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INSIGHTS INTO FACTORS OF DAMAGE OF SURFACE ROLLING OF RAILWAY WHEELS DURING OPERATION

Summary. The systematization results of microstructure studies of carbon steel has made it possible to explain the mechanism of formation of certain damages to the rolling surface of railway wheels during operation. The evaluation ability of metal to strain hardening was used to explain the nature of the influence compactly located non-deformable dispersed particles on the strength properties steel during cold plastic deformation. In the process of the interaction of a railway wheel with a rail, successively occurring heterogeneities in the distribution of the plastic flow metal are one of the main reasons for the formation of defects on the rolling surface of the wheel.

Keywords: carbon steel, microhardness, strain hardening, rolling surface of a railway wheel, non-metallic particles

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1. INTRODUCTION

The process of damage formation on the rolling surface of railway wheels is determined not only by the rate accumulation of defects in the crystalline structure but also by the uniformity of their distribution in the metal [1-4]. A high degree localisation of the plastic deformation carbon steel on the rolling surface of the wheel leads to a corresponding increase in the heterogeneity of the strength properties in adjacent micro volumes of the metal [5]. In addition, the very nature of loading introduces certain difficulties in the development processes of strain hardening of carbon steel. Indeed, when compared with simple deformation schemes, a change in the magnitude and even the sign of the deformation is accompanied by qualitative structural changes, which greatly complicates the assessment of the service life of cyclically loaded metal structures [6]. Additional strengthening of the negative effect of inhomogeneous metal hardening should be expected from the presence of non-deformable particles of non-metallic inclusions of various nature of origin and their location [7]. Based on this, the formation of defects in the rolling surface of railway wheels is the result of the gradual accumulation of metal damage with a rather complex interaction with the rail.

2. MATERIALS AND METHODS

The material for the study was a part of a rim railway wheel, which was withdrawn after completion of its service life. The carbon steel of wheel with a carbon content of 0.59%, silicon 0.31%, manganese 0.75% and other chemical elements fully met the regulatory and technical documentation requirements for railway wheels [8]. The microstructure was examined under a light microscope. To identify the structure of the steel under study, the standard reagent "nital" was used. The size of the structural elements was estimated using quantitative metallographic techniques [9].

Microhardness ($H\mu$) was used as a characteristic of the strength of micro volumes of metal. The ability of the metal to strain hardening in micro volumes was evaluated by a technique similar to the construction of a tensile curve [10]. In the $H\mu$ magnitude, for a certain load on the indenter, the current stress value (σ_i) was determined (the maxima load on indenter 0,098 N). The true deformation (ε_i,) was determined by the ratio: $\varepsilon_i = ln(d_i/\overset{\circ}{d}_a)$, where d_i - is the current value diagonal of the imprint, and $\overset{\circ}{d}_a$ - is the initial value (of minimum). The diagonal $\overset{\circ}{d}_a$ of print was taken with a minimum load on the indenter. Analysis of the obtained ratio σ_i - ε_i, allows us to judge the nature of the development strain hardening processes in micro volumes of metal [11].

3. RESULTS AND DISCUSSION

The cyclic nature of the change in stress on the rolling surface causes the development of fatigue processes in the metal of wheel rim [5]. These phenomena in metallic materials are irreversible, and traces of their presence are detected even at stresses significantly lower than when the first signs of plastic deformation appear [12]. A detailed analysis [5] indicates that in the absence of negative influence from nonmetallic particles of various nature origin, one of the main signs of fatigue damage to be considered are the formation of extrusions (extruded) and intrusions (absent) of metal volumes on the rolling surface [13].

Studies of the rolling surface profile railway wheel after operation confirms the above positions (Fig. 1a). According to external signs, the observed anomalies on the surface of rolling should be considered as a certain alternation of extruded and concave volumes of metal. The study of the microhardness distribution of the metal matrix near the contour of the rolling surface (Fig. 1a) showed the existence of a certain pattern in the change of $H\mu$ (Fig. 1b).

