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RESEARCH DISTRIBUTION OF RESIDUAL STRESSES IN THE RIM OF A HEAT-PROCESSED RAILWAY WHEEL

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Annotation

In the rim of a railway wheel hardened by surface plasma hardening, the nature and distribution of internal residual stresses are investigated. It is shown that during surface plasma hardening, the nature of the distribution of residual stresses depends on the power of the plasma jet (arc), the hardening rate, and the initial state of the metal. It is noted that in order to increase the wear and crack resistance, as well as the fatigue strength of the wheel metal when setting the plasma quenching mode, it is necessary to create conditions leading to a maximum value of the residual compressive stresses in the surface and subsurface layer and a change in the sign of the residual stresses at the interface with the initial structure by translating compressive stresses in stretching. This can be achieved with a plasma jet power of 14-15 kW, hardening speed of 10-15 mm / s, the width of the hardened track 25-30 mm.

It is shown that the results of x-ray studies of the distribution of residual stresses are qualitatively confirmed by the data of the destructive mechanical method. Assessment of the nature of length of the sample indicates that compressive stresses act in the surface layers of the rim, which in tensile layers of the rim transform into tensile stresses.

Keywords

Plasma hardening, residual stresses, X-ray and mechanical methods, stress distribution, wear resistance, fatigue strength, wheel rim, plasma jet, contact surface, hardened layer.

Introduction

The creation of large internal compressive stresses in the surface hardened layer of the material is an important factor increasing the performance of parts and assemblies operating under conditions of large contact and alternating loads. This is due to the fact that fatigue cracks on the surface of heavily loaded parts arise under the influence of internal tensile stresses. When internal compressive stresses occur on the surface, they reduce tensile stresses arising from an external load, which leads to an increase in wear resistance, fatigue strength, and brittle fracture resistance [1,2].

During operation, various stresses act on the wheel, the main components of which are stresses from wheel pressure on the rail, dynamic loads from impacts on rail joints, stresses arising from braking heat, etc. These stresses are superimposed on the field of residual stresses arising in the wheels during their hardening heat treatment. Thus, in addition to large static and dynamic stresses, the wheel also receives significant thermal stresses. Residual stresses of various origins add up algebraically and therefore can enhance or weaken operating stresses. The strength of the wheel under such operating conditions will depend on the actual size and nature of the distribution of operating stresses, which determine the actual stress state of the wheel [3].

As you know, one of the main reasons for the occurrence of internal residual stresses is a different change in the specific volume at different points of the product during compression and expansion during heat treatment. If thermal compression and expansion, leading to a change in the specific volume of the material, passed simultaneously and to the same extent throughout the volume, then internal stresses would not have arisen. But when heating and cooling, there is always a temperature gradient over the cross section of the body, and therefore the above-mentioned changes in the specific volume at different points of the metal proceeds unevenly, as a result of which internal stresses arise.

It should be noted that there is clearly not enough information about the effect of hardening heat treatment modes on the magnitude and nature of the distribution of internal stresses in solid-rolled railway wheels, so it is of undoubted interest to study the factors affecting the magnitude and distribution of tensile and compressive internal stresses over the cross section of the hardened wheel.

Tensile internal stresses in the surface layers are especially harmful to parts and assemblies such as wheelsets working under alternating loads, since such stresses contribute to fatigue failure of the wheel; As is known, a fatigue crack nucleates, as a rule, on the contact surface of a wheel-rail friction pair [4].

Materials and methods of research

In this work, the determination and nature of the distribution of residual stresses were evaluated by X-ray and mechanical methods.

As you know, the X-ray method is one of the main methods for determining residual stresses, which allows you to measure the residual stresses on the hardened surface, since X-rays penetrate the metal surface to a small depth.

The distribution of internal stresses on the surface and in the depth of the hardened layer of metal of the wheel was studied by the X-ray method using a DRON-1 X-ray diffractometer. The method is based on precision measurements of the interplanar spacings of the crystal lattice in the presence of internal stresses. This is due to the fact that, under the action of mechanical stresses, elastic deformations cause a change in the atomic interplanar spacings in the crystal lattice, in accordance with which changes the x-ray diffraction angles change. A change in the diffraction angle in the presence of mechanical stresses leads to a shift of the diffraction peak in the recorded diffraction pattern relative to its position in the absence of stresses. The magnitude of elastic deformation is directly determined from this displacement [5,6].

