wear mechanism of railway wheels, plastic deformation, formation of "white layer"

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INVESTIGATION OF WEAR MECHANISM OF TREAD DURING OPERATION OF RAILWAY WHEELS

Summary. Causes of wear particles formation on railway wheels tread were investigated. Structural factors connecting with plastic deformation, formation of "white layer", and also with non-metallic inclusions and corrosive products of wheel steel, defining wear of railway wheels tread during operation were fixed.

ИССЛЕДОВАНИЕ МЕХАНИЗМА ИЗНОСА ПОВЕРХНОСТИ КАТАНИЯ В ПРОЦЕССЕ ЭКСПЛУАТАЦИИ ЖЕЛЕЗНОДОРОЖНЫХ КОЛЕС

Реферат. Исследованы причины образования частиц износа на поверхности катания железнодорожных колес. Установлены структурные факторы, связанные с пластической деформацией, образованием «белого слоя», неметаллическими включениями и определяющие износ поверхности катания железнодорожных колес в процессе эксплуатации.

1. INTRODUCTION

Complex approach for wear mechanism of railway wheels includes not only investigation of structural changes happening in surface layers of wheel rims [1, 2], but also analysis of wear particles and establishment of mechanism of their formation. Analysis of conditions of wear pairs operation allows to accept that common approach perhaps the idea about wear nature of fracture of surface layers [3]. Interest for investigation of wear mechanism connects not only with necessity of cutting down of wear losses but also with development of effective methods of prediction of wheels service life, and with ensuring of their operation especially in extreme conditions. Wear mechanism of railway wheels tread presents assemblage of mechanical, thermo-physical and chemical effects. It connects with wear particles and microcracks formation in areas of intensive plastic deformation and "white layer", near non-metallic inclusions and corrosive products of wheel steel [1, 2]. Influence of some structural changes on the wear of tread was discussed [1, 2, 4 - 7] but analysis of these processes on mechanisms of wear particles formation on railway wheels tread during operation was not conducted.

The aim of this work was investigation of mechanisms of wear particles formation on railway wheels tread during operation.

2. MATERIALS AND METHODS OF INVESTIGATION

Mechanism of wear of railway wheels made of steel R7 and operated about 5 years under passenger rolling stock was researched. Wheels were taken off operation by limit wear of rims. Microstructure of wheel steel and defects were investigated by a few methods: metallographical, micro X-ray spectral, X-ray diffraction analysis, electron microscopic.

3. INVESTIGATION RESULTS AND DISCUSSION

Analysis shown that along the whole railway wheels tread microcracks and separations resulting in formation and spalling of wear particles and brittle fracture of cove zone were discovered. Formation of wear particles has different causes. Shape of wear particles dependents on conditions of their formation.

One of main cause of wear particles formation is plastic shears proceeding near tread with big degree of deformation which has heterogeneous character [1, 2]. On the boundaries of zones with different degree of deformation and also in areas of intensive and turbulent deformation the microcracks (fig. 1, a) and wear particles (fig. 1, b) are formed. In cove zone the group of wear particles was formed that was evident about considerable localization of plastic deformation and results in fracture of crest.

