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SOME PECULIARITIES OF CORROSION OF WHEEL STEEL

Summary. Corrosion mechanism and rate of different chemical composition and structural condition of wheel steel were investigated. It was shown that "white layers", variation in grain size and banding of wheel steel structure results in corrosion rate. Microstructure of steel from different elements of railway wheels after operation with corrosion was investigated. Wheel steel with addition of vanadium corroded more quickly than steel without vanadium. Non-metallic inclusions are the centre of corrosion nucleation and their influence on corrosion depends on type of inclusion. Mechanism of corrosion of wheel steel corrosion was discussed.

НЕКОТОРЫЕ ОСОБЕННОСТИ КОРРОЗИИ КОЛЕСНОЙ СТАЛИ

Аннотация. Исследованы механизм и скорость коррозии колесной стали с разными химическим составом и микроструктурой. Показано, что «белые слои», разнотернистость и полосчатость структуры колесной стали влияют на скорость коррозии. Изучена микроструктура стали с участками коррозии в различных элементах железнодорожных колес после эксплуатации. Колесная сталь, микролегированная ванадием, корродировала быстрее, чем сталь без добавки ванадия. Неметаллические включения являются центрами зарождения коррозии и их влияние на ее развитие зависит от типа включения. Обсуждается механизм коррозии колесной стали.

1. INTRODUCTION

Operation and transportation of railway wheels are realized without effective anticorrosion protection. Increase of influence of environment aggressive factors by large industrial centres becomes an acute problem preventing corrosion fracture of railway wheels.

Railway wheels are exposed to corrosion during operation. Corrosion fracture of steel promotes embrittlement of wheels. Corrosion of different parts of railway wheel takes place in dynamic and static conditions (atmospheric, wet, soil, gas, sea-water, stress, fretting, stray-current corrosion). Task of this work is to compare investigation of corrosion rate of wheel steel with different structure from different elements of wheels after hot deformation, heat treatment and operation.

2. MATERIALS AND METHODS OF INVESTIGATION

Microstructural research of wheel after operation was done. Structural changes near tread were researched in worn-out wheel 1. The zones of corrosion in different parts of wheel 1 and non-operated wheel 3 were studied. Selection of specimen for corrosion tests were realized from different parts of tread, rim and disk of wheels 1 and 2 after operation (5 years), non-operated wheels 3 and 4. Wheel 4 was produced from steel with microalloying of vanadium, wheels 1 – 3 were from usual wheel steel. Chemical compositions of wheels are given in Table 1.

Table 1

Chemical composition of wheel steels

Wheel №	Contents of elements, %								
	C	Mn	Si	S	P	Cr	Ni	Cu	V
1	0,59	0,72	0,34	0,025	0,012	0,14	0,15	0,20	-
2	0,65	0,79	0,36	0,027	0,010	0,13	0,18	0,18	-
3	0,61	0,78	0,30	0,029	0,024	0,17	0,15	0,16	-
4	0,46	1,04	0,47	0,024	0,018	0,09	0,11	0,18	0,10

Accelerate corrosion tests were carried out by special camera with moist atmosphere contained 10 mg/m³ SO₂, also NO, NO₂ at temperature 20-25⁰C, time 25 days. These conditions are coincided with industry atmosphere [1], but in another operation conditions atmosphere may be aggressive too by wet, soil, sea water, etc. Before corrosion tests specimens were weighed and all their faces were covered by paraffin but one of them was exposed to corrosion.

Microstructure of corrosion zones of wheel steel before and after operation of railway wheels and also after hot deformation and heat treatment was investigated with optical microscope “Neohpot-21” and scanning microscope JSM-35.

3. INVESTIGATION RESULTS AND DISCUSSION

Examination of wheels 1 and 2 after operation was shown that many parts of their surface are covered by rust. Oxidation of steel takes place on tread, disk, hub. The particles of oxides were discovered by metallographic research (Fig. 1). Oxidation of steel started from surface and penetrated to considerable depth. Thus long operation of railway wheels allows show big sections of corrosion. Investigation of non-operated wheel 3 also was allowed small sections of corrosion in different parts of wheel. These zones are the ready centre of corrosion fracture during operation of railway wheels.

