

# Formation of defects in railway wheel rims during operation

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**Abstract.** During operation, under the influence of mechanical stress, temperature, and external environment, the initial structure of a railway wheel undergoes changes that lead to its fatigue-corrosion wear.

The wheels with different tread profiles that were removed from operation due to the maximum wear of the rims were studied. The studies were carried out using the metallographic method (Neophot-21) and scanning electron microscope JSM-35.

The causes of cracks and wear particles formation near the tread surface of railway wheels associated with phase and structural changes occurring during operation were analyzed. The possibilities of changing the tread profile due to uneven wear were established. It was shown that structural and phase changes near the tread surface are associated with the development of plastic shifts due to the action of external loads, thermal stresses during braking, and the formation of "white layers" when the metal is heated by the heat of braking and abrupt cooling when the brakes are turned off. The role of non-metallic inclusions and corrosion products of wheel steel in the formation of cracks near tread of railway wheels has been established.

**KEYWORDS:** RAILWAY WHEEL, TREAD, CRACKS, RIM, DEFORMATION, WHITE LAYER, NON-METALLIC INCLUSIONS, CORROSION..

## 1. Introduction

Ensuring high quality of railway wheels, their reliability and durability requires a comprehensive analysis of the mechanisms of formation and change of structure and properties of the wheel material during operation under various conditions [1-9]. The goal of the work is to analyze the causes and conditions of crack formation near the rolling surface during operation of railway wheels.

During operation, under the influence of mechanical stress, temperature, and the external environment, the original structure of a railway wheel undergoes changes that lead to its fatigue-corrosion wear. A change in the profile of the rolling surface is possible due to uneven wear and the appearance of surface defects (Fig. 1, a – c, 2, a - c). Structural and phase changes near the tread are associated with the development of plastic shifts from the action of external loads (Fig. 1, d), thermal stresses during braking, and the formation of "white layers" when the metal is heated by the heat of braking and sharp cooling when the brakes are turned off (Fig. 1, e) [1 - 9].

The "white layer" areas are highly brittle and cracks often occur here. Due to the uneven distribution of contact stresses across the rim width [2, 3, 5, 9], plastic processes develop unevenly: the most intense plastic deformation was observed in the cove and the rim edge zone. The degree of grain elongation allows us to judge the degree of steel deformation in the surface layer of the rim. In the cove zone, the  $\epsilon$  values reach 60...65%, then decrease to 18...22% in the middle of the tread and increase again (up to 40%) in the rim edge zone.

At all stages of operation, the metal in the cove zone is the most stressed, and at later stages of service – in the bulge zone. Along the entire tread of worn wheels, microcracks and delaminations are found, leading to brittle fracture, primarily in the cove zone, which in practice causes massive undercuts of the wheel flanges. In the cove zone, brittle cracks appear due to localization of deformation (Fig. 1, f, g). In the bulge zone, delaminations oriented parallel to the rolling surface were found (Fig. 1, h), as well as cracks separating sections with different degrees of deformation (Fig. 1, i - l). In the presence of non-metallic inclusions, they become stress concentrators [10 - 18], and in the process of

