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Contact-Fatigue Strength of Locomotive Tires

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We studied the contact-fatigue strength of tire steel with different hardness and structural condition. It is established that an increase in the hardness of steel from 275 to 350 HB and the change in the structure of the ferritic-pearlitic state to fine-pearlite with acicular ferrite and bainite leads to increased resistance to the formation of contact-fatigue spalling more than 100%. On the basis of X-ray diffraction studies the mechanism of formation of defects on the surface of tires was determined.

Keywords: LOCOMOTIVE TIRES, THE CONTACT-FATIGUE STRENGTH, MICROSTRUCTURE, HARDNESS, CHIPPING, X-RAY ANALYSIS

Introduction

In the interaction of wheel with the rail in their contact areas high pressure (1000 MPa) is used, resulting in high friction to plastic deformation. The second feature of the process of rolling with sliding wheels rolling on the rails, is that in this couple longitudinal and transverse slipping is significant that provide also a great damaging effect. It should be emphasized that the contact-fatigue defects treads make more than a third of all the defects of wheels and taking into account damage that surface at wheel sliding, more than 60%[1].

Given these features of work of locomotive tires in the Iron and Steel at Institute National Academy of Sciences and JSC "Interpipe NTRP" developed TS 35.2-23365425-641:2009 that provide production tires of vanadium micro-alloyed steel "T" with the level of hardness more than 320 HB.

In the present study we investigated the influence of hardness and structure of tire steel БЛТ on its tendency to contact-fatigue damage at a hardness of 275 HB, 300 (hardness of serial tires) and 325-350 HB (optimal hardness of tire steel in terms of its durability [2]). Billet samples of microalloyed steel T were thermally hardened at hardness levels 275, 300, 325, 350 HB.

Results and Discussion

Tests for contact-fatigue endurance were conducted in the Institute of Ferrous Metallurgy at National Academy of Sciences on the friction machine СМЦ-2 [3, 4] with continuous feed to the contact surfaces of the sample and counterface lubricant according to the method used in [5].

The nature of variation of the fine crystalline structure of ferrite in the surface layer of the sample of vanadium micro-alloyed tire steel T (0.63% C; 0,72% Mn; 0,094% V) with a hardness of 275 HB in the contact-fatigue loading in a testing machine was produced by X-ray diffraction by the following procedure. Four perpendicular diametrically opposed positions were set on the sample for contact-fatigue testing, and on their rolling surface we performed recording selected for the analysis of interference maxima of ferrite (110) and (220) in automatic mode (X-ray diffractometer ДРОН-3М, monochromated MoK α-radiation). As a reference, we used a sample of compressed carbonyl iron, annealed under the special mode.

Data processing of fine crystal structure of ferrite was performed by the method of approximation [6, 7].

Microscopic stress analysis was performed by relation [6]

$$\rho = \frac{4}{5} \times \frac{\beta^2}{\text{в}^2 tg^2 \theta}, \tag{1}$$

Where θ and β - respectively, the Wolf-Bragg angle of reflection and physical broadening of the analyzed X-ray line; *в* - the Burgers vector of dislocations ($\text{в}_{<111>} = 2{,}47 \times 10^{-8}$ cm).

Macroscopic stress analysis was conducted by the ratio given in [6], for the same diffraction line

(220)

$$\sigma1+\sigma2=-\frac{E}{\mu}\times\frac{\Delta d_{(220)}}{d_{(220)}}, \qquad (2)$$

where σ1+σ2 - tangential stresses; E - Young's modulus for steel E = 210 000 H/mm^2; μ Poisson's ratio for steel μ = 0.26; Δd/d - relative change in the distance between planes.

To verify the results the experiment was also reproduced on all the samples of the studied hardness (275, 300, 325, 350 HB) using X-ray diffractometer ДРОН-2, monochromatic Cu K α-radiation.

Criterion for evaluating the resistance of contact-fatigue fractures was taken the number of loading cycles before the first signs of damage (pitting) on the friction surface of the test sample. The results are shown in **Figure 1**. It is established that an increase in hardness from 275 to 350 HB contact-fatigue strength of the investigated steel increases continuously from 1.5 to above 3 million cycles. According to the results of tests and metallographic studies of surface areas of the samples it can be said that the steel БЛТ structure of fine pearlite with acicular ferrite and bainite with hardness 325-350 HB in comparison to HB 275 and ferrite-pearlite structure (typical of standard tire steel 2 to GOST 398-96) is 1.8-2 times more resistant to the formation of chips in contact loads.