It is interesting the role of research of corrosion processes in the development of structural changes near tread during operation of railway wheels. Macrostructural analyses of wheel 1 with heavy worn-out tread were discovered fatigue-corrosion wear accompanied distorting of tread profile. Lots of cracks with corrosion of steel were shown from the slider to depth parts of wheel. Microstructure of wheel rim near tread is characterized by presence of deformed grains zone and also sections of “white layer” (Fig. 2) [2]. The depth of the “white layer” is 20-40 mkm, it has a break off character by flaking during operation of railway wheel. In cove zone the grains of steel are considerably elongated and refined (Fig. 2a), but the passage to tread grains are bigger, degree of their elongation is far and on the middle of tread their elongation is still less (Fig. 2b). By the passage from the middle of tread to the border of rim degree of grain elongation is increased again and stayed considerable. Character of structure of steel in this part of tread evidences about considerable flow of steel assisted to change of profile of railway wheel [2]. In roll zone the separations parallel oriented to tread with creaks were discovered (Fig. 2c). As a rule they are disposed on the boundary between

areas with different microstructure of steel and are divided zones of elongated and equiaxed grains. Roll took place by layers of metal which were deformed during shifting. In the time of shifting the brittle cracks were originated which promoted fracture of metal in layers. At the end of roll on the rim side lobes with strong deformed structure were disposed (Fig. 2d). There also are evidenced about lamellar mechanism of roll of metal from the middle part of tread to border of rim. Between these layers and also between roll metal and side of rim lots of cracks are shown. By the investigation of steel structure in the plane parallel tread the signs of turbulent flow of metal layers in roll zone were discovered (Fig. 2e).

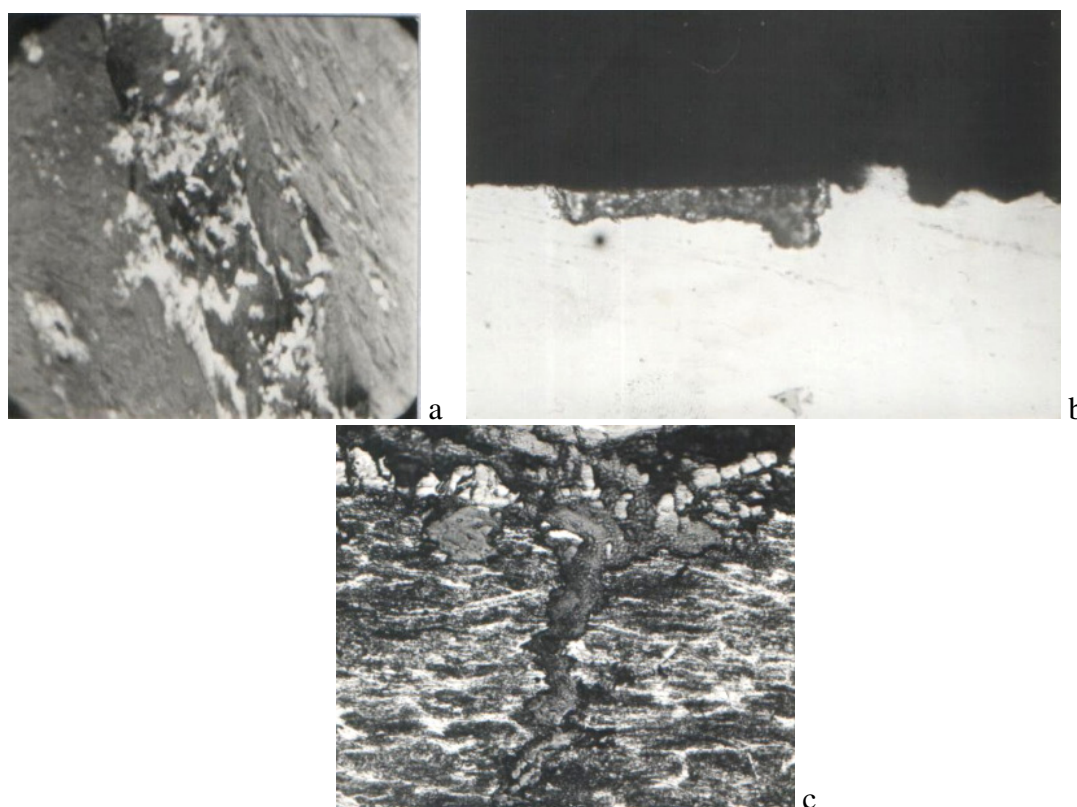


Fig. 1. Sections of corrosion in railway wheels 1: a – x100, b,c –x500

Рис. 1. Участки коррозии в железнодорожном колесе 1: а –x100, б,в –x500

Zone of plastic deformation is heterogeneous by depth and degree of elongation of grains. In cove zone degree of deformation ε is about 65-75%, by the passage to the middle of tread ε is decreased to 22-25% and considerably increased in the roll zone – to 90%. Appearance of deformed grains zone connects with bearing strain of metal in the contact with rail. Plastic shears in thin surface layer were took place in the conditions of high pressure and cyclically change of temperature. Character of microstructure of steel is evidenced about heterogeneous plastic deformation along section of rim connected with heterogeneous distribution of contact stresses: it is known in cove zone they are higher than in the middle of tread [2,3].