## 2. Materials and Procedures.

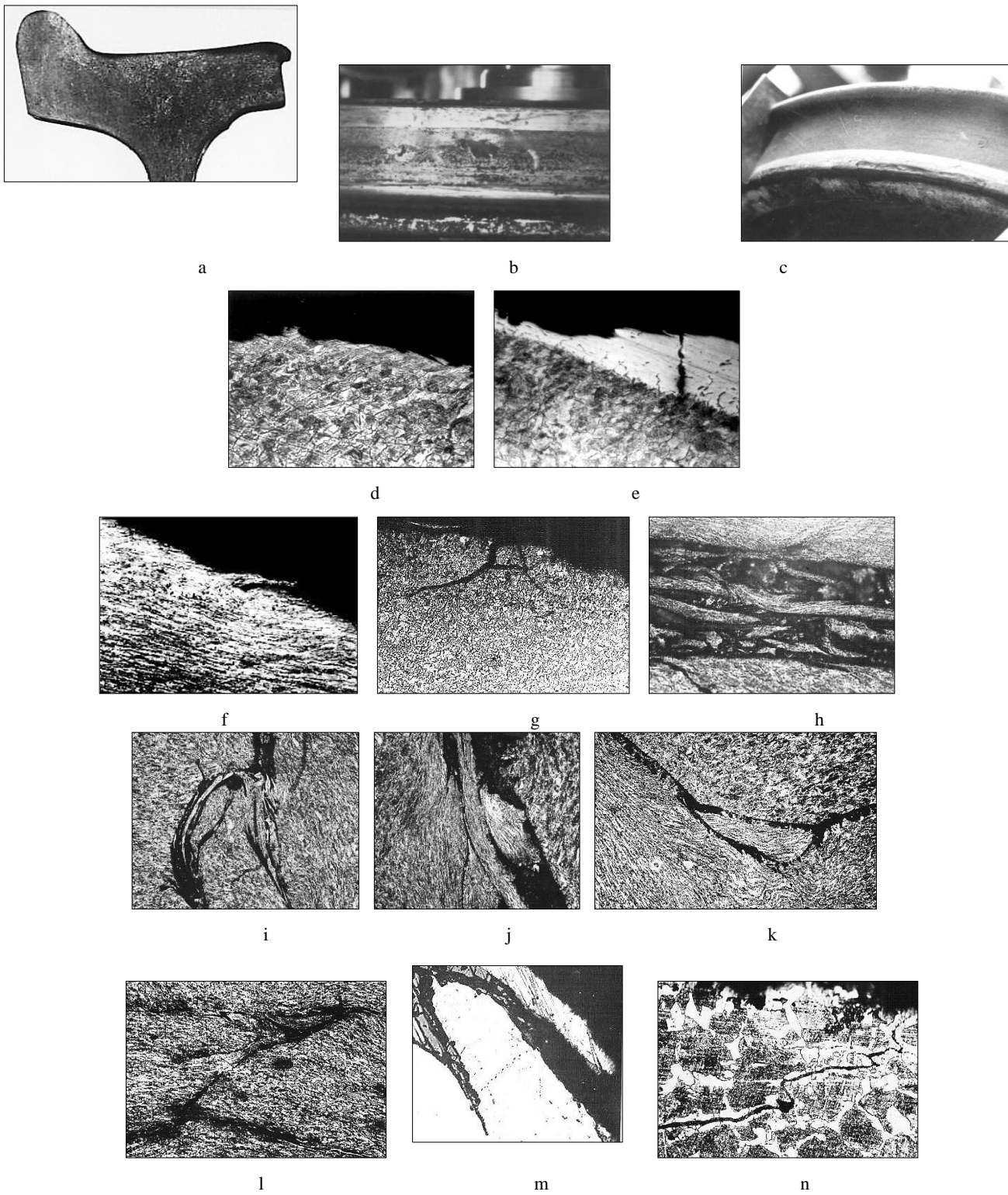
The wheels with different rolling surface profiles, which were removed from operation due to the maximum wear of the rims, were studied. The studies were carried out using the metallographic method (Neophot-31, scanning electron microscope JSM-35)

## 3. Results and discussion.

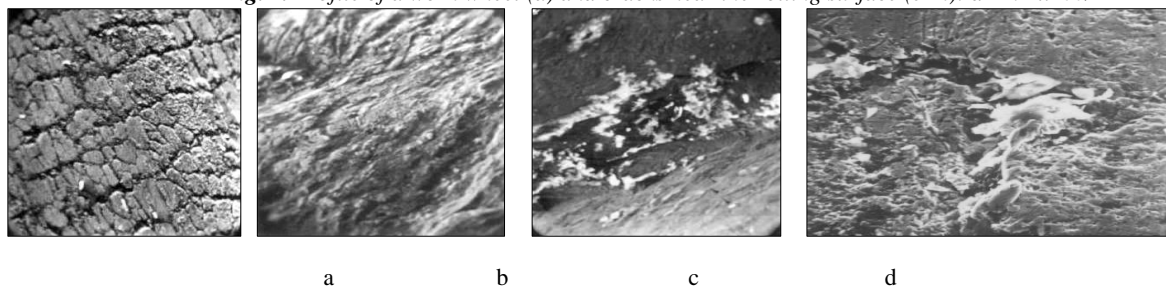
development of plastic shears they are the centers of crack initiation (Fig. 1, m). Cracks were also found on the side face of the rims (Fig. 1, n).

Fatigue processes are associated with the formation of a plastic deformation zone, "white layer" areas, as well as non-metallic inclusions and steel corrosion products near the tread of a railway wheel [19]. One of the main reasons for the formation of wear particles is the occurrence of plastic shear with a fairly high degree of deformation. Microcracks, delaminations, and wear particles (Fig. 3, a), which are flakes or plates of varying thickness, occur at the boundaries of zones with different degrees of deformation, as well as in areas of intense and turbulent deformation. flow of steel near the tread of the wheel. According to the theory of "flaking" wear, during friction, the maximum dislocation density occurs not directly on the surface, but at a certain depth, where extended microcracks appear (Fig. 3, b), which grow to a critical size as a result of plastic flow of steel. In the area between the cracks and the rolling surface, plastic flow of steel is localized and wear particles are formed in the form of flakes (Fig. 3, c - f), which peel off.

