МАТЕРІАЛОЗНАВСТВО

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THE PROCESS OF FORMATION OF RAILWAY WHEEL DAMAGES AND TIRES IN OPERATION

Purpose. The dependence analysis of structural changes in the metal of railway wheels and tires from indicated influences in operation, for the further development of strategy of service reliability growth. **Methodology.** Test materials are the details selected from railway wheels which were taken out of operation beforehand because of various damages. Micro-structural researches were made with the use of light microscope Epiquant and electron microscope. The sizing of structural elements was done by using the methods of quantitative metallography. **Findings.** Over the past few decades the rapid development of industry was supported by the steady growth of intensity of using railway transport. In this case simultaneous increase of load at wheel set axle, with the increase of speed was accompanied by natural increase of the amount of cases of premature wheels and tires' withdrawing out of operation. Railway wheel, except the formation of metal layer at rolling surface with the high defects concentration of crystal structure and first of all dislocations, falls under thermal influence from interaction with break blocks. The nature of joint influence (cold deformation and heating) on the metal rim of a wheel is conditioned by the appearance of sufficiently high gradients of structural changes that can be considered as the influence on the level of internal residual stresses. In case of the rise of volume part of carbide phase at a constant ferrite grain size, it is achieved only by the increasing of dislocation nucleation sources without changing the number of annihilation positions. In this case the accumulation of dislocations at the initial stages of plastic deformation (in metal volume in front of delta arm crack) will lead to the formation of cementite globes around certain interlocked dislocation density. In contrast the sharp increase of deformation hardening carbon steel parameters is observed. **Originality.** During the braking of locomotive the speed rise of metal heating at rolling surface is provided with the increase of temperatures that is enough for the beginning of phase transformations. Under the further cooling there is the formation of a number of structures formed from sliding to diffusive mechanisms. As a result the chosen areas become the centers of future metal deformations on wheels' rolling surface and tires. **Practical value.** Based on the study of patterns of damages' formation in railway wheels and tires from the peculiarities of internal metal structure and the working conditions «Classifier of defects» was developed and «Technical tips for determination of causes of cracks in solid-rolled railway wheels and destruction in general», which have been implemented on Ukrzaliznytsia.

Keywords: railway wheels; tires; microstructure; damage; destruction

Introduction

In contact with the rail a wheel is under significant static and dynamic loads. As a result in the areas of wheels' touching with the rails large contact stresses are appeared. During the breaking between wheels and blocks large frictional forces are formed which help to create a variety of defects [2, 6, 14, 18]. Wheel impacts on splice joints can cause the appearance of cracks on the rim.

Represented factors of operation with the metal disadvantages on the requirements of technical standard documentation on products can lead to untimely operation elimination of railway wheels.

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Over the past few decades the rapid development of industry was supported by steady growth of operation rate of railway transport. In this case simultaneous increase of loads on the wheel set axis together with speed increase was accompanied by natural increase of the number of cases of premature wheels and tires' withdrawing out of operation [11]. For reasons given just to adjust wheels' withdrawal it is necessary to increase their production about 5…10% per year [13]. Taking this into account the problem of increasing service reliability of railway transport is the urgent one. The problem is quite difficult and depends on the solution of a number of questions that have defined the impacts on the level of operation reliability of wheels and tires.

Purpose

The analysis of structural changes in metal of railway wheels and tires from defined impacts during operation for the further development of increasing concept their operation reliability.

Methodology

Test materials are the details selected from railway wheels which in turn prematurely due to various damages were taken out of operation. Micro structural researches were made with the use of light microscope Epiquant and electron microscope. The sizing valuation of structural elements of steel in a wheel was done by using the methods of quantitative metallography [7].

Findings

Railway wheel without reference to the technology of its production must conform such requirement as accumulation on its rim the necessary level of tangential residual compressive stresses. These stresses break the process of appearing and increasing cracks of different origin [19].

Wheels that are produced under the technology of hot deformation at thermal strengthening (after the last shape-generating operation) are subjected to constrain differential cooling. Roll surface and the part of flank rim surface are cooled by heavy water flow, wheel disc and wheel hubs are cooled in the air. Then the wheel is subjected to dropping-out in the mode: about 500 ºC, 3 hours.

For producing the railway wheel the casting technology under pressure is used. The wheel that is produced with the help of such technology is different with chemical composition of steel and its structure.

Through this the wheels that are produced with the help of various technologies have their design peculiarities.

During thermal rim strengthening (the technology of thermal deformation) the temperature of rolling surface reduces quickly and comes up about 250 ºC, when the disc and the hub of a wheel are cooling much more slowly. That's why in the wheel rim (at rolling surface) tangential tensile stresses are appeared, that considerably exceed the mark of metal fluidity. The relaxation of these stresses is done due to plastic deformation. At that time a wheel disc is under the action of compressive stresses. The process of temperature equalization during cooling in the air after thermo strengthening and tempering of steel is accompanied by the change of sign before formed stress field. Thus in the rim the residual stresses become the compressive stresses and in the disc they are tensile. Above-mentioned conclusions as to the level and the sign of residual stresses that appear in different elements of a wheel are proved by known facts [19]. The measurement of residual stresses showed that in the wheel which was produced by technology of hot deformation and the further thermo strengthening mentioned stresses approximately in twice, exceed the value of similar characteristics in the wheel made by casting technology. Mentioned differences are due to various structural metal conditions according to the production technology and the difference in division of thermal fields in the elements of a wheel during cooling. It should be noted that the level of residual stresses in the wheels which are manufactured by the technology of hot deformation meets the requirements of ISO and State Standard Specification 10 791 [9].

