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INVESTIGATION OF SLIDE MECHANISM OF TREAD DURING OPERATION OF RAILWAY WHEEL

Summary. Causes of reasons and explanation of mechanism forming damages of railway wheels tread were investigated. At slipping on contact surfaces wheel-rail a between by simultaneous development of processes of work-hardening and softening metal determines the terms of origin damages of railway wheels tread were fixed.
Keywords: damage, railway wheel tread, hardness, slipping, work-hardening, softening, energy of activation

1. INTRODUCTION

During operation of railway wheels different level of strength, the forming damages of metal railway wheels tread are conditioned the simultaneous action forces of friction and cyclic change of stresses [1]. Supposing that forming damages of surface tread is mainly determined the internal structure in volumes of metall near the tread of realway wheel [2], it is

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necessary to expect different of character development of processes structural changes in a metal with the different level of strength.

Taking into account the tendency of produce railway wheels with the high level strength as a result of microalloying, change of content carbon in steel and use hardened heat treatments, the internal structure of metal near by the surface of railway wheels tread in majority of cases corresponds quenching and follow tempering in the middle interval of temperatures. It ensues from experience of exploitation of railway wheels, that at the identical level of strength and high-quality different structural state of metal, the processes of wear can substantially differ [2].

On the basis of analysis reasons of premature withdrawal of railway wheels it is discovered from exploitation, that except for the unrationed amount of nonmetallic inclutions of different morphology and nature of origin at arrangement near-by with railway wheels tread [3], substantial value, arising up acquire additional moving of wheelpair in relation to the frame of light cart [4]. The indicated displacements of wheelpair during exploitation are reason of origin shear component of deformation to the constituent of metal on a contact surface wheel-rail. As a result on-the-railway wheel tread areas are formed with the different degree of wear and complicated internal structure of metal from simultaneous influence of a few factors [5]. Forming of such areas is a break by homogeneity of distributing of internal stresses in the metal of wheel and results of bring nonhomogeneous strain hardening metal on the railway wheels tread.

On the basis of it the estimation terms of forming of the local slipping presents certain interest in the process of exploitation of railway wheels with the different level of strength, as one of the stages of complicated process of formation damage on the railway wheels tread.

2. PURPOSE OF WORK

The purpose of this work was investigation of mechanism of slipping on the railway wheels tread during operation.

3. MATERIAL AND RESEARCH METHOD

For research carbon steel of railway wheel served as material with contain of carbon 0,6%. Heat treatment was reach at the different state of structure of metal. As a result of quenching from the normal temperatures of heating the structure of martensite was formed with hardness 65 HRC, and after subsequent tempering at temperatures 450 − 470°C is a structure of the tempered martensite with hardness 39 HRC. Heat higher than temperature Ac_3, the required self-control for homogenization of austenite and cooling with a furnace allowed to get lamellar pearlitic structure in steel with hardness 13 HRC.

The analysis of behaviour speciment of the probed steel in conditions of the normal contact rolling was carried out use the proof-of-concept machine of SMC-2 for the normal load 18 kg on the speciment. At tests, the change of kinematics chart of machine become possibility of receive of different sizes of slipping on the contact surfaces of speciments, due to the change of their angulator speed of rotation. Speed of turns spindle of proof-of-concept machine was 300 and 500 $\min^{-1}$, at the temperatures of test 20 and 120°C (293 and 393°K). As a result of test determined the beginning moment of forces in the area of contact surfaces speciments.