Table 1 shows the average values of the degree of deformation  $\epsilon$  (the degree of elongation of steel grains), the depth of the plastic deformation zone  $h$  and the density of dislocations  $\rho_{\perp}$  in different zones of the tread of wagon and locomotive wheels. Wagon wheels 1 and 2 had different profiles of tread. The values of the structural parameters indicate developed plastic shears near the rolling surface. Within each of the tread zones (cove, middle, overhang) the distribution of  $\epsilon$  is also non-uniform, which is obviously associated with the influence of new phases that have appeared ("white layer", corrosion products)



**Fig. 1.** Profile of a worn wheel (a) and cracks near the rolling surface (b–n): d – n - x200/



**Fig. 2.** Structure of different areas of the wheel tread and areas of corrosion on the rim surface (g); a - x110, b, c - x550, d - x200.

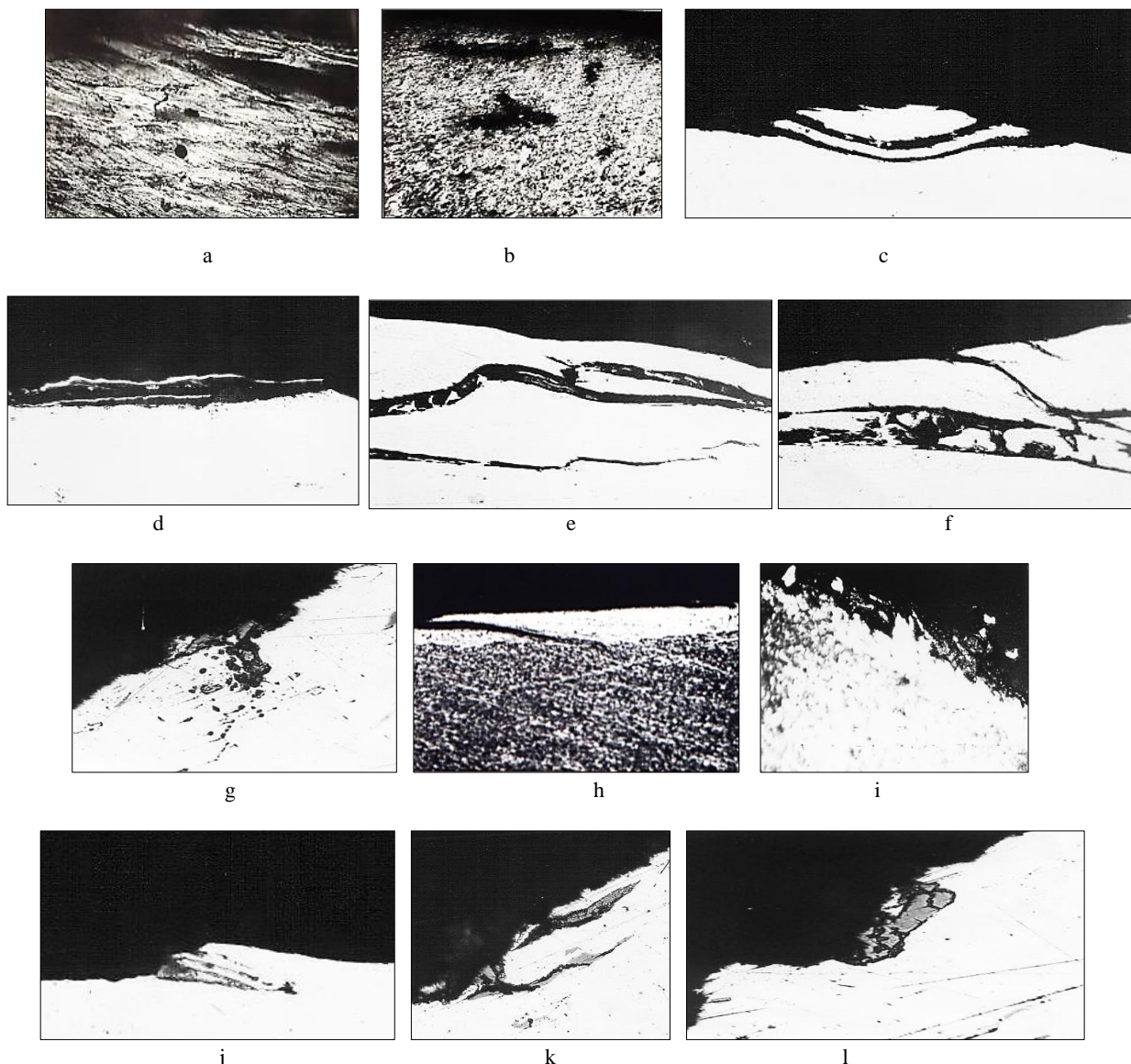


Fig. 3. Wear particles on the tread: x500, x1000.