Comparative analysis of internal structure of the investigated wheels showed the existence of differences and also a significant similarity. Indeed if the rim of a wheel which is under accelerated cooling has in general more fine-grained structure and for these reasons higher strength properties than in the condition of hot deformation for a cast wheel the situation is different. Low cooling rates lead to the formation of such primary structure in different elements of a wheel (Fig. 1, *a*) which with slight differences in dispersion is similar to that which is observed after hot deformation.

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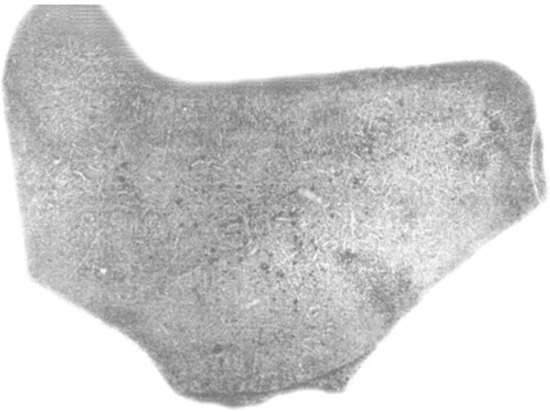
a



b

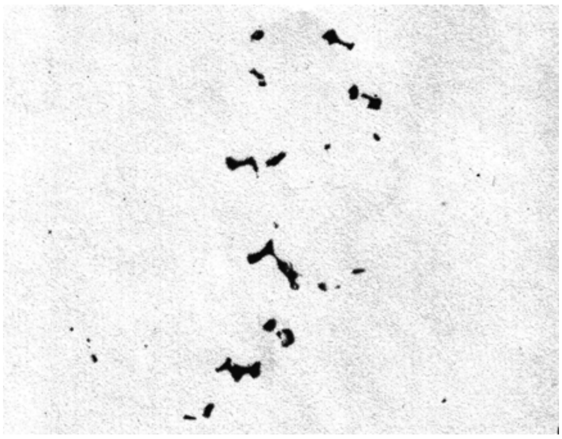


Fig. 1. The structure of spray wheel
(*a* – macrostructure, *b* – no solid).
Magnification: *b* – 100 times

Taking into consideration that the layer of metal thermo hardening with high strengthening properties on the average is to 8% of rim volume, mentioned differences may be compensated for the account of dispersion increase of pearlite component or the increase of its volume part. Indeed the increase of the pearlite quantity in cast wheel for account of steel using with a high content of carbon allowed exceeding the requirements as to the strengthening properties of a wheel (State Standard Specification 10 791) on average at 3% from higher and at 25% from lower interval boundary as to hardness on average at 18%. However plastic properties were lower due to the presence of coarse-dispersion on pearlite structure and excessively high carbon content of steel as a result an excessive quantity of pearlite component is formed. Besides, as addition researches of internal structure of metal showed that the steel of cast wheel especially near the surfaces has the slight adhesion (Fig. 1, *b*) and a number of non-metallic inclusions in the form of sulfides (total number below 0,5).

Recently the developments as to the proposals in the direction of increasing the load on the rolling stock elements are not left without attention the wheel pair. On the basis of this the estimation of the current level of stresses in the most loaded places of wheels was conducted depending on their structural features (Fig. 2) and the diagrams of operational forces. It is established that the highest stress concentration that occurs and operates in the places of transition from the hub to the disc (application area 1) and from the disc to the rim (application area 2), as it is shown in Fig. 2.

a *b*

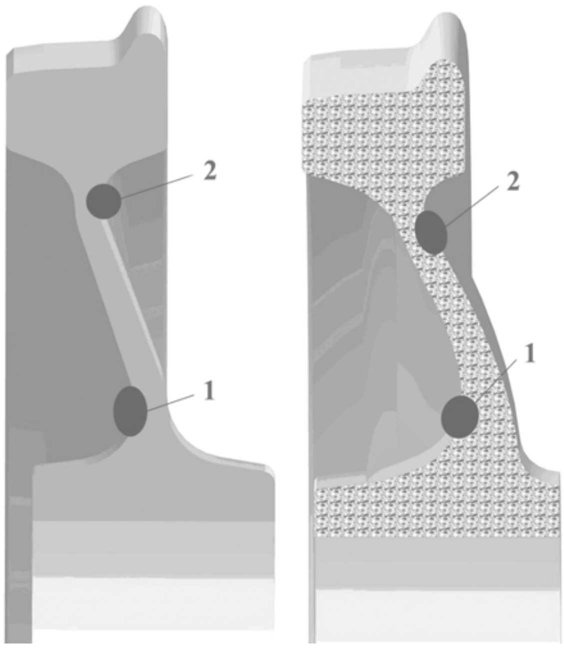


Fig. 2. The places of stress determination on the wheels produced according to the technology of hot deformation (*a*) and casting (*b*)

The level of stresses was defined by the methods described in the work [15], adapted to the form of cast wheel which differs from the wheel shape which was made according to the technology of hot deformation. To determine the stress level the form of a wheel was modeled by separate elements of tetrahedral form, the total number of which rose from 55 to 85 thousand. For the solution of the cubic polynomials their coefficients were determined by using parametric functions as given in [12]. On the basis of this it is considered that the stress of arbitrary point moving $\overline{U}(P)$ is the line of combination of tetrahedron moving:

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$$\vec{U}(P)=\sum_{j=1}^{4} l_j(P)\vec{U}(V_j)$$

Where $l_j(P)$ – linear function of coordinates, which is equals to 1 at the top of (V_j) and 0 in another places of element; $\vec{U}(V_j)$ – elastic moving of the top V_j of the element.