Analyses of metallography investigation results allow to accept that structural changes happened near tread of railway wheel are accompanied by corrosion. Zones of corrosion fracture were discovered along section of rim in areas with strong deformed structure also in areas of “white layer” (Fig. 2a). By the roll formation on the side of rim when thin layers of steel are removed to side of rim and disposed one over another the areas with oxidated surface of steel are found in internal parts of rim (Fig. 2c, d) and they are arranged between layers of deformed metal (Fig. 2e). Evidently presence of large oxide particles promotes not only to local fracture of tread areas but also to heterogeneous development of structural changes in thin layer of metal.

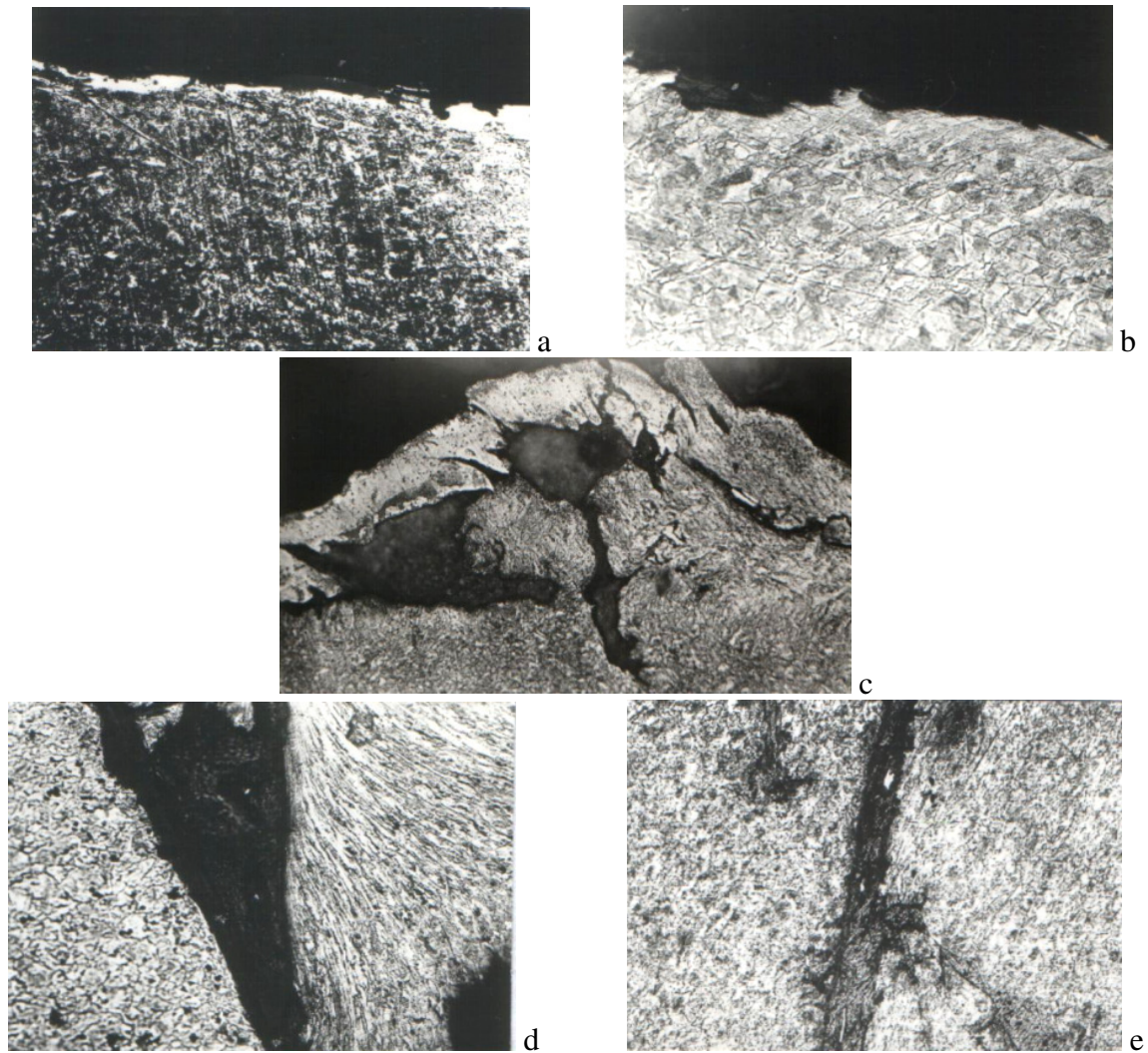


Fig. 2. Sections of corrosion near tread of railway wheel 1 after operation: x500

Рис. 2. Участки коррозии вблизи поверхности катания колеса 1 после эксплуатации: x500

Structural changes happened near tread showed different behaviour of wheel steel by corrosion tests. Specimens from shabby wheels 1 and 2 were exposed to corrosion tests. Specimens from wheels 1 corroded at different rate which was decreased from cove zone along rim width and only near end of tread in the roll zone it again was increased (Fig. 3, curve 1). Thin parts of “white layer” corroded very quickly and were not discovered in structure of steel.