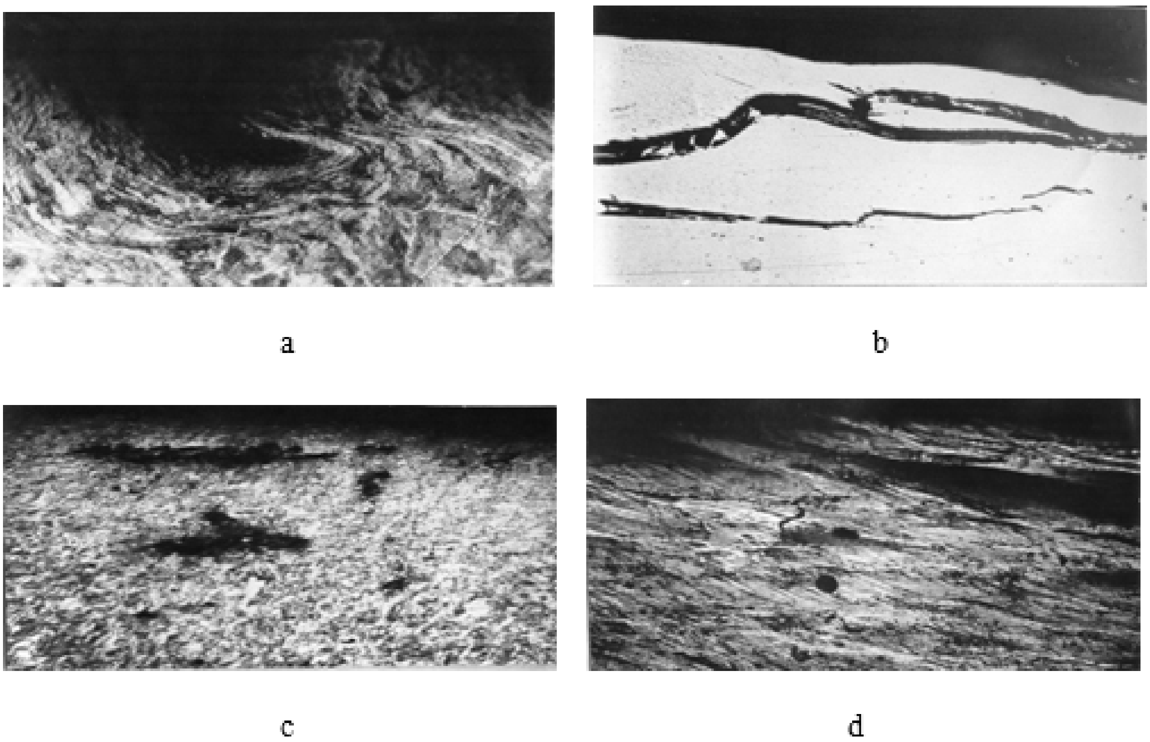


Fig. 1. Wear particles near tread in zone of intensive plastic deformation; a – x100, b – d –x200

Рис. 1. Частицы износа вблизи поверхности катания в зоне интенсивной пластической деформации; a – x100, b – d –x200

Wear particles formed on account of development of intensive plastic deformation near tread have the shape of scales or plates with different thickness. They are typical for normal conditions of wear [3]. According to wear theory by “spalling” [8] maximum dislocation density under wear origins is not near the surface but deep. Just microcracks growing to critical size in the results of plastic flow of steel are formed (fig. 1c, d). Plastic flow of steel are localized between microcracks and wheel tread and particles having shape of scales are formed and spalled. Formation of wear particles happens in the result of ductile spalled of metal in the time of coalescence of these microcracks and are accompanied by plastic flow of steel near wheel tread.

Data by definition of dislocation density on and near wheel tread citing in [1, 2] evidence about development of intensive plastic deformation during operation of railway wheels. Dislocation density was 10^{10} - 10^{11} cm^{-2} on wheel tread, but on the depth of 100-200 μm from wheel tread it was higher about in 2 – 3 time as compared with wheel tread. Such difference of dislocation density connects with going out of moving dislocations on free surface during plastic deformation. In addition to it is a known fact of "braiding" influence of surface (in our case it is wheel tread) on moving dislocations [8]. Wear stresses for wear particles with definite thickness near wheel tread were defined [9].