From the analysis of the given distribution of microhardness, it follows that in the vast majority of cases, convex volumes of metal correspond to higher values, and concave volumes correspond to lower values. Indeed, in the conduct of a joint analysis location of indenter prints and the corresponding value of the microhardness of the metal (Fig. 1), we can find that regardless of the size (depth) of the intrusion, the minimum values of the hardness metal remain almost unchanged. Furthermore, as it moves along the banks of the recess, towards the surface of the skating, the absolute values of microhardness begin to increase gradually, reaching certain extreme values around the middle of the convex part. Based on the presented character of the distribution microhardness, it can be assumed that the convex sections should, in fact, correspond to the extrusion or that part of them that remained on the surface of the wheel. The fact is that after extrusion is formed, the extruded part of the metal is partially carried away from the interaction with the rail and only a certain part of it remains, as evidenced by the absolute values of microhardness (Fig. 1b).

On the other hand, the sites of formation of future intrusions can be unambiguously determined by the nature $H\mu$ of the change. This is due to the fact that during the propagation of plastic flow, the development of processes strain hardening of the metal leads to an increase in the strength characteristics [12]. Based on this, in places of current maximum stresses, in the direction of the likely localisation of plastic deformation, a certain increase in microhardness should be expected. The given position was confirmed by the data of microhardness measurements on places with numbers from 19 to 22 and designation "A" (Fig. 1a). Subsequently, considering that the values of $H\mu$ qualitatively reflect the level of residual stresses in the micro volumes of metal [12], traces of the increased solubility of metal in the etchant should indicate the most probable direction of the local propagation plastic deformation (from $N = 19$ to $N = 22$). After the metal has exhausted the resource of accumulation defects of crystal structure and, in the first place, dislocations, an intrusion was formed with an inevitable relaxation of internal stresses. Thus, micro volumes with local plastic flow become places of origin of future damage rolling surface of railway wheels during operation.

Compared to the mechanism influence of a non-deformable non-metallic inclusion considered in detail on the formation system of internal stresses in carbon steel [14], the compact arrangement dispersed particles can have a qualitatively different effect. This was confirmed by the results of a study in which a site with a local arrangement of dispersed carbide particles in ferrite during plastic deformation was able to behave as a whole [15].

Figure 2 shows such volume metal of the wheel rim in which, next to insulated particles (designation B), a section with compactly dispersed non-metallic inclusions was observed. In accordance with the methodology [11], microhardness was measured at various levels of loading on the indenter and the corresponding curves were constructed to evaluate the ability of the metal to strain hardening (Fig. 3). Considering that the accuracy of microhardness determination is inversely proportional to the load on indenter [16], the section curve with values $\varepsilon_i, < 0.4$ is most likely due to a large error in the determination of $H\mu$. Subsequently, the indicated section curves (Fig. 3) was excluded from the analysis of nature strain hardening of the metal. At initial loads on indenter ($\varepsilon_i, > 0.4$), a metal with dispersed non-metallic