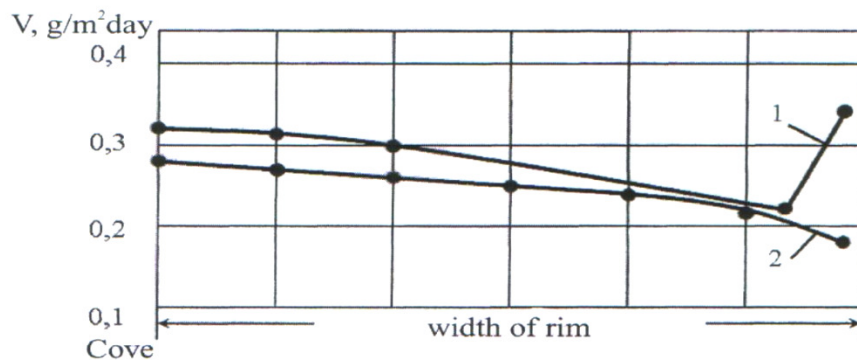


Fig. 3. Change of corrosion rate V of specimens of wheel steel from tread along width of wheels 1 and 2 rims

Рис. 3. Изменение скорости коррозии V образцов колесной стали от поверхности катания по ширине обода колес 1 и 2

Change of corrosion rate and mechanism is obviously connected with change of character of plastic shear zone. In cove zone where grains are elongated and thin layer of steel was strongly deformed corrosion rate was maximum. Numerous small (< 20 mcm) oval corrosion centre of localized corrosion were discovered (Fig. 4a), which were penetrated to considerable depth. In the time of corrosion the layer of elongated grains almost fully disappeared. Maximum corrosion rate in the cove zone are explained by influence of plastic deformation created stresses in metal. In the middle of tread character of corrosion was changed (Fig. 4b). Along surface of specimens porosity corrosion film was formed and microcracks near oxides were discovered. Corrosion rate of specimens from the middle of tread and along to side of rim is essentially lower. In roll zone corrosion rate was increased again (Fig. 3, curve 1), and large pitting corrosion centres were discovered (Fig. 4c). Their average size was 0,6 mm. Increase of corrosion rate of wheel steel in roll zone is explained by influence of considerable plastic deformation and also by the presence of cracks between layers of rolling metal. Corrosion centres in roll zone are considerably larger than in cove zone. Thus heterogeneous plastic deformation along rim which took place during operation of railway wheels promotes to heterogeneous corrosion fracture of tread.

Specimens from shabby wheel 2 also were corroded with different rate which was monotonously decreased from cove zone along width of rim (Fig. 3, curve 2). "White layer" was pitting by pitting corrosion practically on all the depth (Fig. 5a). In areas with base structure of steel (pearlite + ferrite) and small zones of "white layer" corrosion started on the surface and penetrated deep into steel by cracks (Fig. 5b) or by compact front (Fig 5c). From the corrosion areas microcracks were penetrated into interface boundaries ferrite-pearlite and also by pearlite, which has well-developed interface boundaries ferrite-cementite.

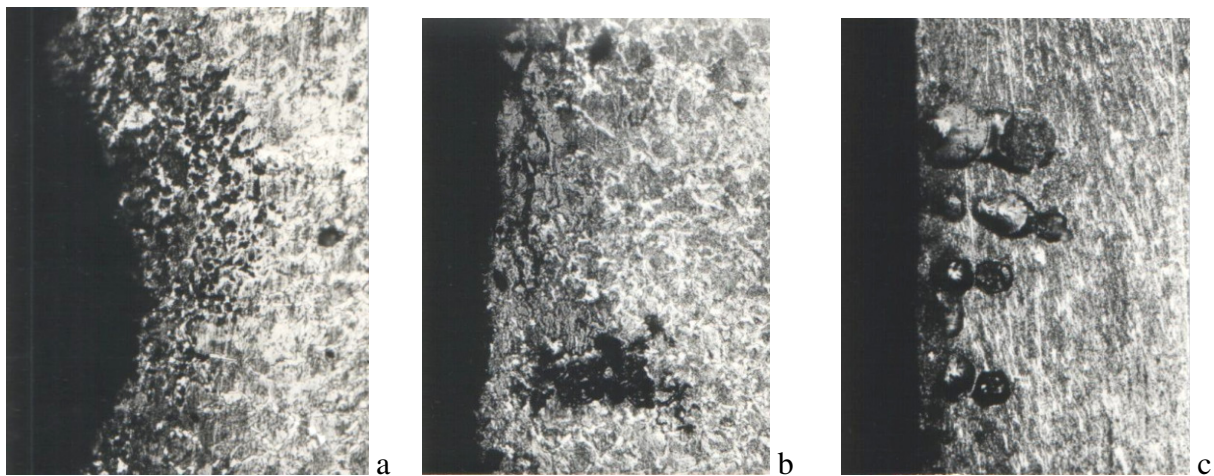


Fig. 4. Microstructure of wheel steel (wheel 1) after corrosion tests in different parts of tread along width of rim: x200