Examine of peculiarities of plastic deformation development in wheel steel near wheel tread it is essentially to take into account interaction of this surface with ambient air bring to formation of corrosive damages. It is known that the elementary stage of corrosion includes absorption of atoms of elements from damp ambient air that can evoke effect of absorptional relief of plastic deformation near wheel tread (Rehbinder effect) [10]. On the elementary period of operation of railway wheel this effect promotes burnishing of roughnesses on the wheel and rail surfaces and also permital changing of profile of wheel tread. This process accelerates useful wear which is necessary for acceleration of process of alignment in wheel-rail system. Further it is a necessary improvement to limit condition of deformational strengthening of steel for the formation of surface defects (wear particles). This stage of deformation is quickened under action of surface-reactive medium [10]. In the time of formation and spalling of wear particles the new "fresh" surfaces of cracks are appearing and these surfaces absorb atoms of elements from damp ambient air activelly. Absorption penetration of surface-reactive elements into cracks happens with high rate [10] that result in fall of surface energy of cracks (and work of their formation) and also makes easier their development in process of plastic deformation of steel. Thus damp ambient air contenting different soil dressings renders negative influence on the fatigue strength of wheel tread thanks to absorption and corrosive effects.

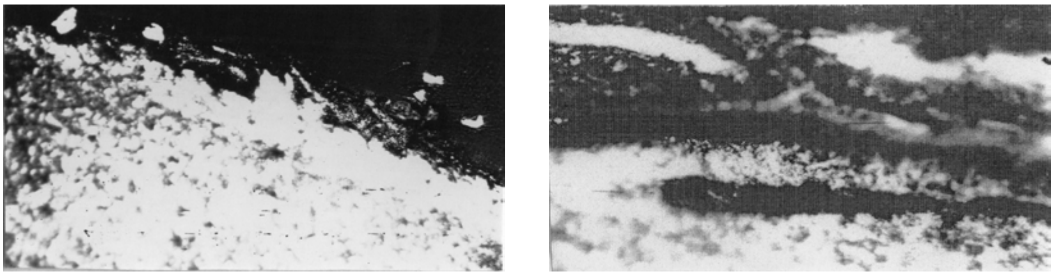
According to data [8] wear particles represent scales or plates with different thickness are formed when uniform distribution of dislocation is along their thickness. After formation of these scale-particles some of them get between two sliping treads of wheel and rail. In the results of they can be spinned with change of shape or fractured, or can remained their previous size and "flat" shape.

Wear of wheel tread accompanying by development of intensive plastic deformation happens by laminating and each layer consists of a big number of scales or wear particles. Their quantity N in each layer varies with number of microcracks forming under plastic deformation. Rate of coalescence of microcracks and critical deformation degree which necessary for formation of free wear particles depend on depth of plastic deformation zone with maximum dislocation density. General wear of tread under development of plastic deformation, sizes and level of roughness of wear particles and also rate of wear of tread were determined [9]. It was shown the rate of wear decreased when intensity of plastic deformation in surface layer of wheel rim decreased too.

Second source of wear particles formation on wheel tread is "white layer" which possesses big brittleness [1, 2]. Near areas of "white layer" localization of plastic deformation promoting stresses concentration and chipping of "white layer" was discovered. Wear particles have the shape of fractions with sharp edges (fig. 2a). Usually they arise under very high pressures and their appearance one can connect with formation of small fatigue cracks in surface layers of wheel rims [3].

It is necessary to note under brittle "white layer" steel is deformed plastically and on the boundary of these structural components the repulsive forces acting on moving dislocations are origined [8]**.** This can result in formation of microcracks both along boundary "white layer"-deformed structure of steel and on the same distance from it, analogous to microcracks shown on fig. 1c, and also parallel to wheel tread (fig, 2b). For transformation of such microcracks into wear particles reasoning about plastic deformation citing above are just.