To study the mechanism of chipping on the surface of rolled products we investigated stress variation of the first and second kind in the samples at the contact-fatigue loading by X-ray analysis.

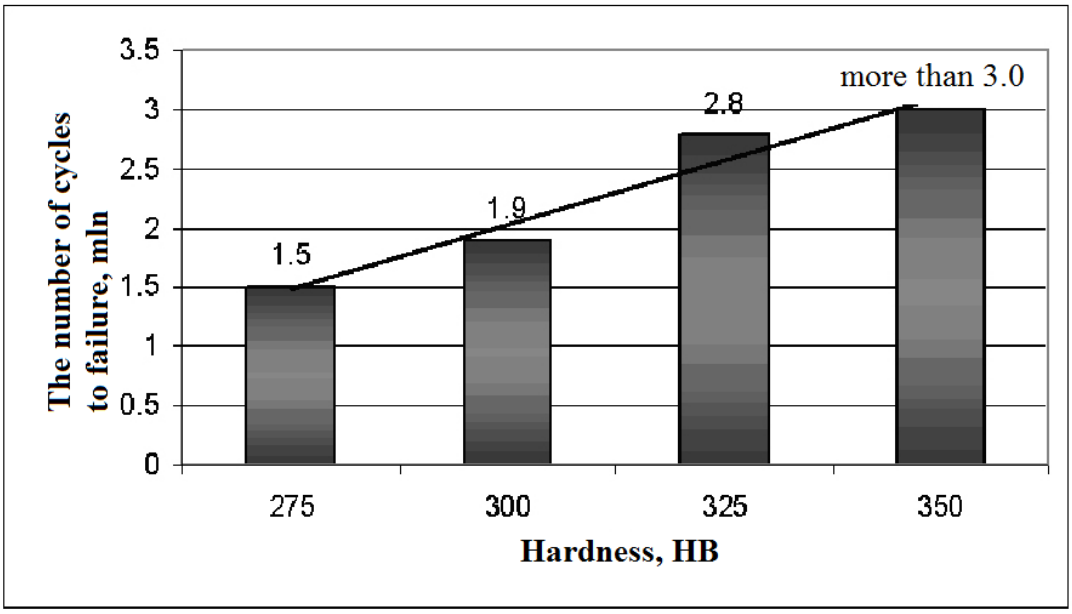

Figure 1. Dependence of contact-fatigue strength of tire steel T according to TS U 35.2-23365425-641:2009 on its hardness

Analysis of the results presented in **Figure 2** showed the following: in the contact-fatigue tests after 100,000 cycles of loading values of physical broadening β_{220} and the dislocation density in the ferrite ρ significantly reduce. According to [8], it is related to the manifestation of the effect of structural adaptability, when in very thin surface layers of the contacting bodies, heated as a result of friction heat to temperatures causing the annihilation of dislocations, a dynamic equilibrium between the emerging and annihilating in the process of fatigue-contact loading dislocation ensembles is established.

This process with increasing number of load cycles causes the appearance of cracks and reduces runoff dislocations in these cracks to some extent the dislocation density in the ferrite ρ (**Figure 2**). With a significant increase in the number of load cycles chipping is formed on the contact surface.

Shown in **Figure 2**, the experimental data on the lower level of β_{220} and ρ in the sections of the surface of relevant defects just confirms the assertion of the flow of dislocations in micro-and macro-cracks.

According to the provisions developed in [8], the formation of gross defects of chipping on the contact surfaces of friction bodies is associated not only with their high defect concentration per se,