With the help of given methods the values of stresses were identified that appear in the transition areas between the elements of the wheel (application areas 1 and 2) in Fig. 2. So for the wheel that has the form shown in Fig. 2, and equivalent stresses in application area 1 added the meaning $120\ \text{Н/мм}^2$, and in application area 2 – $110\ \text{Н/мм}^2$ .The increase of radius of curvature in two times for application area 1 resulted into reduction of the level of working stresses approximately at 20% ($100\ \text{Н/мм}^2$), and in application area 2 they went down to $38\ \text{Н/мм}^2$. Thus taking into consideration the given facts it is possible to suppose that the increase of curvature in transition areas between the elements of the wheel reduces the equivalent stresses that occur in it during the operation.

The magnitude of railway wheel skidding from interaction in the places of contact with the rail connected with durable properties significantly, as metal on the rolling surface and on the working surface of the rail [20]. On the basis of a sufficiently large number of studies on modeling the process of wear, as well as field testing it is determined that the minimal values of the railway wheels' wear and rails are achieved by the conditions of approximately the same values of their hardness [11, 20]. On the other hand it is known the same level of durable properties in steels can be achieved by various structural condition – after thermal hardening treatment –improvement, when the carbide phase has globular form or after accelerated cooling (at speeds below the critical value) laminar form [19].

The analysis of normative and technical documentation [1, 9] shows that in the conditions of Ukraine the railway wheels mainly made of carbon steel at 0,55…0,65% carbon while for the rail higher carbon steel is used at 0,7…0,8% C. In hot-rolled condition or after annealing the steel structure for railway wheels with stoichiometry can have about 25% of structurally free ferrite. It is in the form of layers separating the pearlite colonies or at a sufficiently low cooling speeds in the form of separate volumes – grains (Fig. 3, *a*).

a

b

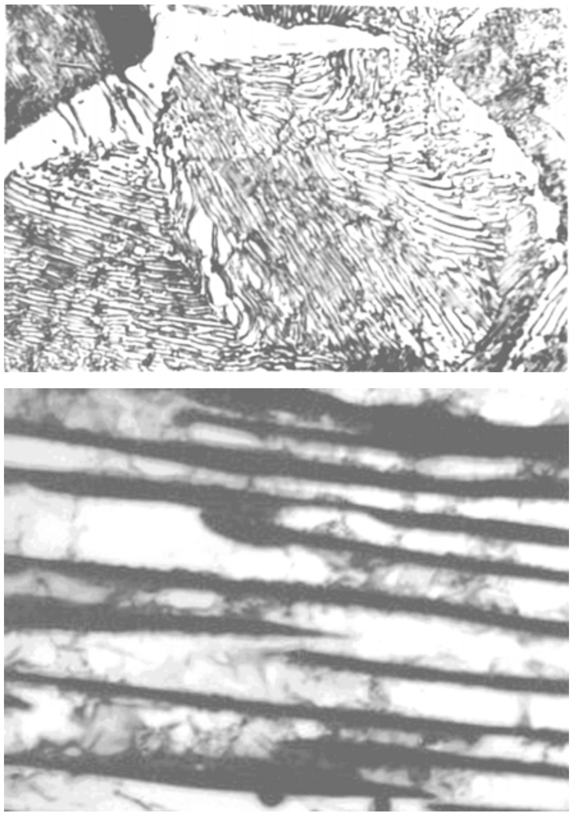

Fig. 3. The structure of metal rim of railway wheel after thermal hardening (*a*), pearlite colony after 30% of plastic deformation (*b*), (magnification 1 000 – *a*, 16 500 – *b*)

The increase in the rate of cooling such as during thermal strengthening of wheels' rim is accompanied by a simultaneous dispersion of pearlite and partial reduction of the volume fraction of structural free ferrite due to the formation of pseudo-eutectoid. However even the usage of highest possible cooling rates (limitation by the geometrical sizes of wheels' rim) does not eliminate the presence of structurally free ferrite completely. According to normative and technical documentation [19] it is allowed the presence of structurally free ferrite in the form of irregular grid on the limits of austenitic grains. At the same time the cooling rate is sufficient to austenitic grains after the removal of structurally free ferrite turned into a finally differentiated sorbitol for pearlites mechanism (Fig. 3, *b*).

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Thus the metal structure of railway wheels in the volumes near the surface of the rolling surface is the sorbitol pearlite with layers of structurally free ferrite which provides the required level of resistance to the processes of fatigue and wear during operation.

In comparison with the laminar form of carbide phase which is as a part of pearlite colonies is capable to plastic deformation, globular carbides for example after the improvement on the contrary even after deformation which leads to the complete destruction of the product practically remain unchanged [4]. In this case on the processes of deformation strengthening at metal loading it is very important the location of carbide globules in the matrix [17]. In case when globular particles are mainly located along the boundaries of ferrite grains (Fig. 4, *a*) the increasing of plastic properties is observed and particularly the resistance of metal nucleation and propagation of cracks at low temperatures.

The explanation of given example is based on the fact that interfacial ferrite-carbide surface performs the function of both source and the place of annihilation of dislocations [1]. Based on this it becomes clear that the increase of volume fraction without changing the dispersion of carbides, is accompanied not only by the increase of durable properties and that is the most important that the resistance to nucleation and growth of cracks at low temperatures of loading is increased.