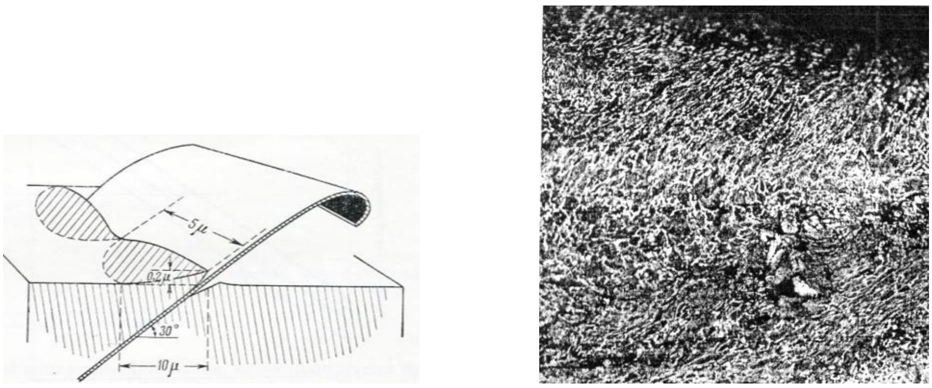
For explanation the character development processes changes of structure for tests descriptions, analysis parameters the thin crystalline structure of metal, were used. Estimation degree of tetragonality crystalline lattice of ferrite, size of areas coherent dispersion (L), density of dislocations (ρ) and distortions of the second-type (μ) carry out, through the methods of x-rays analysis [6].

4. DISCUSSION OF THE GOT RESULTS

The analysis of known experimental of facts [1, 3, 7] bear witness that to the formation of extrusions and intrusions (Fig. 1) on the railway wheels tread which become the turn into of superficial damages in future, local changes are preceded in the area of contact wheel-rail. Taking into account high-rate of heating at the local slipping, the temperature of beginning of phase transformations in steel of wheel can be arrived in thin of layer near railway wheels tread. After completion of the stage of slipping a sharp cooling from the heated metal in more remote volumes of rim of wheel is able to provide development of phase transformations on intermediate or even to diffusionless transformation [2, 5].

On that was transformation railway wheels tread with the practically homogeneous strain hardening of metal, transform into alternating areas with different hardness and capacity for the deformation work-hardening. During subsequent exploitation of wheel on the indicated areas with different hardness and internal structure (cold work state and structures after quenching) it is necessary to expect further growth of distinctions in character of the local slipping and proper changes in the level of strength properties.

The make use of disk brake systems far of the wheel light carts the estimation of localization plastic flow of metal on a contact surface a wheel-rail is presented by certain practical interest.



a b

Fig. 1. Chart of forming extrusion (a) and their real kind on the profile of railway wheels tread (b) Magnification 100

4.1. Estimation of beginning slide on a contact surface wheel-rail

At certain correlations of strain hardening of metal on the railway wheel tread (degree and distributing of plastic deformation) and temperature of warming-up during exploitation, there must be a change of balance between the indicated effects. Above all things the process of slipping will be determined in size tripping of metal of wheel with a rail. The indicated characteristic can be estimated on the origin moment of forces in the area of contact surfaces. From other side, the size of tripping of wheel with a rail must change with the temperature of warming-up of metal near-by with the railway wheel tread. On the basis of it, as description for the estimation of the looked after phenomenon it is necessary to avail in size of energy, which must be expended for achievement effect of slipping.

Taking into account that a process of slipping is thermally activated, will take advantage of equalization of Arrhenius for energy activation of process of plastic deformation. In a general view equalization can be written [8]:

$$\dot{\varepsilon} = A\exp(-\frac{Q}{RT})M^{m}, \tag{1}$$

where $\dot{\varepsilon}$ − speed of deformation, A − value of constant, Q − energy of activation process, R − universal gas constant, T − temperature (°K), M − moment of forces at slipping, m − index of degree. After taking the logarithm of correlation (1) get:

$$\ln\dot{\varepsilon} = \ln A - \frac{Q}{RT} + m\ln M \tag{2}$$

For a condition of constant temperature, after differentiation (2), m determined as a tangent angle of slope from a graphic construction $\ln\dot{\varepsilon} = f(\ln M)$:

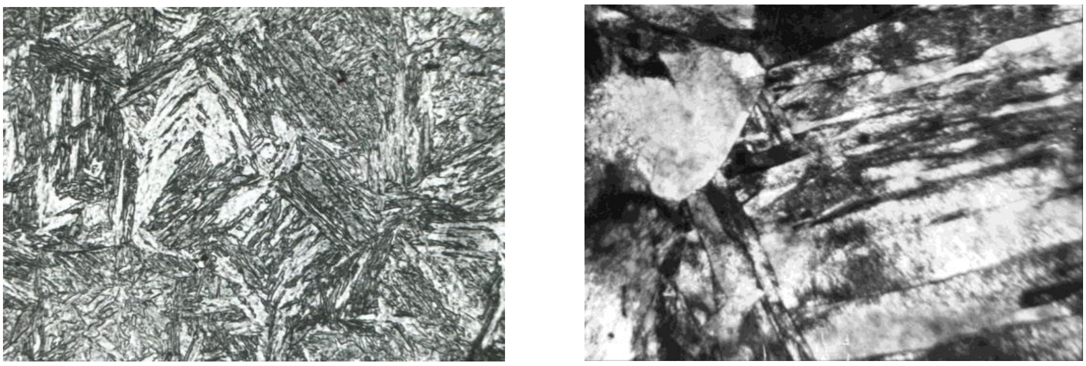
$$m = \frac{d\ln\dot{\varepsilon}}{d\ln M} \tag{3}$$

There is a size of relation at unchanging speed of deformation $\frac{Q}{m}$ determined as an angular coefficient from dependence $\ln M = f(\frac{1}{T})$:

$$\ln M = \frac{Q}{mRT} + \frac{\ln\dot{\varepsilon}}{m}, \tag{4}$$

and take into account (3) get a numeral value Q [8].

Estimation of size energy activation of process slipping, carried out from experimental data, on speciments of railway wheel steel became able after quenching from the normal temperatures of heating (Fig. 2). The resulted structure is largely similar to the structure of metal railway wheel after forming of slide-block onthe tread [2, 7].



a b

Fig. 2. Structure quenching railway wheel steel. Magnification (a) − 1000, (b) – 13000

As speed of deformation the number turns of spindle of proof-of-concept machine was accepted (ν). As show in [7] a calculation of energy activation carried out on tests at no less as two speeds of deformation and two temperatures of loading. Size ν made values 300 and 500 mines^{-1}, at temperatures +20 and +120°C and the moment of forces in the area of contact surfaces was arrived at the size of slipping 10%.

Beginning from the first cycles loadings at rolling, from the diagrams change of size M it was found out high instability of values. In area of first hundred cycles of loading decrease of size of moment of forces on contact surfaces arrived at a few times. As far as the increase of number of cycles at rolling of unmonotony in character change of the indicated description went down and only after set in relation to the stable mode, determined the moment of forces. For the estimation of size Q used values M at reject 3 − 5% in relation to the average set level.

From a correlation $\ln\nu - \ln M$ (Fig. 3) values were certain m, which were 0,83 and 0,2 for temperatures 293 and 393°K (20 and 120°C) accordingly. Size Q estimated rewritting correlation (4) with preliminary replacement $\dot{\varepsilon}$ on ν and by the substitution of numeral values proper descriptions:

$$Q = RT(m\ln M - \ln\nu) \quad (5)$$

It was discovered from the analysis of the got results, that in the interval of the use speeds (300, 500 мин$^{-1}$) decrease of temperature from 120 to 20°C accompanied decrease of the required energy for development of process slipping approximately in 1,3 of time (from 20,6 to 15,3 $\frac{kJ}{mol}$).

Thus, at permanent level of loading and speed of rotation, the indicated decrease of temperature on the tread metal is accompanied decrease size of tripping with speciments approximately on 25%. In the isothermal terms of loading the increase of speed of rotation in the use range of values practically does not change the size energy of activating process of slipping.