inclusions (Fig. 3a) has almost the same resistance to plastic flow (of the order 1 GPa) compared to the volume without particles (Fig. 3b). As the load on indenter increases, the degree of plastic deformation increases in proportion to its introduction into the metal. A comparative analysis of the constructed curves under loading volumes of metal with and without particles indicates the existence of certain differences in the shape of the curves.
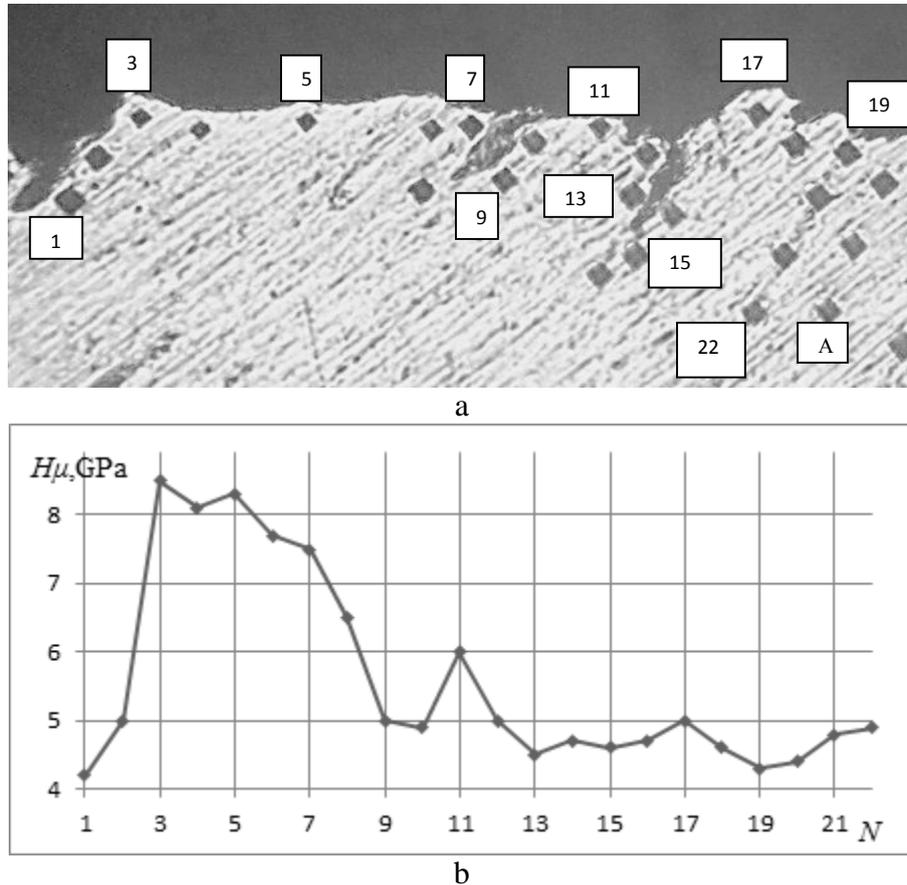
Fig. 1. The profile surface rolling of wheel's (a) and the nature of change microhardness (load on the indenter is 0,196 N) in accordance with the numbers (N) of measurement sites (b). Magnification 350 x 1.2

Visually, the stress growth rate for a place with inclusions (Fig. 3a) significantly exceeds the similar characteristic for a metal without inclusions (Fig. 3b), thereby ensuring a higher hardness level at the same values of ε_i. The above increase in microhardness does not contradict the well-known effect of dispersion hardening metal matrix from the presence of particles second phase [17]. Based on this, it can be assumed that the indicated differences in curves can be explained to a certain extent by the nature of accumulation defects crystal structure during the plastic flow of the metal. Hence, according to [12, 18], the estimation of the rate accumulation dislocations by the value of angular coefficient of tangent in the region of uniform strain hardening was fairly well confirmed by the analysis of density dislocations by the expansion of X-ray interference [15]. Considering that, the strain hardening characteristics quite unambiguously estimate the growth rate of defects in the crystal structure during plastic deformation of carbon steels [17, 18], this technique can be used to analyse the loading curves under study (Fig. 3). As a characteristic of strain hardening, the angular coefficient of the tangent, constructed at points with the same value of ε_i, was adopted.

Numerically, the coefficient of tangents corresponded to the magnitude of the increase in microhardness at a unit change of ε_i, $(\Delta H\mu/\Delta\varepsilon_i)$, when the $\Delta\varepsilon_i \rightarrow 0$. The values of the angular coefficient were determined in the range of ε_i, 0.4 - 0.6. The analysis of $\Delta H\mu/\Delta\varepsilon_i$ values indicates that for a volume of metal with non-metallic inclusions, this characteristic is approximately an order of magnitude higher than the value for a metal matrix without inclusions (7.5 versus 0.6 GPa, respectively). The observed difference in the parameters of strain hardening is in fair agreement with the estimate of the ductility margin for carbon steels [19]. From the results of the studies [20], it is obvious that the lower characteristics strain hardening, the higher the plastic properties of medium- and high-carbon steels.
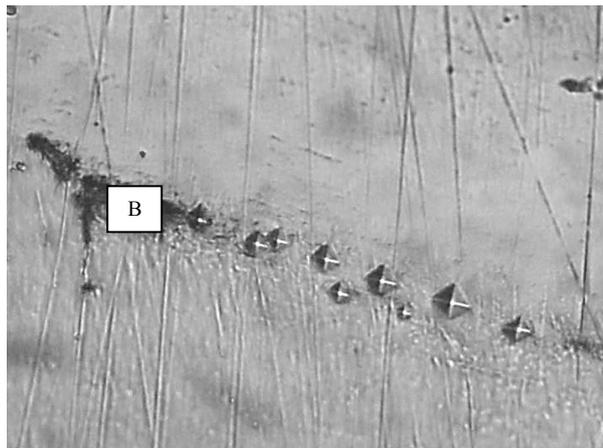
Fig. 2. The volume of metal with compactly located disperse non-metallic inclusions after measuring microhardness. Magnification 350 x 1.6