In cases when the grain size of ferrite significantly exceed inter carbide distance (Fig. 4, *b*) the picture changes significantly. Taking into consideration that interfacial surface of the ferrite globule carbide has the ability to absorb the dislocations only in the case when the fraction is located in the slide area of dislocations; it becomes clear the role of multiannual boundaries of ferrite in the development of annihilation processes of dislocations during plastic deformation. The result will be that the increase of volume fraction of the carbide phase at a constant grain size of ferrite will be accompanied by the increase of the number of sources of dislocations while the number of places of their annihilation remains unchanged. In this case the excessive balance of dislocations will be on the initial stages of plastic flow of the metal and facilitate the formation of globular carbide layer particles from mutually blocked dislocations. In turn the formation of given volumes around the carbides can be considered as future centers with high probability of nucleation of submicrocracks.

a

b

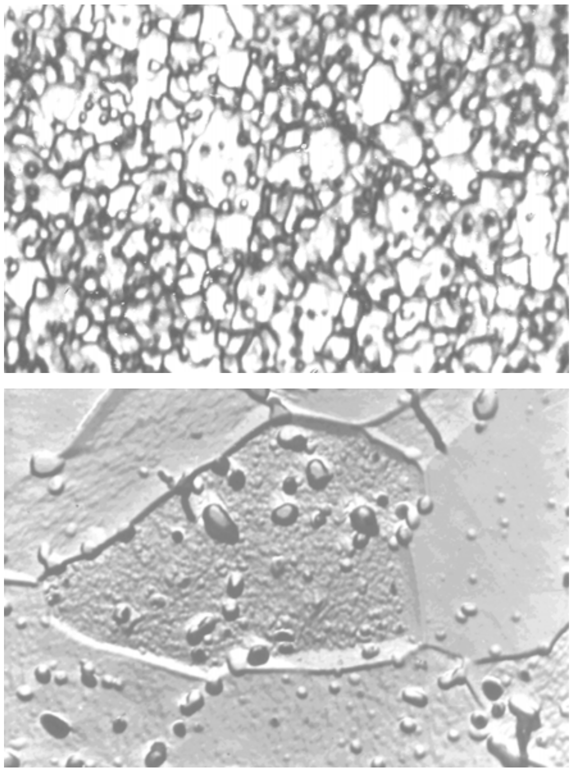

Fig. 4. The structure of carbon steel after cold plastic deformation and heating up to 700 °C, when the grain size of ferrite (d) is equal to the distance between carbides (λ) (*a*),and at $d \succ \lambda$ (*b*), (magnification 2 000 – *a*, 4 000 – *b*)

On the basis of the analysis of the development of the processes of deformation strengthening in carbon steels with different morphology of carbide component it becomes possible to determine the optimal structural state of metal, taking into account the operating conditions of the product.

Thus the railway wheel except the formation of metal layer on the surface of the rolling element with a high concentration of crystalline defects and first of all dislocations is open to thermal influence from the interaction with brake blocks. The nature of joint influence (cold deformation and heating) on the metal rim of the wheel specified the appearance of sufficiently high gradients of structural changes which in turn can be considered as the influence on the final level of internal residual stresses. But the effect largely depends on numerous factors the main of which are the degree of metal work hardening of the wheel rolling surface and the intensity of heating (energy density brak-

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ing, frequency and duration of interaction with braking blocks). Taking into consideration the existence of temperature gradient from the surface of the rolling element the intensity of the heating will be accompanied by the development of the processes of structural transformations in metal.

In this case the character of given structural changes will largely be connected with the distance of the layers of metal from the surface of heating. Thus in the surface metal layers due to the very high temperatures up to 700…800 C, the fine-grained ferrite structure with cementite particles of different morphology is formed. Moreover the metal volumes with a high degree of accumulated deformation (higher libel) will correspond more fine-grained ferrite structure with a high number of globular cementite with different ratios of mid-axles. In the metal layer, through the development of the processes of coalescence and dynamic recrystallization, the residual stresses from libel will be reduced significantly and as a result there will be the increase of the metal ability to deformation strengthening and resistance to crack nucleation [10].

For more in-depth from the surface of the rolling of metal layers for which the temperature does not exceed 500…550 °C, the picture is different. It is known that at temperatures of metal heating until the beginning of recrystallization in curing cycle polygonizational processes begin their development. Their development is accompanied by the redistribution of dislocations which are accumulated during libel and eventually the configurations in the form of polygonal sub structural distribution surfaces. It should be taken into consideration that the more complete the processes of polygonization the less integrity of the development of recrystallization. Thus at a certain depth from the rolling surface, a metal layer with fully or partially completed processes of forming structures of polygonization occurs. According to the different estimates [1] it can be up to 70% of the accumulated density of dislocations which almost all are in the bound state. Numerous successive stages of braking except heating will be accompanied by metal wear from the rolling surface. The metal layer with polygonal structure will be closer to the rolling surface and in succession (in proportion to the deformation gradient) will be opened to libel. New dislocations interacting with a polygonal structure will be blocked which in turn will lead to the complication of the development of the process of recrystallization and the required level of libel reduction will not be achieved. In this case the slowdown of the development of relaxation of internal stresses must reduce the metal ability to the deformation hardening and as a result of such position to reduce the resistance of wheel steel and emergence of submicrocracks.

Thus at a certain depth from the rolling surface of the railway wheel the metal layers with a high level of fragility are formed. Experimentally observing the lack of appearing in the given metal layer (except the examples of locations outside the normative oxides restrictions, slag inclusions and etc.) cracks can be obliged to the existence of the broken grid of structurally free ferrite. The availability of such component in the structure of wheel steel additionally promotes the development of relaxation processes at achieving the maximum possible concentration of crystalline defects in the ferrite pearlite. One explanation is the very rapid development of recrystallization of structurally free ferrite in comparison with paralytic colony at heating during the braking of rolling stock.