Рис. 4. Микроструктура колесной стали (колесо 1) после коррозионных испытаний различных участков поверхности катания по ширине обода: x200

Corrosion of specimens from centre part of rims of wheels 1 and 2 took place by formation of large centres of oxidation of steel (Fig. 6a, b). Corrosion centres were formed on the surface of specimens and then were penetrated into depth of specimens and were grown by width to contact one another. Under corrosion in oxides and on the interface boundaries oxide-steel structural and phase stresses and microcracks were beginning. Sizes of corrosion centres in these cases are 1-2 mm. Corrosion rate of rim metal of wheels 1 and 2 possessed ferrite-pearlite structure are approximately the same and was higher than corrosion rate of steel from tread (Tabl. 2).

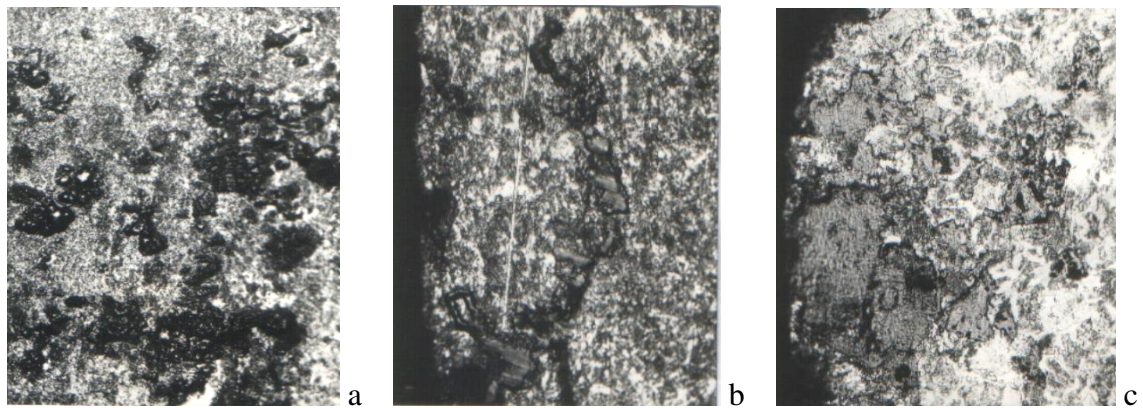


Fig. 5. Microstructure of wheel steel (wheel 2) after corrosion tests in different parts of tread along width of rim: x400

Рис. 5. Микроструктура колесной стали (колесо 2) после коррозионных испытаний различных участков поверхности катания по ширине обода: x200

Metal disk corroded more quickly than metal of central part of rim (Tabl. 2). Corrosion process was spreading along pearlite areas (Fig. 6c), and also along ferrite-pearlite boundaries. Kind of corrosion damages of metal from rim and disk is different: in the first case small corrosion centres were discovered, in second case large corrosion centres were discovered. From corrosion centres intercrystalline cracks were spreading along pearlite and ferrite-pearlite boundaries. Corrosion rate of specimens from disk of wheel 1 was a little higher than corrosion rate of disk of wheel 2.