Table 1. Parameters of structural changes in the surface layer: degree of deformation  $\epsilon$ , depth of deformation zone  $h$ , dislocation density  $\rho_L$

Parameters								
$\epsilon, \%$			$h, \text{MKM}$			$\rho_L, \text{cm}^{-2}$		
*1	2	3	1	2	3	1	2	3
In the areas of the wagon wheel 1								
65...75	22...25	90	300	30	600	$9,22 \cdot 10^{11}$	$3,73 \cdot 10^9$	$9,9 \cdot 10^{11}$
In the areas of the wagon wheel 2								
60...65	18...22	40	180...300	50...670	30...300	$9,3 \cdot 10^{11}$	$4,7 \cdot 10^{10}$	$6,7 \cdot 10^{10}$
In the areas of the locomotive wheel 3								
65	21	85	290	35	480	$5,4 \cdot 10^{11}$	$3,45 \cdot 10^9$	$7,1 \cdot 10^{11}$

\*1 – cove zone, 2 – middle of the tread, 3 – overhang zone

It is necessary to take into account the interaction of this surface with the surrounding atmosphere, leading to the formation of corrosion damage (Fig. 2, g). As noted in [20], the initial stage of corrosion (adsorption of atoms of elements from the surrounding humid environment) causes the effect of adsorption facilitation of plastic deformation near the wheel tread (P.A. Rebinder effect). Plasticization of the tread contributes to an acceptable change in the tread surface profile at the initial stages of wheel operation, which accelerates the so-called useful wear necessary to accelerate the running-in process in the wheel-rail system. For the formation of

surface defects (wear particles) under conditions of alternating stress, it is necessary to achieve the limiting state of strain hardening of steel, and this stage of deformation is accelerated by the action of a surface-active medium. Adsorption penetration of surface-active components leads to a decrease in the surface energy of cracks and facilitates their development - the P.A. Rebinder effect or adsorption decrease in strength [20, 21].

The second source of wear particles on the wheel tread is the so-called "white layer", which has increased brittleness (Fig. 3, h, i). Wear particles look like fragments with sharp edges of

irregular shape. The formation of cracks and wear particles is also facilitated by particles of non-metallic inclusions (Fig. 3, j, k), as well as products of corrosion of wheel steel (Fig. 2, d, Fig. 3, l). Near particles of corrosion products of wheel steel, wear particles have the form of loops, spirals, similar to chips during cutting. Such wear particles precede damage and are found mainly on the rolling

surface before local destruction [22]. In addition, melting of low-melting sulphide and silicate inclusions and their eutectics is possible during moments of high-speed heating of the tread during sudden braking of the rolling stock, which causes the manifestation of red brittleness and formation of wear particles (Fig. 4).

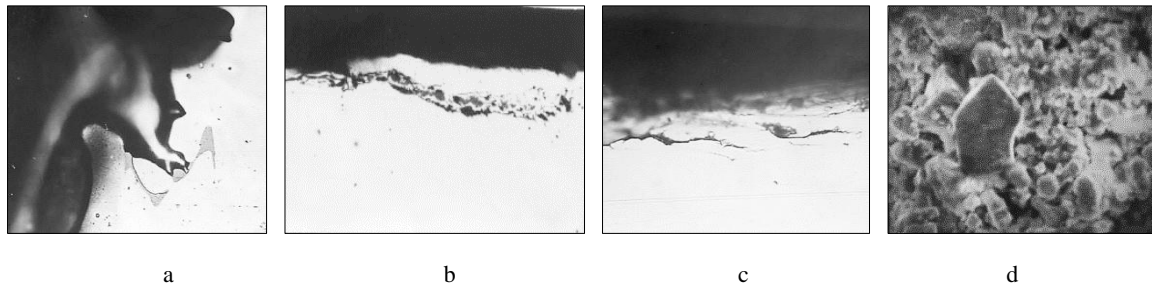


Fig. 4. Formation of wear particles in sulphide brittleness zones on the tread of railway wheels:  $\times 600$

#### 4. Conclusions.

A study of defects formation in rims near the tread of railway wheels made it possible to identify the causes of crack

formation and wear particles associated with phase and structural changes occurring during operation, as well as with the presence of non-metallic inclusions and corrosion products of wheel steel.

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