Formation Structural Phase Gradients in Rail Steel During Long-Term Operation

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Abstract. The paper presents results of the structural and phase analysis of the surface layer composition in the type R65 rail steel in its original state and after long-term operation. It is shown that long-term operation of rail steel is accompanied by its structural and phase modification at a depth of not less than 2 mm. The structural elements are detected that can be stress concentrators.

1. Introduction
The reliable operation of railways mostly depends on the quality and durability of rails. The increase of traffic loading and working capacity of railways requires the increase of their reliability and durability and improved requirements for hardness, rolling-contact fatigue resistance, and brittle fracture resistance. Oil quenching and tempering according to the State Standard, is currently one of the widespread methods of thermal strengthening of rails. This method allows producing quenched rails with a uniform sorbite or troostosorbite structure that, in turn, allows the choice of the optimum hardness level [1-3]. It should be noted, however, that carbon steels are characterized by a variety of structures the formation of which strongly depends on thermal treatment conditions and defines the material behavior during its operation [2,4-7].

This work aims at the investigation of the structural evolution of the type R65 rail steel that occurs during its long-term operation.

2. Material and methods
The type R65 rail steel was used for investigations the properties and the elementary composition of which is subject to terms of the State Standard. The steel specimens were cut of the original product that was in service (1000 mn t gross tonnage). All specimens demonstrate the increased wear of gauge corner or the inner edge of a rail the structural phase condition of which was analyzed.

Thin films were evaluated using the transmission electron microscopy (TEM), while section etching was carried out by metallography techniques (4% solution of nitric acid and alcohol). Thin films were prepared by electrolytical thinning of plates situated on the railhead running surface and at 2 and 10 mm distance from this surface.

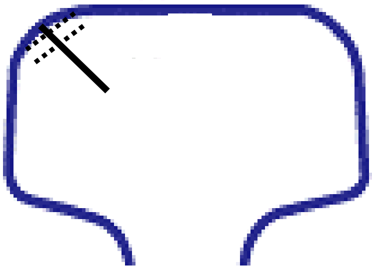

Figure 1. Schematic of specimen preparation for TEM examination. Solid line – direction of gauge corner; dash lines – layers used for thin films.

3. Results and discussion

A visual examination allows detecting arc-shaped discontinuity flaws in steel specimens the original product of which was in service and has 1000 mn t gross tonnage. These discontinuity flaws are observed at 500 μm depth at a certain angle to the surface (Figure 2 *a*) and are filled with corrosion products.

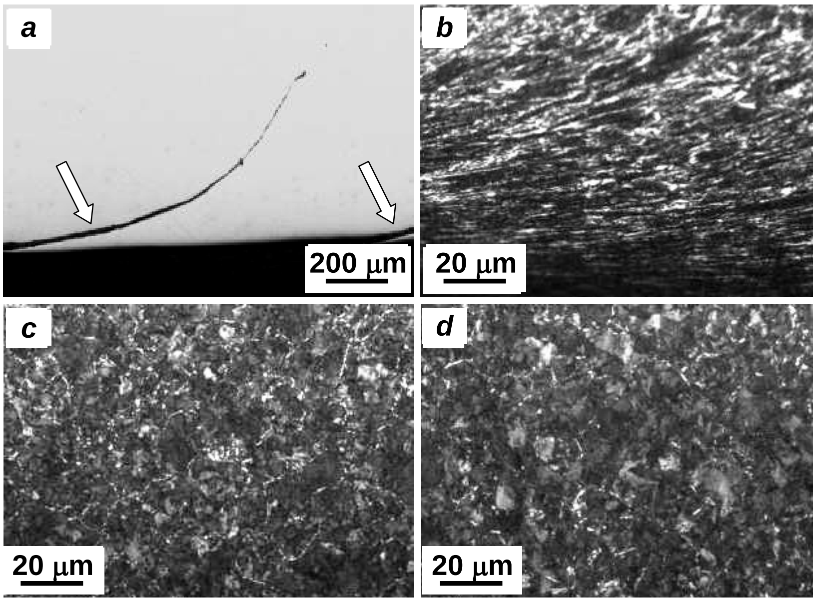

Figure 2. Optical images of gauge corner microstructure (after rail service); *a* – rolling-contact fatigue while in service; *b* – deformation bands on gauge corner surface; *c*, *d* – steel section microstructure at 2 mm (*c*) and 10 mm (*d*) distance from rail head running surface.

No traces of oxides, brittle-fractured and plastic silicates as well as any defects of metallurgical origin are observed on edges and discontinuity flaw propagations that indicates to the formation of these defects while in operation. Deformation of the metal structure is observed on the surface of gauge corner, grains being oriented at an angle of 30 degrees or less to the surface (Figure 2*b*). The metal microstructure is sorbite after the section etching having the ferrite network fragments (Figure 2*c*). With distance from the center, perlite dispersion insignificantly decreases as well as the amount of ferrite (Figure 2*d*). The grain size in the rail steel is estimated according to the State Standard.

Investigation of the steel failure after the rail operation, shows the formation of the multilayer structure presented in Figure 3a. This layer comprises 20 μm thick surface layer (Figure 3b) and 200-

300 μm thick transition layer (Figure 3a) that transits to the base material. The surface layer has the great number of microcracks, micropores, and shelly spots (Figure 3*b*). The structure of the transition layer is characterized by a relatively small (0.5 ... 1 μm) size of fracture facets (Fig. 3*c*). It is important to note that the interfacial layer that separates the transition layer from base material has no structural defects induced by deformation (micropores, microcracks, etc.