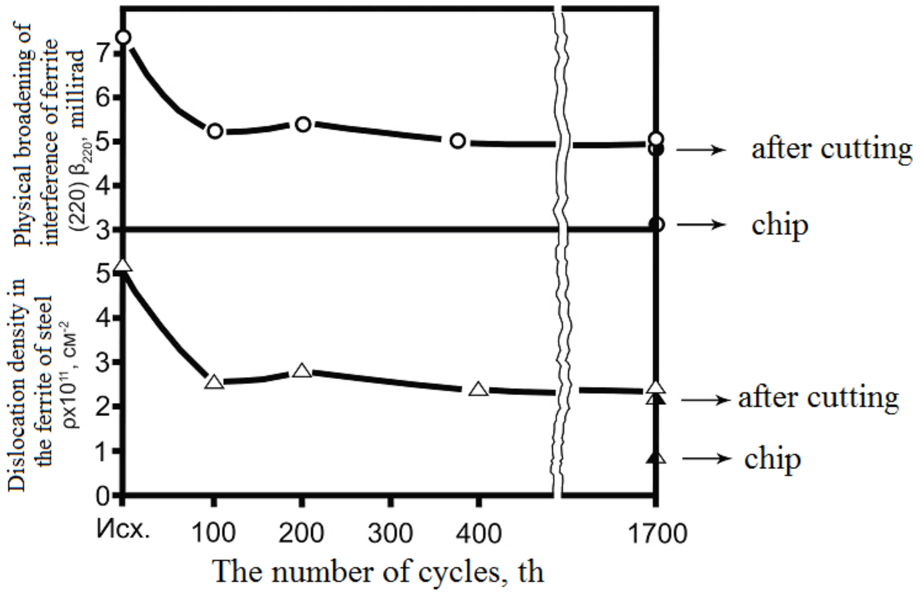

Figure 2. Physical broadening of the interference maximum and the dislocation density in the ferrite steel

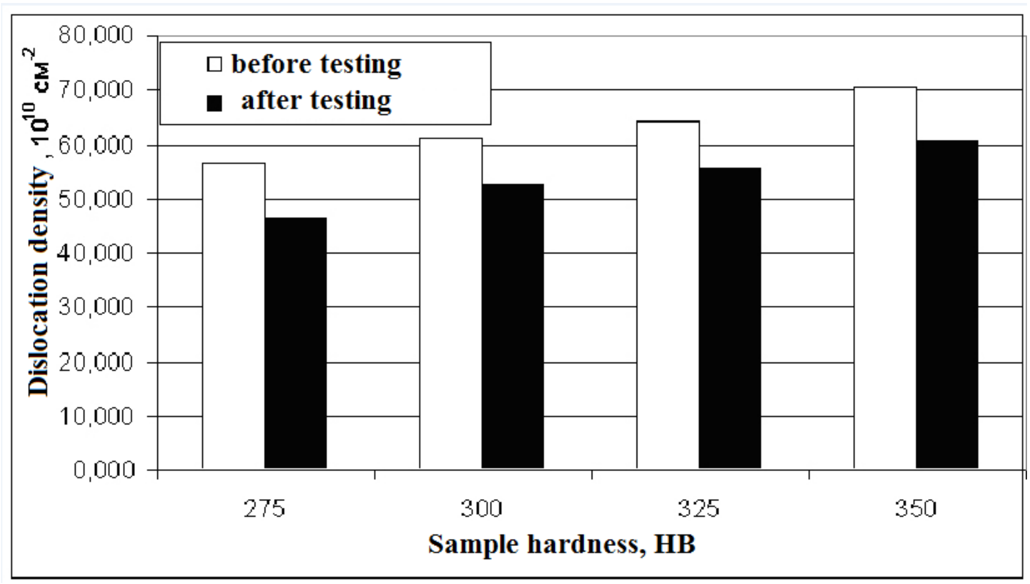

Figure 3. Change in the dislocation density on the surface of the samples after testing, line (220)

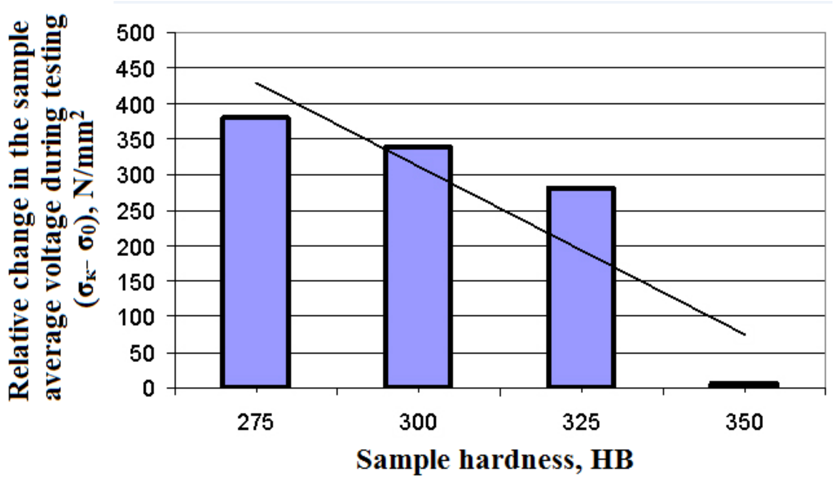

Figure 4. Relative change in the average voltage in samples before and after the sample test ($\sigma_к$- σ_0)

but also a factor of influence of macroscopic stresses in the surface layers of contacting samples contributing so-called "disclosure" of microcracks and their transformation in large formations - macro defects.