Thus, one of the reasons formation damage railway wheels along the rolling surface should be considered is an increase of density defects of crystalline structure and, firstly, dislocations, in areas with a local arrangement non-metallic dispersed particles. Based on this, during the operation of railway wheels, regardless of the strength level and structural state of the steel, the location of metal volumes with such non-metallic dispersed inclusions near the rolling surface will lead to the rapid exhaustion of the resource of accumulation defects of crystal structure and cause the formation of surface damage.

Based on this, assessment nature of the accumulation defects of crystalline structure in a metal near the rolling surface should be considered as a tool for studying the processes of structure formation and developing measures to increase the service life of railway wheels.

4. FINDINGS

1. The formation of extrusions on rolling surface of a railway wheel was accompanied by an increase in microhardness carbon steel and intrusions by its decrease.
2. Regardless of the intrusion depth, the microhardness carbon steel remained practically unchanged.
3. The local arrangement of non-metallic particles contributed to an increase in the strain hardening characteristics in micro volumes carbon steel.
4. The formation of damage rolling surface due to accelerated growth density defects of crystalline structure from the presence of non-metallic dispersed particles.
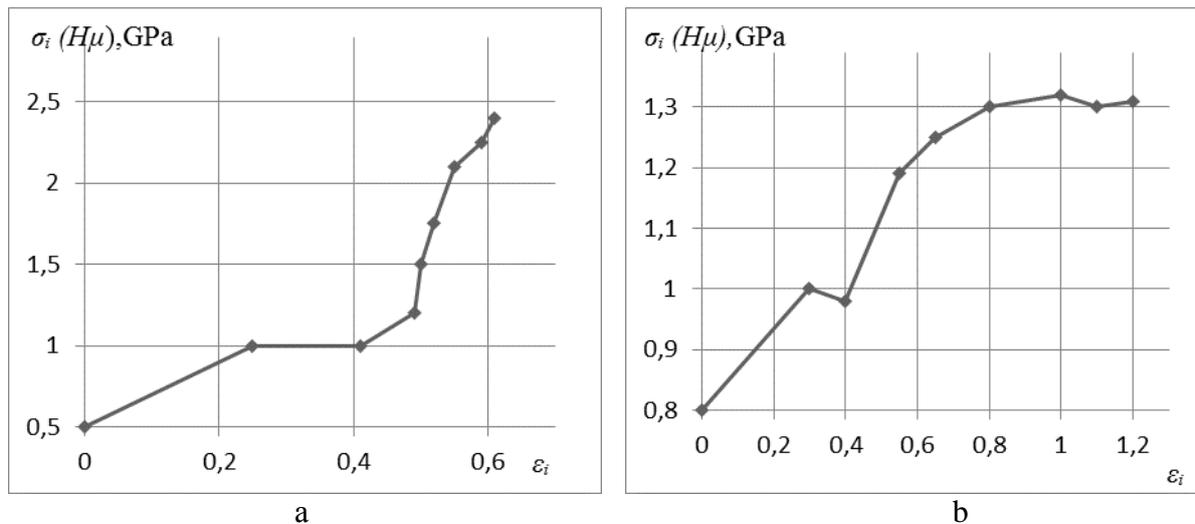
Fig. 3. The ratio of σ_i - ε_i for volumes of metal with dispersed particles of non-metallic inclusions (a) and without them (b)

Acknowledgements

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