$\ln\nu$ $\ln\nu$

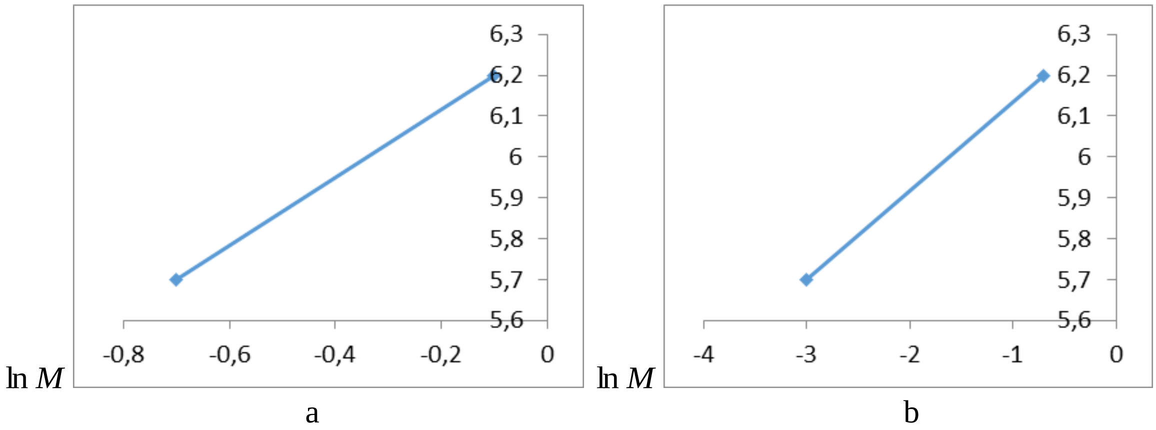


Fig. 3. Correlation between ν and M at the temperatures of test (a) − 20, (b) − 120°C

At the change of the structural state of metal, depending on the terms of rolling it is necessary to expect other character of dependence of tripping in the area of contact surfaces high-quality. So, as compared to tempering on a martensite, metal of railway wheel after the homogenizing annealing with the level of hardness 13 HRC, at the temperature of test +20°C, with the increase of speed of rotation in the use range (300 to 500 mines $^{-1}$) a show growth in 1,5 of time moment of forces in the area of contact surfaces. Moreover, confirmation was predictably got high-quality other character of change of tripping of metal at slipping. As compared to a quenching metal on a martensite, for speciments after annealing there was absence of area with the unmonotonous change of size M on the initial stages of increase of cycles of loading.

It was found out the analogical character of behaviour carbon steel and able after quenching with subsequent tempering in the middle interval of temperatures, for example at the level of hardness 39 HRC. In both cases, since the first cycles of loading there was a monotonous increase of hardness on-the tread of the tested speciments.

Thus, forming of structures on a diffusionless transformation mechanism on the tread of railway wheels results in appearance of neighbour areas with a high-quality different conduct at a loading.

4.2. Research mechanism of soften steel after quenching at rolling

After quenching (Fig. 2) the level hardness of carbon steel (65 HRC) is provided the beginning certain degree of tetragonality crystalline lattice, which in same queue is conditioned the concentration atoms of carbon, dissolve in austenite. With the increase concentration of carbon in steel growth of degree of tetragonality of crystalline lattice of ferrite ($\frac{c}{a}$) as a result of quenching estimated on correlation [9]:

$$\frac{c}{a} = 1 + 0,045p \, , \tag{6}$$

where p − gravimetric % carbon in steel, a − a parameter of crystalline lattice of ferrite, c − size of rib of lattice ferrite after forming crystal of martensite [9]. After a substitution in (6) for the probed steel of size p and the experimentally got values a and c, there was a calculated degree of tetragonality of crystalline lattice of ferrite after quenching, which made $\frac{c}{a} = 1,027$. Comparative analysis with the known experimental dates for steel with analogical concentration of carbon after quenching on a martensite [9] show a good enough coincidence. It is necessary to examine the got result as a confirmation of absence of disintegration of super soturation solid solution at cooling.