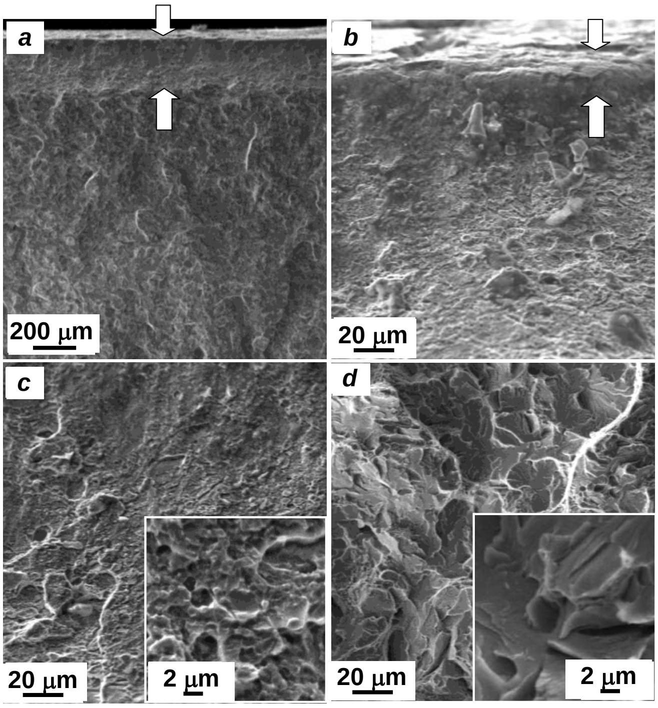

Figure 3. SEM image of multilayer structure: *a* - rail head running surface (upper arrow), transition layer and base material interface (lower arrow); *b* – surface layer; *c* – transition layer; *d* – base material.

TEM investigations of thin films allow detecting the structural phase conditions of the rail steel. As a result, the morphology of the base material at 300 mm distance from the head running surface is detected, namely: lamellar perlite (Figure 4a); grains (regions) of ferritic-carbide mix (Figure 4b). The structure mainly comprises perlite grains the content ratio of which is 0.7 (Figure 4a), while that of ferritic-carbide mix is 0,2; the rest content is free ferrite.

The steel structure significantly depends on its operation. A substructure forms in the surface layer with the fragment size of 500 nm (Figure 5). TEM images show that the obtained layer contains a large number of the second phase inclusions (iron carbides and oxides).

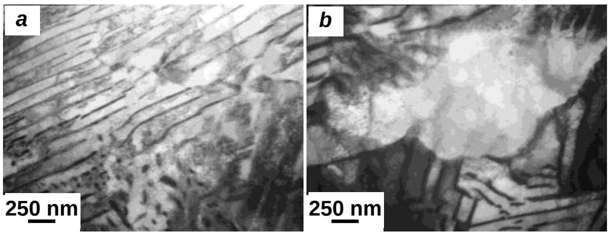

Figure 4. TEM images of rail steel structure: *a* – lamellar perlite; *b* – ferritic-carbide mix.

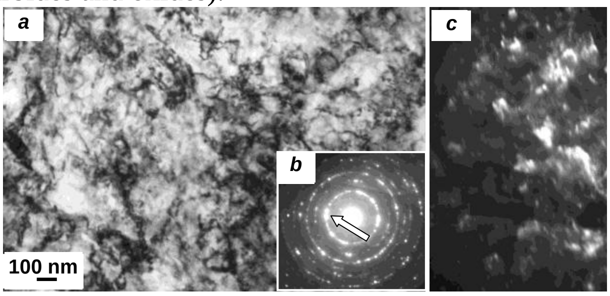

Figure 5. TEM images of the surface layer structure while in service; *a* – bright field; *b* – X-ray diffraction pattern (arrow indicates the dark

field reflection); *c* – dark field obtained in α-Fe reflection [110].

At a distance of 2 mm, the steel structure is similar to that of the base material after its operation. The difference is in the degree of the material deformation. Perlite grains are fragmented and a great number of extinction bend contours is detected (Figure 6a). The regions of free ferrite and ferritic-carbide mix have a higher density of dislocations (Figure 6b).

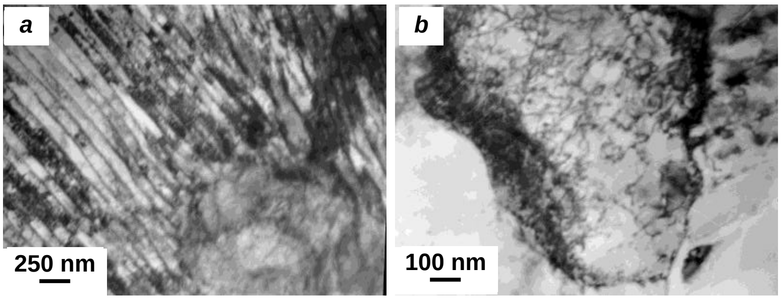

Figure 6. TEM images of base material formed after the rail service. Layer locates at 2 mm distance from the rail head running surface.

4. Conclusion

A study of the structural phase structure of the type R65 rail steel formed as a result of its operation (1000 mn t gross tonnage) was carried by SEM, TEM and optical microscopy investigations. It is shown that the rail operation leads to the formation of a multilayered steel structure. The surface layer 20 µm thick is characterized by micropores, microcracks and shelly spots.

The morphology of the layer located at 2 mm distance from the rail head running surface is similar to that of the base material (steel structure before its operation). The structure is mostly presented by lamellar pearlite, ferritic-carbide mix and free ferrite. They are characterized by dislocation density higher than that of the original state of the structure.

Acknowledgement

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