In modern conditions the increase of the mass of rolling stock, with a simultaneous increase of the intensity of movement, accompanied by the increase of loading on railway wheels and rails. Taking into consideration that under the conditions of high traction and breaking powers the motion process is on the verge of clutch, the question of optimal structural condition of railway wheel, tires and rails becomes relevant. Apart from this for higher speed movement the temperature influence is significantly increased especially in the area of contact of the wheel (tire) -rail. The given impact significantly connected not only with the structural state of the metal, but also with the peculiarities of the braking process. The comparative analysis of the influence on metal on the rolling surface, using disc brakes and block scheme, showed the existence of having much in common and also their features. Taking into account the specific character of loading, operating conditions, there is a certain different and optimal structural state of the metal of railway wheels and rails. Thus for the railway wheels the thermal strengthening processes are used especially for the amounts of metal rim which help to form small differential laminar structures of sorbitol with intermittent grid of structurally free ferrite, which is located on the former multi angular austenitic boundaries. The rails, on the contrary

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are strengthening by thermal treatments, which lead to the structures of improvement – the structural transformations by sliding mechanism with the further steel tempering [16]. In this case the structural metal state is the finely divided globules of carbide phase evenly located in ferrite matrix.

Based on the analyses of the internal structure of metal rim of railway wheel it is determined that after thermal hardening treatment the structure is a ferrite-pearlite mixture of various degrees of dispersion and morphology, depending on the distance from the surface of forced cooling [5]. During operation the railway wheel is open to a variety of influences. Thus, the emerging metal libel on the rolling surface having a certain gradient of values in the depth of the rim at the same time with the temperature gradient on the rim thickness from the interaction with a rail is determined the nature of structural changes in metal. However the nature of structural changes in metal of railway wheel during operation may vary depending on the used braking scheme.

For braking schemes with the use of braking pads it is determined that the compression of railway wheels on the rolling surface helps with sufficiently high speed to increase the temperature in subsurface metal layers. In this case the temperature of heating according to various estimates [1] in the metal layer up to 1 mm may be sufficient for the beginning of phase transformations (up to 800 C). Thus, for the metal volumes which are being heated up to 600…650 °C with the previous cold hardening, adequate 40–50% of plastic deformation, in the places of pearlites colonies partially formation is observed (depending on the degree of plastic deformation and the heating temperature) spheroidized carbide particles (Fig. 5).

The layers of structurally free ferrite after given influence can turn into chains which consist of small grains of different morphology. The reduction of the distance from the rolling surface at the same time increases the cold hardening degree of metal rim and the temperature of heating. As it was determined by the research, the heating of carbon steel from 0,6% C up to the temperatures of 700…720 °C after the previous plastic deformation 60…70% is accompanied by the development of the processes of recrystallization, the grain size of ferrite is inversely proportional to the heating rate and the cold hardening amount.

Taking into consideration that the contact spot of the railway wheel-rail has sufficiently small size for one rotation of the wheel on the rolling surface, a narrow strip with sufficient slander degree is formed, while adjacent areas on the rolling surface remain unchanged. So, only due to the interaction of a wheel and a rail during free rolling, quite heterogeneous metal cold hardening on the working surface of the rim occurs.

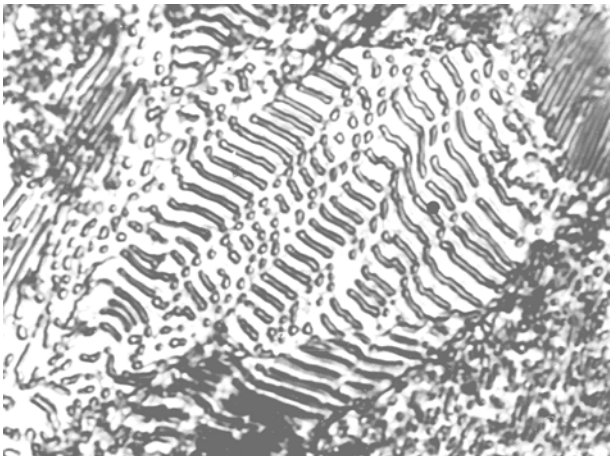

Fig. 5. The structure of pearlite colony of carbon steel after deformation 30% of heating up to 65 ºC. (Magnification 2 000)

In the process of braking, during the interaction of braking pads with the wheel, relatively equable metal heating over the total contact surface is accompanied by the development of the processes of structural changes with simultaneous volume alignment and the reduction of accumulated defects in the crystal metal structure. Except this, the braking pads function as a kind of tool that removes the surface metal layer including the areas with little surface damages.

Thus, in the process of braking the equable cutting of heterogeneous cold-worked with possible surface damages in metal layer takes place, which can be considered as a kind of improving quality process of the rolling surface. The surface heating contributes to the relaxation of internal stresses from the remains of work-hardened metal.

Further, during the railway wheel operation the structural changes on the rolling surface will have their development. After the end of braking stage, without train stopping, the heated wheel with partially removed damaged metal layer further is accessible to the plastic deformation with high temperature heat. When the heating degree is enough, the processes of relaxation of internal stresses on the places are taken place. With the gradual reduction of temperature, the consistent development of the processes of recombination of defects in the

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crystal structure up to about 400 ºC, dynamic aging strain up to 350…200 °C can lead to the increase of durable properties at constant stock of plasticity and in some cases to increase the plasticity and brittle destruction resistance [4].