From the theory of x-ray diffraction it is known that if the radiation wavelength λ and the angle of incidence α satisfy the Wulff-Bragg condition:

$$n \lambda = 2d \cos \alpha,$$

then the incident rays are reflected without penetrating deep into the crystal. (Here n is an arbitrary integer, d is the distance between two adjacent atomic planes of the crystal lattice). The X-ray method allows to determine the total stress state of the wheel as a result of the impact of operational loads and the influence of internal residual stresses.

It should be noted that the accurate determination of internal macroscopic stresses (stresses of the first kind) is difficult due to the presence of phase stresses that arise as a result of phase (structural) transformations during heat treatment. The occurrence of phase stresses, as is known, is due to the fact that the phase and structural components of steels (austenite, ferrite, martensite and two-phase structures - perlite, sorbitol) have different specific volumes. During heating and cooling, this leads to the appearance of thermal and phase stresses due to the gradient of thermal expansion and compression of these structural components of steels.

The difficulty in accurately determining residual stresses of the first kind, especially in bodies of complex shape such as railway wheels, makes it necessary and advisable to use the mechanical method to determine the nature of the distribution of residual stresses in the wheels.

The use of this method is based on the fact that in a metal with residual stresses, there are regions of elastic strains of different signs. If the surface layer is cut off (or pitted) from it, then elastic removal of residual stresses becomes possible, i.e. mechanical methods for determining the magnitude and sign of residual stresses are based on measuring the resulting elastic deformations. The value of residual stresses can be calculated from deformations. Therefore, a technique was adopted to study the distribution of residual stresses in the wheel rim, based on the measurement of the residual deformation that occurs when it is cut. The deformation can be judged by the change in the length of the sample, which must be accurately measured. Measurements were made with an accuracy of 0.05 mm. The method of cutting and testing the wheels was as follows.

The test sample 5 mm thick with dimensions 40 x100 mm is cut from the wheel rim. The ends of the sample must be adjusted exactly 90 degrees to its edges.

A 0.5 mm thick layer is removed from the outer edge of the sample thus prepared. For this, we used the Uniton-2 manual bench cutting machine (manufactured in Denmark), in which the cutting disc was cooled with water with an anti-corrosion additive. Before and after removing the layer, the length of the sample is carefully measured with a caliper, and the width of the sample with a micrometer.

The sign of residual stresses is determined by the change in the length of the sample. If the length of the sample has increased, it means that the metal layers in which tensile residual stresses acted have been removed. A reduced sample length is an indication that the metal layer in which compressive residual stresses acted has been removed. To do this, carefully measure the length of the sample before removing the edge, and then after each removal. From the difference in sample lengths before and after removal, Δ l is determined.

The cross-sectional area F = bxh is calculated before and after each removal. The difference in the respective areas determines ΔF– the cross-sectional area of the remote strip. The stress in the sample is $\sigma = E\Delta l / l$, kg / mm2, where E is the modulus of elasticity of steel, E = 21000 kg / mm2. According to the results of measurements and calculations, a conclusion is made about the nature and distribution of residual stresses [7].

The main results of research

As is known, the nature of the distribution of internal stresses during plasma hardening depends on many factors: the parameters of the hardening regime, primarily the power of the plasma jet, the hardening rate, the initial state of the wheel metal, etc.

The distribution of residual stresses across the hardened bandage layer during plasma quenching shows the following. When processing without melting the surface in the range of jet powers P = 4–11 kW, tensile stresses σv = 100–140 MPa are observed in the center of the hardened layer, and at the interface with the base metal they increase to 250 MPa.

With an increase in the power of the plasma jet (arc) in the interval P = 11-14 kW, compression stresses σv = 180-250 MPa are formed in the center of the hardened layer. A further increase in power to P = 15–17 kW with access to the micromelting mode is noted by an increase in the value of residual compressive stresses to σv = 250–380 MPa [8.9].