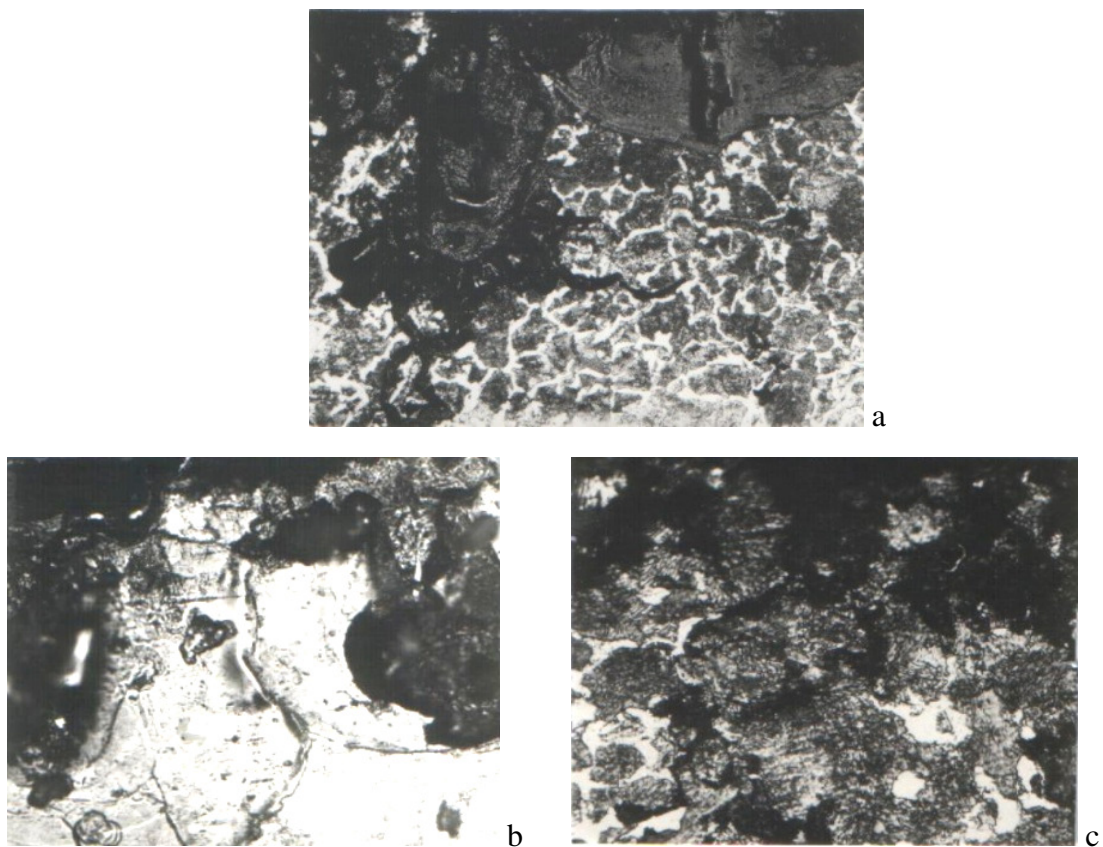


Fig. 6. Microstructure of specimens from centre part of rims of wheel 1 (a) and 2 (b) and also from disk of wheel 2 (c): a, c – x400, b – x200

Рис. 6. Микроструктура образцов из центральной части ободьев колеса 1 (а) и 2 (б) и из диска колеса 2 (в): а, в – x400, б – x200

Corrosion of specimens from tread of heat treated wheels 3 and 4 (with addition of vanadium) having structure of sorbite of tempering had lamellar or film character. Specimens from centre part of rim of wheels 3 and 4 had the same character of corrosion (Fig. 7a, b). Brittle cracks were spreading from porosity oxides to steel. Steel with addition of vanadium corroded more quickly than ordinary wheel steel (Tabl. 2). It is known vanadium promotes to decrease of corrosion resistance of steel and influence of manganese is the same [1]. The tread after heat treatment corroded more quickly than tread after operation.

Corrosion of specimens from centre part of rims of wheels 3 and 4 had pitting character with small corrosion centres and cracks were spreading by pearlite. Steel with addition of vanadium corroded more quickly than ordinary wheel steel (Tabl. 2).

It is known steels with martensite structure have a little corrosion resistance [1]. By heat treatment in martensite structure considerable stresses are formed which decrease corrosion resistance of steels. Also martensite structure decreases the resistance of brittle fracture of steels. So martensite structure is inadmissible in railway wheels.

Table 2

Results of corrosion tests of wheel steels

Wheel №	Place of specimens selection	Microstructure of wheel steel	Corrosion index		h, mcm
			$K_1, g/cm^2$	$K_2, g/m^2.h$	
1	middle of tread after operation	elongated grains of ferrite and pearlite	24,058	0,408	222
2		“white layer”	22,9643	0,359	204
1	centre part of rim after operation	equiaxed grains of ferrite and pearlite	13,30	0,225	140
2		equiaxed grains of ferrite and pearlite	17,0642	0,289	125
1	disk after operation	ferrite and pearlite, banding	21,7702	0,389	166
2		ferrite and pearlite, no banding	22,8889	0,368	159
4	tread after heat treatment	sorbite of tempering	17,8182	0,302	148
4	centre part of rim after heat treatment	ferrite and pearlite	18,8102	0,319	167
3	tread after heat treatment	sorbite of tempering	19,6316	0,327	115
3	centre part of rim after heat treatment	ferrite and pearlite	24,069	0,401	138