Third cause of wear particles formation is non-metallic inclusions which have metallurgical origin and are concentrators of stresses and deformations in wheel steel [10]. Oxidation and corrosive fracture of wheel tread also promote formation of cracks and wear particles. These processes result in formation of coarse inclusions of composite oxides on wheel tread. Presence of inclusions and corrosive products essentially raise rates of formation and coalescence of microcracks that raise intensity of wear (both fatigue and under friction) [10].



a b

Fig. 2. Wear particles in areas of “white layer”; x1000
Рис. 2. Частицы износа в областях «белого слоя»; x1000

Analysis of microstructure of wheel steel near wheel tread shown non-metallic inclusions and corrosive products promote heterogeneous development of deformation and appearance of turbulent flow zones (fig. 3a) and also promote formation of zones with high deformation degree. Behaviour of non-metallic inclusions presence in steel layer near wheel tread under working stresses depends on their type [11]. They are non-deformed (oxides, silicates, carbo-nitrides) or ductile (sulphides). Non-metallic inclusion presencing in steel layer near wheel tread is been in the composite stress condition defining by system of contact, dynamic and cyclic stresses. Temperature gradient appearing during operation of wheel near treads results in heterogeneous distribution of deformations in steel matrix and also of forces acting on non-metallic inclusion.

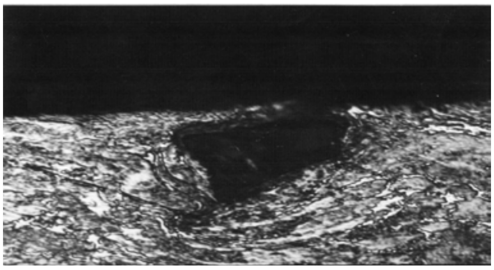
In conditions of high presures and cyclic temperatures the interaction between contact surfaces of non-metallic inclusion and steel matrix happens by establishment of mechanical contact and development of diffusional processes.

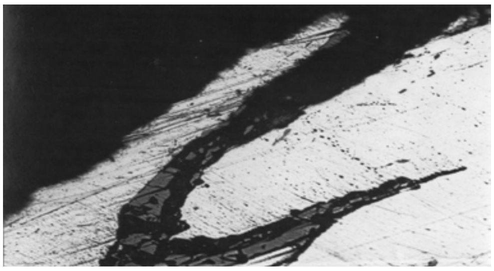
Mechanical contact is established in result of burnishing of roughnesses of surfaces of inclusion and wheel steel matrix by development of contact friction of their surfaces relative to each other preventing their relative moving. Such friction is kinematic dry sliding friction [11].

Conditions of friction on interphase boundaries non-metallic inclusion-steel matrix were analysed [9]. Contact friction intensifes the heterogeneity of deformation of wheel steel matrix near non-metallic inclusions which can influence not only on stresses level but also on the sheme of stress condition in these areas [11]. In the result of contact interaction between non-metallic inclusions and steel matrix it is possible the rotation of inclusions (fig. 3a) causing moment stresses and promoting local plastic rotations and flow in steel matrix.

In process of joint deformation of non-metallic inclusion-steel matrix system characteristic fiber grain structure of wheel steel near tread was formed (fig. 3a). Fibers of steel matrix bend non-metallic inclusion (fig. 3b) and it is possible separation along interphase boundaries inclusion-matrix (fig. 3c). On interphase boundaries inclusion-matrix compression and shear stresses are concentrated which is capable of fracture of non-metallic inclusions if these stresses are higher than compressive strength of inclusions (fig. 3b).

Under special braking in the condition of abrupt rise of temperature it is necessary to take into account possible influence of grain slip along intergranular boundaries in austenite and along interphase boundaries inclusion-steel matrix in deformation development near wheel tread [11]. Non-metallic inclusions often are the centres of local decarburization of steel promoting structural heterogeneity and heterogeneous development of plastic shears and also formation of microcracks and wear particles.