The nature of structural changes, during the railway wheel operation, when using the disc braking system, is different from the observed ones when using the pads. At first, it should be noted the lack of equable metal heating on the rolling surface. The emerging of metal cold hardening from the interaction with a rail as it is above mentioned has a very high heterogeneity in the rolling surface. The energy transmission at braking from the braking discs through the axis of wheels' pair on the place of contact with a rail is limited by sufficiently little area. Based on this it can be assumed that sufficiently large voltages from a high energy density are appeared. This is due to the relatively low heating temperatures of subsurface metal layers of a wheel. In this case the lack of development of relaxation processes (insufficiently high temperature), the accumulation of defects in the crystal structure to the maximum possible boundary and at diverse beginning of brake elements operation to a failure of conditions of in adhesion, all this will help to appearing of defects on the rolling surface and the wheels removal out of service. Taking onto account the experimental data [8], which showed that lately on the train, the cases of using the disc braking system become more frequent, premature wheels' withdrawal at a failure of the geometry conditions. The rolling surface of railway wheel from the form of like circle, relatively quickly turns into a polygon. Given information can be considered as one of the evidences of probability of structural changes in the metal of wheel rim when using the different braking systems.

Steels that are used for the manufacture of wheels and tires, after hot plastic deformation as it is showed above, have the structure that consists of pearlite colonies and the areas of structurally free ferrite. The increasing of cooling rate, for example as at thermal strengthening treatments of railway wheels simultaneously with the dispersion of pearlite colonies it is observed the decrease of volume fraction of structurally free ferrite due to the formation of pseudo eutectoid [7]. However even in the case of achieving the highest cooling rates, it is impossible to eliminate the allocation of layers of unbound ferrite on multiangular boundaries of austenite grains (Fig. 6, *a*).

So, the optimal structure that can be formed in the process of accelerated cooling of the rim of railway wheel is laminar sorbitol with intermittent grid of structurally free ferrite. Taking into consideration sufficiently complex form of railway wheel and the size variation of its elements, fully train wheel and its individual elements can be under strengthening thermal treatment. Such approach for the solving the problem of increasing the reliability of railway wheel service are depending on the loading conditions. One of the possible characteristics can be the occurring stresses that appear in wheel's elements from interferences. Taking into account the structural peculiarities of the wheel disc, the form of the diagram stresses gave the opportunity to develop the process of thermal strengthening treatment which allows through the formation of structural state of a wheel disc influences on the level of internal stresses of the rim. So, during the using of forced accelerated disc cooling, especially in the places of transition to the rim and hub, due to the formation of bainitic structures at a certain depth from the cooling surface and further self-tempering (adequate individual heating up to temperatures of 600…650 ºC) globular structures of carbide phase are achieved.

In comparison of the laminar form of cementite, which is a part of pearlite colony is able to bear large plastic deformation [7], globular carbides on the contrary even after the degrees of deformation when the metal is destroyed, remain practically unchanged. In this case, the development of the processes of dispersive hardening largely determines the metal behavior under loading. So in the case when cementite globulars are located on the multiangular boundaries of ferrite grains (Fig. 6, *b*), it is experimentally observed the increase of metal resistance nucleation and the growth of cracks, especially for the relatively low temperatures [4].

The shown position by the ratio between the number of nucleation sites and annihilation of dislocations during the metal slander is conditioned. In the case of location of cementations globulars on the multiangular ferrite boundaries, interfacial surface of ferrite- cementite performs the functions of both the source and the places of annihilation of dislocations after they perform the deformation act [4, 7]. Based on this it becomes evident that the increase of volume fraction of cementite, even without taking into consideration the dispersion, increases the resistance to nucleation of cracks due to the low level of deformational strengthening [4].

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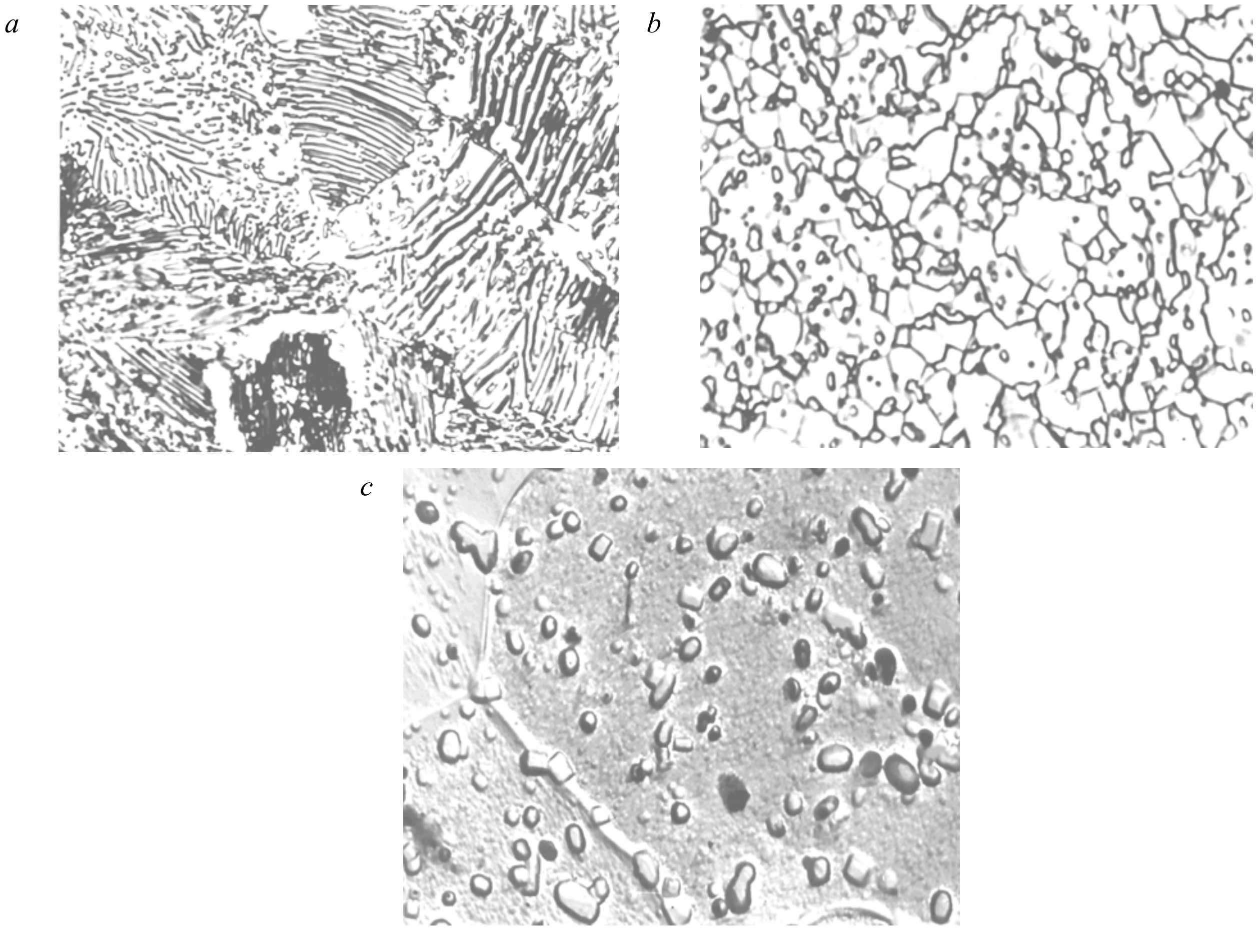

