. 1b). The scalar density of chaotically distributed dislocations is $\sim 1{,}0 \times 10^{10}\ \text{cm}^{-2}$. The net-like dislocation substructure in a pearlite colony, as a rule, is formed in ferrite bridges, the scalar density of dispositions in this structure reaches $\sim 5{,}0 \times 10^{10}\ \text{cm}^{-2}$.

This fact shows that one of the basic sources of formation of dislocation substructures of ferrite plates are the thermal stresses caused by difference of thermal expansion coefficients of ferrite and cementite [4]. The cementite plates are also of defects character. In analysis of pearlite by the dark-field method, the block structure of cementite plates is revealed (fig. 1c, d). The block dimensions vary within the limits of 1525 nm.

The dispersity of pearlite was estimated by the interlamellar distance – the total width of two nearby located plates: ferrite and cementite. The estimates

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done by this way have shown that the interlamellar distance of pearlite colonies varies within the limits of 80-100 nm.

The ferrite grains, in the volume of which the cementite particles of globular or lamellar form are present, are arbitrarily called as grains of ferrite-carbide mixture. The grains of ferrite-carbide mixture can be divided into three sub-groups by the form and mutual location. The grains, in which cementite particles have a form of short plates, refer to the first sub-group. By the morphological character this structure can be referred to the structure being formed by bainite mechanism, namely to the upper bainite [6]. The grains in which cementite particles of the round form are distributed chaotically in the volume of grains, are referred to the second sub-group. It is possible to assume that these grains are formed by diffusion mechanism and are the globular pearlite [4]. The cementite particles of the round (globular) form are distributed in parallel lines, the grains of which are referred to the third sub-group. The structure of these grains was formed evidently by shear mechanism and is packet martencite [5]. The segregation of the cementite particles on the crystals' boundaries is a result of tempering of the quench structure.

In the volume of grains of the first and third subgroups the net-like dislocation substructure is present predominantly, dislocations' scalar density of which is $(5\ldots6) \times 10^{10}\ \mathrm{cm}^{-2}$. In the grains of the second subgroup the net-like, cell-net-like dislocation substructures and also the chaotically distributed dislocations are observed. Often the carbide phase particles are present within the limits of cells and in the cells' volume. In the first case the particle dimensions are 30-50 nm; in the second case – 10-15 nm.

In analyzing the electron microscope images of steel structure the bend extinction contours were revealed. The presence of the bend extinction contours on the electron microscope images indicates to the curvature-torsion of the crystal lattice in the material zone and therefore to internal stress fields curving the thin foil and accordingly strengthening the material. In analyzing the bend extinction contours it is possible to indicate the sources of the internal stress fields, i.e. to reveal the stress concentrators. As a result of fulfilled researches it was established that the stress concentrators in steel are interfaces of cementite plates of pearlite grains, interfaces of pearlite and ferrite grains. In this case the contour begins from the interface of the plates and / or grains. The sources of stress fields are often the second phase particles distributed along the interfaces and in the volume of grains.

It is experimentally shown that the amplitude of the internal stress fields is inversely proportional to the width of the bend extinction contour $h$ [6]. The evaluations done in this work show that the average width of bend extinction contours revealed in pearlite grains, i.e. of contours being formed from the interface of cementite and ferrite plates is 80 nm, and in the grains of ferrite-carbide mixture, i.e. generated by the globular particles is 25 nm.

Consequently the interfaces of particle / matrix are the most significant stress concentrators and can be referred to as the typical areas of cracks forming.

The fig. 2 shows the gradients of curvature-torsion of crystal lattice of rail steel formed in the pearlite grain (fig. 2a, b) and in the ferrite-carbide mixture grain at cementite particles (fig. 2c, d).

In analyzing the results it is possible to note that the extinction contours in pearlite spread out as a rule from one colony boundary to the other. Using the ratio [6, 7]

$$\sigma = \frac{G \cdot t}{h} \qquad (1)$$

where $G$ – shear modulus of steel, (GPa); $t$ – foil thickness, (nm); $h$ – contour width, (nm); the level of far-ranging stress fields $\sigma$ was estimated.

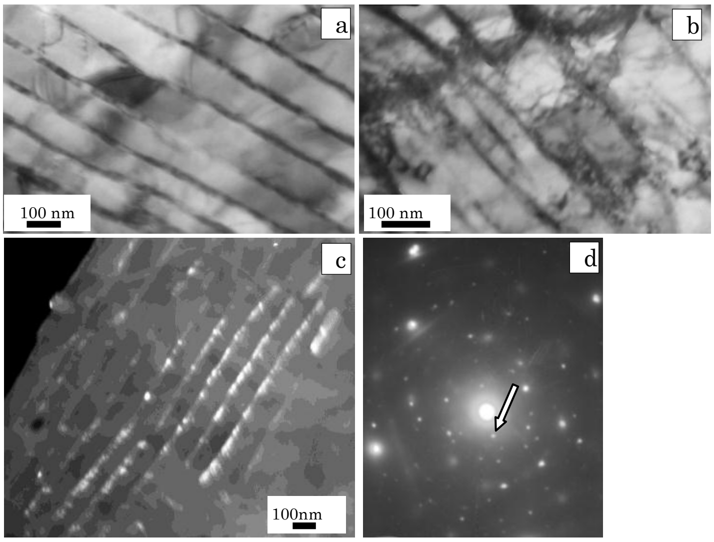

**Fig. 1** – Defect substructure of plates of ferrite (a, b) and cementite (c, d) of pearlite colonies; a, b – light fields; c – dark field obtained in reflex [101] $Fe_3C$; d – micro electron-diffraction pattern, arrowhead shows the reflex where the dark field obtained