As follows from the above analysis, the surface layer of the original sample is a system of contracting macrostresses, the overall level of axial and tangential components which makes (σ_1+σ_2) = -229.59 N/mm^2. Such a system of compressive stresses prevents expanding of cracks. After a significant number of loading cycles (1700 thousand cycles) in the surface layer of the sample quite high system of tensile stresses (σ_1+σ_2) = +467.09 N/mm^2 is set, which are responsible for the disclosure of microcracks, i.e. their transformation into macroscopic defects. Direct measurement of the distance between the special tags before and after cutting the sample, tested during 1700 thousand cycles acts of loading, confirmed that the distance between them is 0.2 mm, which confirms the presence of tensile stress.

The change in the dislocation density on the surface of the samples before and after the tests on the line (220) is shown in **Figure 3**. As seen in Figure 3 the dislocation density decreases after the sample test, which confirms the previous results.

The relative change in the average voltage samples before and after the sample test ($\sigma_к$- σ_0) is shown in **Figure 4**. It is shown that with an increase in the hardness of steel decreases its sensitivity to changes in macroscopic stresses during the tests and, therefore, less probability of formation of contact-fatigue defects on the surface of steel products.

In order to establish the reasons for this pattern microstructure of rolling surface of samples has been studied and the depth of penetration of plastic deformation in the samples after the test was metallographically determined.

As seen in **Figure 5**, the depth of penetration of plastic deformation in the specimens with improved hardness of 275 to 350 HB is continuously decreasing from 0.35 to 0.10 mm, ie relative change in stress in the sample during the tests in this case is directly proportional, and contact-fatigue strength is inversely proportional to the depth of penetration of the deformation in the application process of contact loads.

Thus, the mechanism of formation chipping was studied: in the process applied to the sample of cyclic contact loads steel plastic deformation occurs, as a result of what in the surface layers of the samples the amount of metal changes that leads to the formation of tensile macrostresses that summed with the external loads reveal cracks.

With the increase in the hardness of steel and the change in the microstructure of ferrite-pearlite to bainite state increases its resistance to plastic deformation, therefore, to a lesser extent the amount of metal changes and the formation of tensile macrostresses. As a result, steel with high strength properties has increased contact-fatigue strength.

Conclusions

1. Laboratory tests on the contact endurance of experimental samples of high carbon tyre steel microalloyed with vanadium showed that increasing its hardness from 275 to 350 HB and changes in the structure of ferrite-pearlite state to highly dispersed pearlite with acicular ferrite and bainite increases the resistance to the formation of contact-fatigue chipping more than 100%.

2. Carried out X-ray diffraction studies have established that in the process of contact-fatigue loading on the rolling surface samples from tyre steel microalloyed with vanadium as a result of the effect of structural adaptability, as the number of loading cycles increased dislocation density ρ reduced compared to baseline. It is shown that the disclosure of microcracks with the formation of macroscopic defects in the surface is carried out as a result of exposure of installed sample in the surface layer of during the loading time in tests of the system of the tensile macrostresses with a high level of absolute values.

3. The mechanism of the formation of defects on the surface of tires, according to which, in the process of application of cyclic contact loads plastic deformation of steel, the change metal volume, the formation of tensile macrostresses, and as a result, cracks and their subsequent disclosure occur. With the increase in the hardness of steel increases its resistance to plastic deformation, and increases the contact-fatigue strength.

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Контактно-усталостная прочность локомотивных бандажей

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В работе исследована контактно-усталостная прочность бандажной стали с различной твердостью и структурным состоянием. Установлено, что повышение твердости стали от 275 до 350 НВ и изменение структуры от феррито-перлитного состояния до высокодисперсного перлита с игольчатым ферритом и бейнита приводит к повышению стойкости к образованию контактно-усталостных выкрашиваний более чем на 100 %. На основании проведенных рентгеноструктурных исследований определён механизм образования дефектов на поверхности бандажей.