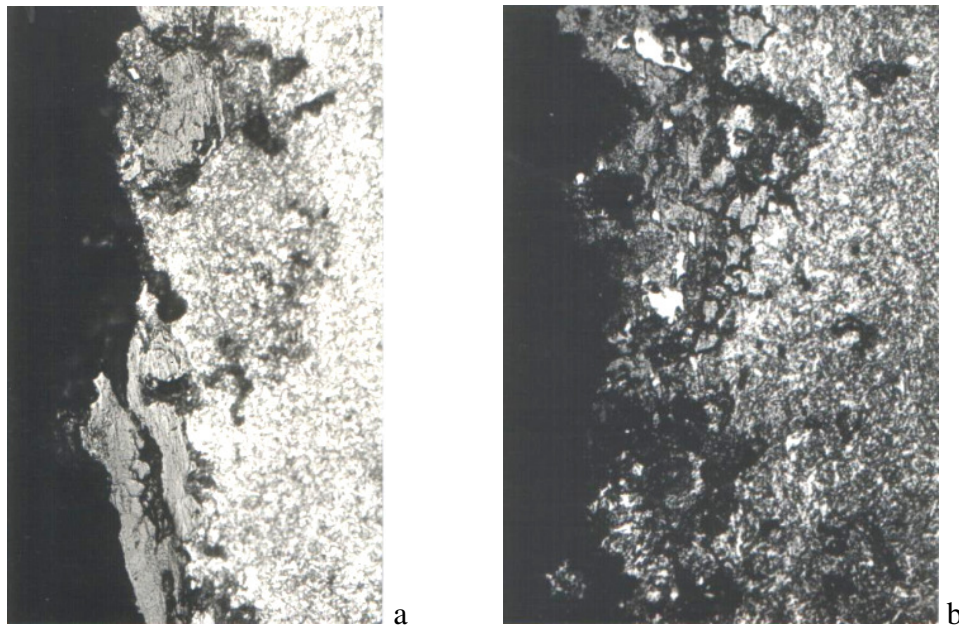


Fig. 7. Microstructure of surface of wheel steel specimens with addition of vanadium (a) and ordinary wheel steel (b) after corrosion tests: x200

Рис. 7. Микроструктура поверхности образцов колесной стали с добавкой ванадия (а) и обычной колесной стали (б) после коррозионных испытаний: x200

Investigation of corrosion product of wheel steel was discovered the heterogeneous structure of powder. Upper part is white powder – hydrate $\text{Fe}(\text{OH})_2$, under it - red rust containing $\text{Fe}_{\text{com}}-48,25\%$, $\text{Mn}-0,37\%$, $\text{C}-2,87\%$.

Different corrosion rate of wheel steel is explained by its different structural state. In worn-out railway wheels tread corroded more quickly than metal from centre part of rim. This is explained by influence of stresses creating plastic deformation in thin surface layer. Areas of “white layer” on the tread promote delay of corrosion. This connect with ultradisperse structure of “white layer” [2,3]. Metal from disk corroded more quickly than metal from centre part of rim thanks to more coarse ferrite-pearlite structure of disk and also ferrite banding of steel structure.

In heat treated railway wheels tread corroded more slowly than metal from centre part of rim. This connect with more disperse ferrite-pearlite steel structure of tread after heat treatment. Microaddition of vanadium promoted acceleration of corrosion of tread and metal from centre part of rim.

Principles of wheel steel structure influence on the corrosion rate are confirmed also by results of definition of the depth of corrosion penetration h from surface to specimens having different microstructure (Tabl. 2). Average value of h was determined from the depth of all researching corrosion zones by metallography method. By analysis of these results it is necessary to take into value of h are cited for middle part of tread after operation of wheels 1 and 2. But in cove zone of wheel 1 value of h was 342 mcm, in roll zone – about 600 mcm.

Thus corrosion rate is smaller when structure of the wheel steel is more disperse. Coarse-graininess, variation in grain size and banding of wheel steel structure promote increase of corrosion rate.

Research of corrosion areas in railway wheels after operation and heat treatment before operation shows a big influence of non-metallic inclusions on process of corrosion. One of the main factors defining corrosion behaviour of wheel steel is electro-chemical heterogeneity of railway wheel surface. Presence of non-metallic inclusions differing from steel matrix by physical-chemical properties results in corrosion microcells and reinforcement of electro-chemical heterogeneity of railway wheel surface. In wheel steel oxides Al_2O_3 , $\text{MnO}\cdot\text{Al}_2\text{O}_3$, $(\text{Fe},\text{Mn})\text{O}$, sulphides $(\text{Fe},\text{Mn})\text{S}$, silicates SiO_2 , $\text{MnO}\cdot\text{SiO}_2$, $\text{FeO}\cdot\text{SiO}_2$ and carbonitrides TiCN are present. All these non-metallic inclusions are cathodes by relation to metal matrix and they are arranged in order to decrease of the

value of electrode potential difference of wheel steel surface near non-metallic inclusions in decreasing series: sulphides, corundum, silica, nitride of titanium. Increasing series by electrical resistance of non-metallic inclusions is the same.