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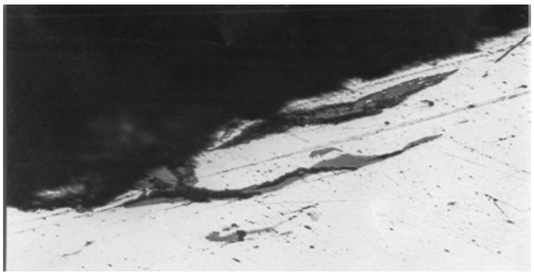
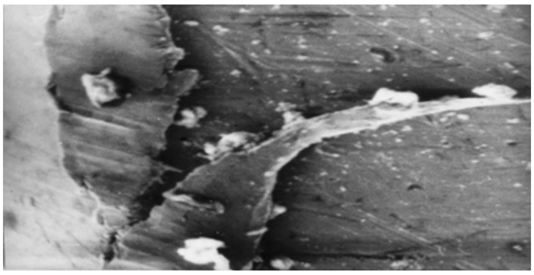




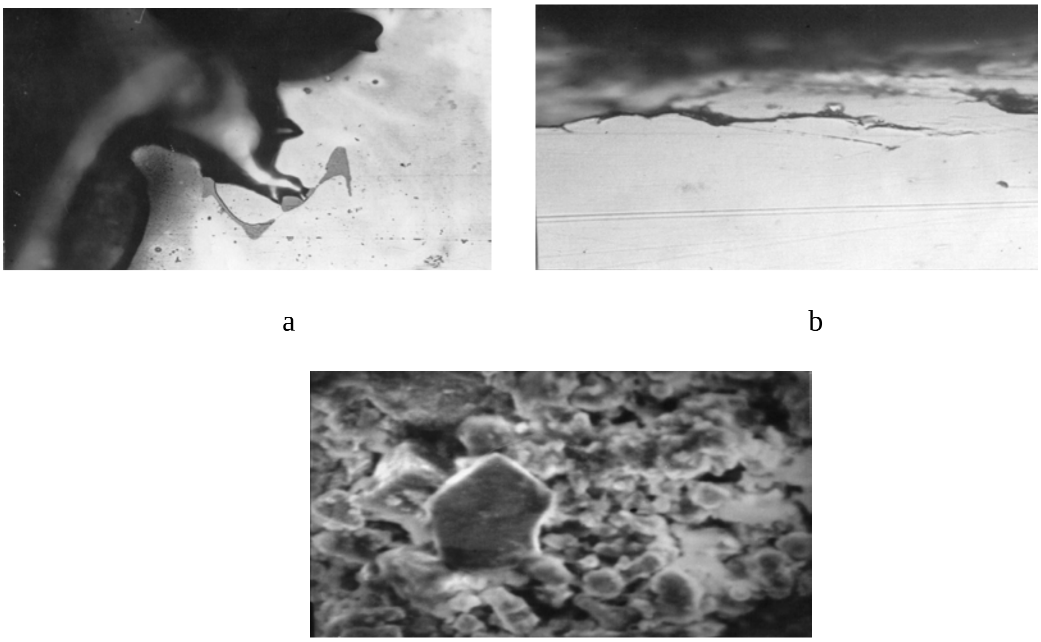
c d

Fig. 3. Localization of deformation (a) and formation of wear particles near non-metallic inclusions and corrosive products of wheel steel (b – d) on railway wheel tread: a, b –x400, c, d – x200

Рис. 3. Локализация деформации (а) и формирование частиц износа вблизи неметаллических включений и продуктов коррозии колесной стали (б-г) на поверхности катания железнодорожных колес: a, b –x400, c, d – x200

It is necessary to examine the influence of low-melting non-metallic inclusions on wear particles formation near railway wheel tread in the conditions of special braking and local heating-up to temperatures corresponding to austenite area of steel when fusion or melting of low-melting iron-manganese sulphides and sulphide eutectics can happen [11]. Then local sulphide red brittleness can happen and ductility and strength of wheel steel are decreased [11]. If wheel tread heats up to high temperatures sulphide inclusions are melted (fig. 4a), abrupt localization of deformation of steel happens and a great number of cracks are arising. Fracture of steel happens by achievement of relatively small deformation degrees. Liquid interlayers are stretched parallel to wheel tread (fig. 4b). Between these interlayers microckacks are spreading that promotes formation of wear particles.