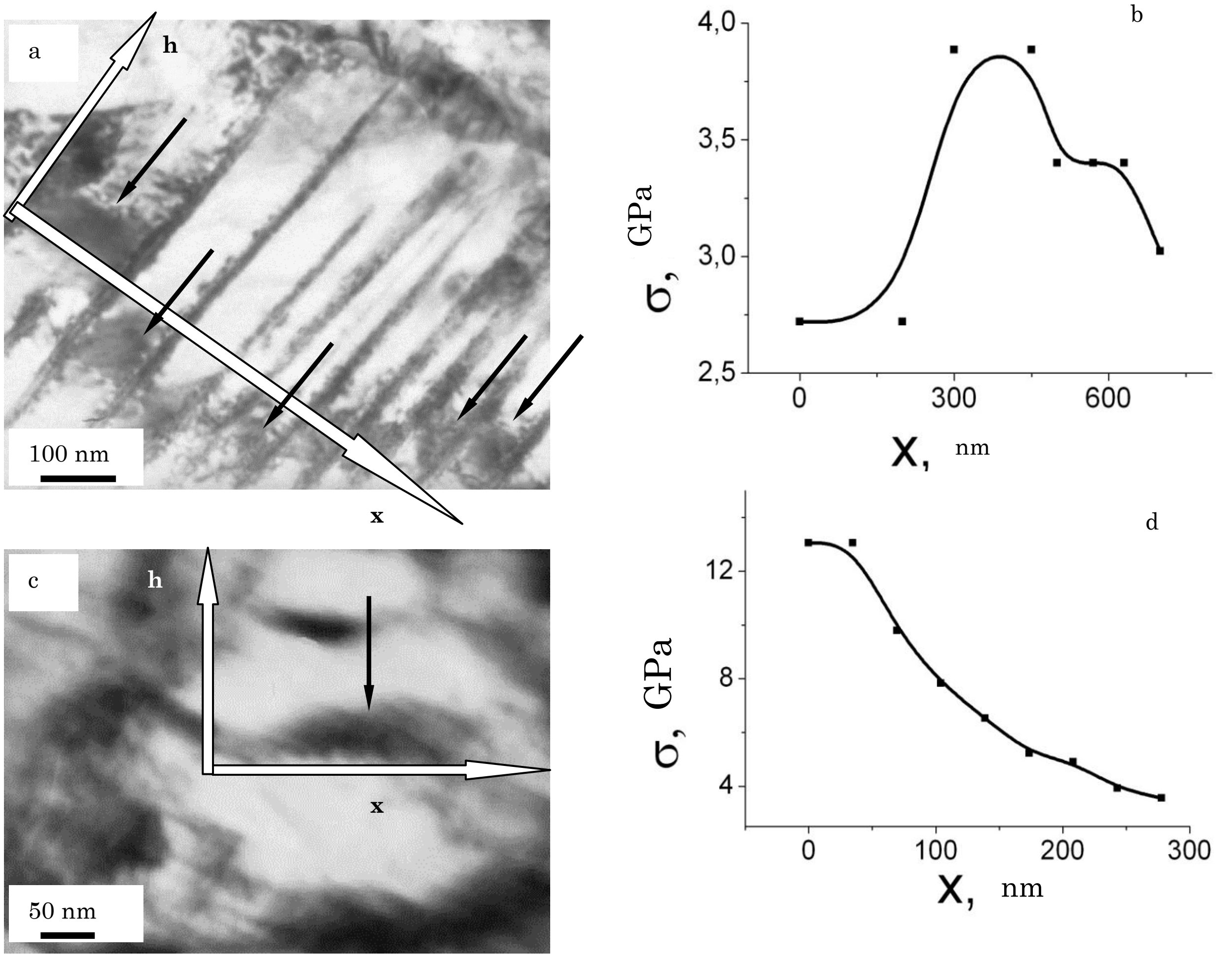

**Fig. 2** – TEM images of the rail steel structure (a, c) and profile of internal stress fields being formed in the pearlite colony (b) and near the cementite particle (d); the arrows on (a, c) show the extinction contours

For the pearlite grains this value can both decrease and increase (fig. 2b).

σ produced by the second phase particles always decreas depending on the moving away from the particle (fig. 2d). The peak level of σ available on the particle / matrix interface can exceed the ultimate strength of steel.

## 4. CONCLUSION

The thermomechanical processing of rails is accompanied by forming of multiphase, morphologically various structure generated by diffusion and shear mechanism of $\gamma \leftrightarrow \alpha$ – transformation of solid solution on the iron basis. At the same time the base structure volume of the rail steel is formed by diffusion mechanism of $\gamma \leftrightarrow \alpha$ – transformation as result of bulk oil hardening. The quantitative analysis is done and general parameters are revealed which describe the gradient character of the structure, the phase composition and the defect substructure of steel. It is established that the preferred areas of micro-cracks nucleation in steel are the globular particles / matrix interfaces.

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