Fig. 6. The structure of wheel steel from 0,6% C after hot plastic deformation (*a*), after quenching from the normal temperature tempering at 650 ºC, deformations 50…60%, annealing at 650 ºC (*b*), after quenching from the normal temperature tempering at 650 ºC, deformations of 15%, annealing at 650 ºC (*c*). Magnification 800 (*a*), 2 000 (*b*), 4 000 (*c*)

In a case when the grain size of ferrite greatly exaggerates inter carbide distance (Fig. 6, *c*), the picture is largely changed.

The given position of different absorption capability of dislocations after the elementary act of the plastic deformation of metal is conditioned. In comparison with multiangular ferrite boundaries, interphase ferrite-cementite can be the place of annihilation of dislocations only in the case when cementite globular is located in crystallographic glide area of dislocations. Then with the increase of volume fraction of carbide phase, at a constant grain size of ferrite only the increasing of sources of dislocations' nucleation is achieved, without the changing the number of annihilation places. In this case the accumulation of dislocations at the early stages of plastic deformation (in metal volumes in front of the delta arm of a crack) will form around the cementite globulars certain density of inter blocked dislocations. Based on this there is a sharp increase of parameters of deformation hardening of carbon steel [3]. Taking into consideration, that for medium and high carbon steels the increase of deformation strengthening is accompanied by the decrease of plastic properties, it can be considered that in this case the metal volumes near inter phase surfaces allocation will be the most likely places of submicrocracks' origin.

Thus, when using carbon steel with the number of carbon when there is no possibility of eliminating the structurally free ferrite, optimal structural condition should be considered as laminar structures. Pearlite colonies together with structurally free ferrite take part in the plastic metal deformation, which makes possible the development of annihilation processes, which help to break the processes of nucleation and the growth of microcracks in metal of railway wheels during operation.

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On the other hand, taking into account the emergence of quite complex stress state of metal in the wheel disc during operation it can be considered that the use of strengthening of thermal treatment of disc will contribute to the change of the stress field in the other elements.

Originality and practical value

In the process of breaking the rolling stock the increase of heating speed of metal on the rolling surface is accompanied by the temperatures' growth, which is sufficient to the beginning of phase transformations. There are the formation of several structures from the formed of sliding to diffusion mechanisms at further cooling. As a result, the indicated areas become the centers of future metal destructions on the rolling surface of wheels and tires.

Based on the study of regularities of damages' formation in railway wheels and tires from the peculiarities of internal metal structure and the operating conditions "The classifier of defects" was developed and «Technical tips for determination of causes of cracks in solid-rolled railway wheels and destruction in general» should be introduced on Ukrzaliznytsia.

Conclusions

Based on the analysis of occurring stresses in the transition areas between the elements of a wheel, the direction of the change of geometrical sizes of the elements is defined, that will reduce the equivalent stresses.

The analysis of changes in the internal structure of carbon steel due to the heating degree from the rolling surface shows that the proportional to the temperature gradient the internal stresses are appeared, which lead to the formation of destruction origination in the places with low metal resistance.

The use of materials with a low coefficient of heat transmission for the manufacture of braking pads in the comparative conditions of braking increase the temperatures' gradient in metal near the rolling surface.