Wear particles near non-metallic inclusions and corrosive products of wheel steel have shape of loops or spirals analogous to chips under cutting (fig. 3d). They have such shape owing to residual stresses connecting with heterogeneous distribution of dislocations along thickness of wear particles forming near non-metallic inclusions [8]. By the work [3] such wear particles come before to damage and are turned up mainly on wheel tread before local fracture. In the cause of local sulphide red brittleness in areas of wheel tread where melting of sulphide inclusions happens a great number of wear particles with spirals and compact irregular shape were observed (fig. 4c). This connects with presence of a great number of microcracks in these areas and also with grinding of wear particles by tough localization of deformation.



a b

c

Fig. 4. Formation of wear particles in zones of sulphide red brittleness on railway wheels tread; x600
Рис. 4. Образование частиц износа в зонах сульфидной красноломкости на поверхности катания железнодорожных колес; x600

Examining the influence of corrosive products of wheel steel on wear particles formation it is necessary to take into account influence of damp ambient air on development of fatigue fracture of wheel tread. As stated above the elementary stage of corrosion includes absorption of atoms of elements from damp ambient air that can evoke effect of absorptional relief of strength (Rehbinder effect) [10]. Plastic shears arising in surface layer of wheel rim (near tread) and thermocyclic processes during braking and also interaction with damp ambient air create conditions for intensive development of diffusive processes which promote more intensive absorption of atoms of elements from damp ambient air. On railway wheel tread absorption-fatigue phenomenons take place resulting in formation of fatigue cracks and wear particles and also accompanying their growth and spalling [3]. Presence of interphase boundaries non-metallic inclusion-steel matrix with their defect structure and interphase stresses [10], and also formation of interphase microcracks promote localization of displaying of effect of absorptional relief of railway wheel tread strength near non-metallic inclusions. This effect is characterized by lowering of work of formation of new surfaces in solid body in the process of plastic deformation and fracture under influence of absorptional layer formation [10]. Apparently such interpretation of effect of absorptional relief of railway wheel read strength is actual for interphase boundaries non-metallic inclusion-steel matrix. This connects with origin of wedging out forces in these boundaries which promote penetration of absorption layer on depth from tread [10]. That promotes spalling of non-metallic inclusions from steel matrix and formation of wear particles.

4. CONCLUSIONS

Repeating heat-mechanical action on railway wheel tread by interaction between wheel and rail promotes incandescence of stresses and defects (microcracks, separations) that promotes wear particles formation having different shape, source and mechanism of nucleation:

- More wide-spread wear particles are the scales or plates with different thickness. Formation of such wear scales happens in the result of ductile spalling of metal. They are typical for normal conditions of wear and their appearance connects with plastic deformation near wheel tread.
- By brittle fracture of areas of “white layer” wear particles are formed with shape of fractions with sharp edges. Their appearance one can connect with formation of fatigue microcracks in surface layers of wheel rims. Spreading of fatigue microcracks to surface is the beginning of wear particles formation.
- Wear particles near non-metallic inclusions and corrosive products of wheel steel have shape of loops or spirals. They are formed by localization of deformation near inclusions and galling of metal matrix on the inclusions and also in the results of separation of interphase boundaries non-metallic inclusion-steel matrix. Such wear particles are discovered on wheel tread before local fracture.
- In the cause of local sulphide red brittleness a great number of wear particles with spirals and compact irregular shape were observed. This connects with presence of a great number of microcracks in these areas and also with grinding of wear particles by tough localization of deformation.

Results of analysis of microcracks, spalles and wear particles and also of mechanisms of their formation was shown that wear of railway wheel tread is a very composite phenomenon. It passes by few mechanisms (fatigue, absorbtional, corrosive, under friction) and is multifactors process.

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