It is known that considerable thermal and deformational stresses causing by different physical-mechanical properties of non-metallic inclusions and steel matrix are excited near these particles [4, 5]. Stresses are formed on different stages of railway wheels production. Concentration of stresses promotes reinforcement of corrosion damage for all kinds of non-metallic inclusions. Especially it is displayed by application of external stresses. In our research the nucleation and localization of corrosion fracture of wheel steel was observed near different kinds of non-metallic inclusions in worn-out railway wheels and also in heat treated railway wheels (Fig. 8).

Thus metallurgical factor namely contaminant of wheel steel by non-metallic inclusions is very important in the problem of corrosion fracture of railway wheels.

Corrosion is very dangerous for reliability and service life of railway wheels. It is known by tests in air, the time for nucleation of fatigue crack on the surface of metal can compose till 90% from common service life of metal article but corrosion promotes shortening of its share till 10% [6]. Chemical energy releasing in results of corrosion can compose effective surface energy necessary for nucleation of crack. Wear-resistance of tread depends on surface condition. Formation of oxides on the tread by corrosion of steel changes properties of this surface (strength, plasticity, wear-resistance) and influence on the condition of interaction between railway wheel and rail during operation.

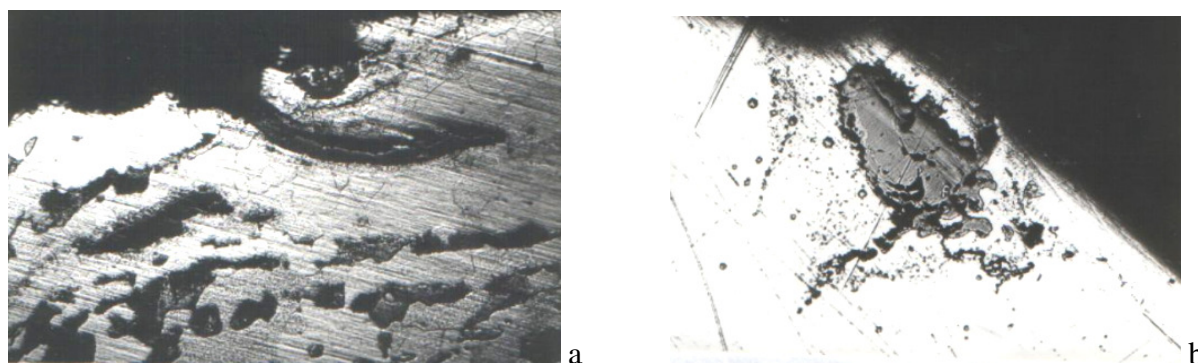


Fig. 8. Corrosion fracture of wheel steel near non-metallic inclusions: a - sulphide $(\text{Fe,Mn})\text{S}$, rim, wheel 2; b - oxide $\text{MnO}\cdot\text{Al}_2\text{O}_3$, tread, wheel 1; $\times 600$

Рис. 8. Коррозионное разрушение колесной стали вблизи неметаллических включений: а - сульфид $(\text{Fe,Mn})\text{S}$, обод, колесо 2; б - оксид $\text{MnO}\cdot\text{Al}_2\text{O}_3$, поверхность катания, колесо 1; $\times 600$

4. CONCLUSIONS

Corrosion of railway wheels during operation decreased their reliability and service life. Mechanism and corrosion rate depend on chemical composition and structural condition of wheel steel. Non-metallic inclusions render great influence on corrosion fracture of railway wheels. It is necessary to work out anticorrosion actions during all stages of wheel production, keeping of railway wheels, their transportation to consumer and also their operation.

References

1. F.F. Azhogin: *Corrosion Fracture and Protection of Steels*. Metallurgy, Moscow, Russia, 1974.
2. Yu. N. Taran, V. P. Esaulov, S. I. Gubenko: *Increase of wear-resistance of railway wheels with different profile of tread*. Metallurgical and Mining Industry, 2000, no 2, pp. 42-44.
3. Yu. N. Taran, V. P. Esaulov, S. I. Gubenko: *Structural changes in rims of railway wheels with different profile of tread*. News of Higher Education. Black Metallurgy, 1989, no. 9, pp. 101-105.

4. S. I. Gubenko: *Transformation of Non-Metallic Inclusions in Steel*. Metallurgy, Moscow, Russia, 1991.
5. S.I. Gubenko, V.V.Parusov, I.V. Derevianchenko: *Non-Metallic Inclusions in Steel*, Dnepropetrovsk, ART-PRESS, 2005.
6. A.V. Rjabchenkov, V.M. Nikiforova: *Some electrochemical aspects of the mechanisms of corrosion Fatigue*. Metal Science and heat treatment, 1956, no. 8, pp. 9-11.

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