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ПРОЦЕС ФОРМУВАННЯ УШКОДЖЕНЬ ЗАЛІЗНИЧНИХ КОЛІС ТА БАНДАЖІВ ПРИ ЕКСПЛУАТАЦІЇ

Мета. У роботі необхідно провести аналіз залежності структурних перетворень у металі залізничних коліс та бандажів від визначених впливів при експлуатації, для подальшої розробки концепції підвищення їх експлуатаційної надійності. **Методика.** Матеріал для досліджень – фрагменти, відібрані від залізничних коліс, які, в свою чергу, передчасно, за рахунок різноманітних ушкоджень, були вилучені з експлуатації. Мікроструктурні дослідження проводили з використанням світлового мікроскопа Epiquant. та електронного мікроскопа. Оцінку розміру структурних елементів проводили, використовуючи методики кількісної металографії. **Результати.** В останні десятиріччя прискорений розвиток промисловості супроводжувався неухильним зростанням інтенсивності експлуатації залізничного транспорту. При цьому одночасне підвищення навантаження на вісь колісної пари, разом із зростанням швидкості руху, супроводжувалося закономірним збільшенням кількості випадків передчасного вилучення коліс і бандажів із експлуатації. Залізничне колесо, окрім формування прошарку метала по поверхні кочення з високою концентрацією дефектів кристалічної будови і, в першу чергу, дислокацій, піддається температурному впливу від взаємодії з гальмівними колодками. Характер сумісного впливу (холодне деформування й розігрів) на метал ободу колеса обумовлює виникнення достатньо високих градієнтів структурних змін, що, в свою чергу, може розглядатися, як вплив на рівень внутрішніх остаточних напружень. При підвищенні об’ємної частки карбідної фази, при незмінному розмірі зерна фериту, досягається лише збільшення джерел зародження дислокацій, без зміни кількості місць анігіляції. В цьому випадку накопичення дислокацій вже на початкових етапах пластичної деформації (в об’ємах металу попереду гирла тріщини) призведе до формування навколо глобулів цементиту визначеної щільності взаємозаблокованих дислокацій. На підставі цього спостерігається різке підвищення параметрів деформаційного зміцнення вуглецевої сталі. **Наукова новизна.** В процесі гальмування рухомого складу підвищення швидкості розігріву металу на поверхні кочення супроводжується зростанням температур, достатніх до початку фазових перетворень. При подальшому охолодженні відбувається поява низки структур, сформованих від зсувного до дифузійного механізмів. Внаслідок цього, вказані ділянки стають осередками майбутніх руйнувань металу на поверхні кочення коліс і бандажів. **Практична значимість.** На основі вивчення закономірностей формування ушкоджень у залізничних колесах та бандажах від особливостей внутрішньої будови металу та умов експлуатації розроблено «Класифікатор дефектів» та «Методичні вказівки з порядку визначення причин виникнення тріщин в суцільнокатаних колесах та руйнування в цілому», котрі впроваджено на Укрзалізниці.

Ключові слова: залізничні колеса; бандажі; мікроструктура; пошкодження; руйнування

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МАТЕРІАЛОЗНАВСТВО

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ПРОЦЕСС ФОРМИРОВАНИЯ ПОВРЕЖДЕНИЙ ЖЕЛЕЗНОДОРОЖНЫХ КОЛЕС И БАНДАЖЕЙ ПРИ ЭКСПЛУАТАЦИИ

Цель. В работе необходимо провести анализ зависимости структурных превращений в металле железнодорожных колес и бандажей от определенных воздействий при эксплуатации, для дальнейшей разработки концепции повышения их эксплуатационной надежности. Материал и методика исследований. **Методика.** Материал для исследований – фрагменты, отобранные из железнодорожных колес, которые, в свою очередь, преждевременно, за счет различных повреждений, были изъяты из эксплуатации. Микроструктурные исследования проводили с использованием светового микроскопа Epiquant. и электронного микроскопа. Оценку размера структурных элементов проводили, используя методики количественной металлографии. **Результаты.** В последние десятилетия ускоренное развитие промышленности сопровождалось неуклонным ростом интенсивности эксплуатации железнодорожного транспорта. При этом одновременное повышение нагрузки на ось колесной пары, вместе с ростом скорости движения, сопровождалось закономерным увеличением количества случаев преждевременного изъятия колес и бандажей из эксплуатации. Железнодорожное колесо, кроме формирования прослойки металла по поверхности катания с высокой концентрацией дефектов кристаллического строения и, в пер-вую очередь, дислокаций, подвергается температурному воздействию от взаимодействия с тормозными колодками. Характер совместного влияния (холодное деформирование и разогрев) на металл обода колеса обуславливает возникновение достаточно высоких градиентов структурных изменений, что, в свою очередь, может рассматриваться как влияние на уровень внутренних окончательных напряжений. При повышении объемной доли карбидной фазы, при неизменном размере зерна феррита достигается только увеличение источников зарождения дислокаций, без изменения количества мест аннигиляции. В этом случае накопления дислокаций уже на начальных этапах пластической деформации (в объемах металла впереди устья трещины) приведет к формированию вокруг глобулы цементита определенной плотности заблокированных дислокаций. На основании этого наблюдается резкое повышение параметров деформационного упрочнения углеродистой стали. **Научная новизна.** В процессе торможения подвижного состава повышение скорости разогрева металла на поверхности катания сопровождается ростом температур, достаточных для начала фазовых превращений. При дальнейшем охлаждении происходит появление ряда структур, сформированных от сдвижного к диффузионному механизмам. Вследствие этого, указанные участки становятся очагами будущих разрушений металла на поверхности катания колес и бандажей. **Практическая значимость.** На основе изучения закономерностей формирования повреждений в железнодорожных колесах и бандажах от особенностей внутреннего строения металла и условий эксплуатации разработаны «Классификатор дефектов» и «Методические указания по порядку определения причин возникновения трещин в цельнокатаных колесах и разрушения в целом», внедренные на Укрзализныце.

Ключевые слова: железнодорожные колеса; бандажи; микроструктура; повреждение; разрушение

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