After 1200 cycles of rolling of specimens slip-free, to the discover decrease of hardness from 5 to 7% diminish of degree of tetragonality of crystalline lattice of ferrite of quenching steel corresponded from 1,027 to 1,0255 (on 0,15%). The decrease of the indicated parameter testifies to development of processes of softened of quenching steel in the process of the contact phenomena at rolling. Analogical results on influence of insignificant plastic deformation on the strength middle carbon steel after quenching is got in [10]. For explanation of mechanism of looked after softened, will take advantage of correlation (6).

After a substitution in (6) values $\frac{c}{a}$ =1,0255 it was discovered that size p corresponds concentration of carbon 0,56%.

It is thus necessary to suppose that way out atoms of carbon from martensite of crystals in the process of rolling, is principal reason of decrease of hardness steel after quenching. However, if looked after soften at heating to the temperatures higher 500 − 550°C the work-hardened carbon steel accompanied the increase sizes of areas of coherent dispersion, reducing the accumulated dislocations and decrease level of distortions of the second-type [11], after rolling was found out an increase ρ on 19% (from $96{,}5 \cdot 10^{10} cm^{-2}$ to $118{,}5 \cdot 10^{10} cm^{-2}$), μ (from $1{,}98 \cdot 10^{-4}$ to $1{,}66 \cdot 10^{-3}$) and diminishing L на 30% (from 618 to 445 $\mathring{A}$). Resulted character of change parameters thinly crystalline structure are show on the presence effect of the deformation work-hardening of martensite crystals in the process of rolling. Moreover, the looked correlation between by the processes of work-hardening and softened at rolling of metal must continuously change depending on the total size of plastic deformation. If on the initial stages of loading, when the effects increase amount of defects crystalline structure are insignificant, a total result is a softened effect. At growth of amount of cycles of loading at rolling, when the role of processes of the deformation work-hardening will continuously increase, and soften from disintegration of super saturated solid solution will go down, after the certain number of cycles it is necessary to expect began exceedings effect of work-hardening.

Research of parameters of thinly crystalline structure of metal at rolling with a 10% slipping did not result in the high-quality changes character of soften of quenching metal. Already after 600 cycles of l0ading with slipping, hardness was 62 HRC (before a test 65 HRC), here L 504 made $\mathring{A}$, μ and ρ attained values $2{,}6 \cdot 10^{-3}$ and $15 \cdot 10^{11} см^{-2}$ accordingly.

On the basis of the known experimental results [1-3] and results of the conducted researches there are the looked after cases of forming on the railway wheels tread areas of «white layer», in actual fact by the appear result of development structural transformations in a metal on a diffusionless mechanism at slipping in the places of contact wheel-rail. Development of processes of softening on these areas will be accompanied the inevitable deformation work-hardening on near by areas without the local slipping. As a result there will be growth of gradient of hardness on the boundary of section between them. Even in the case of absence damage surface of rolling on the area of slipping, a growth of strength properties rate on the indicated near by areas during exploitation of wheel will not be identical.

Taking into account the high enough degree of heterogeneity of distributing size of plastic deformation on the railway wheels tread, an important practical value has a between by development of the indicated processes, especially on the stages of braking of railway carriage. In fact insignificant in size areas with slipping after a roll-up in the process of exploitation of wheel will result in the origin of high gradients of internal tensions in the volumes of metal near by with the tread. The indicated areas during further exploitation of railway wheels become the potential places of forming damages of railway wheels tread.

5. CONCLUSIONS

1. Forming damages of railway wheels tread is conditioned correlation of the developed processes of work-hardening and softening in the area of contact a wheel − rail.
2. The found out the decrease hardness of quenching steel at rolling is accompanied the increase of density dislocations, reduce of areas coherent dispersion and growth of distortions of the second-type.
3. Regardless of the structural state of carbon steel, the decrease of temperature during exploitation of railway wheel is promote in development of the local slipping on the railway wheels tread.

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