The magnitude and nature of the distribution of residual stresses is significantly affected by the plasma hardening rate. At low hardening rates, tensile stresses form in the center of the hardened layer, which is due to the predominance of stresses from thermal volume changes over stresses from phase-structural stresses. With an increase in processing speed over 10 mm / s, the sign of stresses in the center of the hardened zone changes. The nature of the distribution of residual stresses over the depth of the hardened layer depending on the hardening rate is shown in Figure 1

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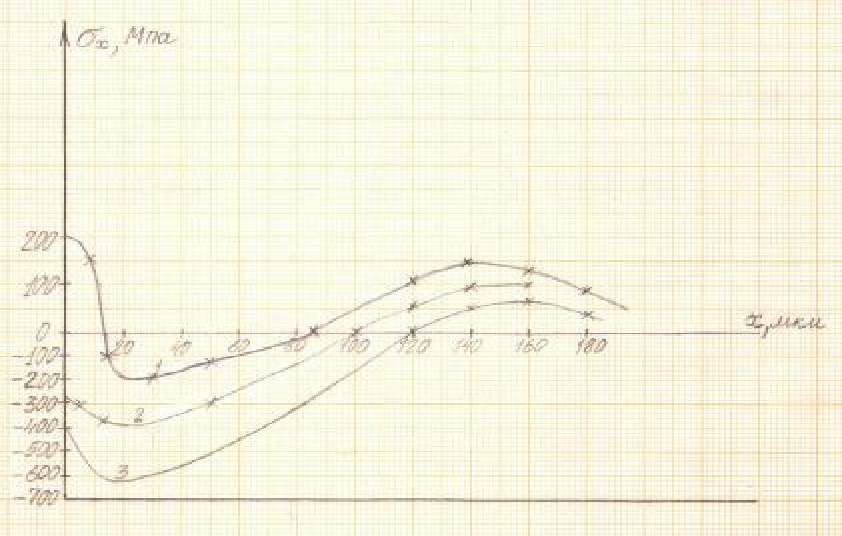

1) V_{hard} = 3,5 mm/s; 2) V_{hard} =10,0 mm/s; 3) V_{hard} = 14,5 mm/s.

Figure 1 - Distribution of residual stresses along the depth of the hardened layer depending on the hardening rate

The distribution of residual stresses along the depth of the hardened layer depending on the hardening speed (3.5 mm / s; 10.0 mm / s; 14.5 mm / s) shows that the maximum value of the residual compression stresses (at Vupr = 10.0 mm / s ~ 400 MPa) is located in the subsurface layer of the metal of the wheel, and at the border with the initial metal structure, the sign of the residual stresses changes. As noted above, the formation of residual compressive stresses in the hardened metal layer enhances crack resistance and fatigue strength.

Discussion of the data

From the experimental results it follows that in order to increase the wear and crack resistance, as well as the fatigue strength of the metal when setting the plasma hardening regime, it is necessary to create conditions leading to a maximum value of the residual compressive stresses in the surface and subsurface metal layer and a change in the sign of the residual stresses at the interface with the initial structure by transferring compressive residual stresses to tensile ones. In our experiments, this is achieved with a plasma jet power of 14-15 kW, hardening speed of 10-15 mm / s, and the width of the hardened track 25-30 mm.

The results of the assessment of residual stresses by changing the length of the sample are presented in table 1. Note that the assessment of internal stresses by changing the length of the sample is not strict, since it is based on certain assumptions.

Table 1-Determination of residual stresses by changing the length of the sample

Operations	*h,мм*	*b,мм*	*l, мм*	*F,мм*^{2}	*ΔF, мм*^{2}	*Δl, Мм*	σ, *кг/мм*^{2}	Character distribution residual stress
Before deletion	5	40	100	200	-	-	-	
After uninstall	-	-	-	-	-	-	-	
1	5	39,5	99,30	197,5	2,5	- 0.70	-148.0	Compressive
2	--*1*--	39,0	98.35	195,0	--*1*--	- 0,95	-202.8	
3	--*1*--	38,5	97.05	192,5	--*1*--	-1.30	-281.3	
4	--*1*--	38,0	96,25	190,0	--*1*--	- 0.80	-174.6	
5	--*1*--	37,5	96.25	187,5	--*1*--	0	0	Change sign stresses
6	--*1*--	37,0	96,75	185,0	--*1*--	+0.50	+108.5	Stretching
7	--*1*--	36,5	97.42	182,5	--*1*--	+0,67	+144.4	
8	--*1*--	36,0	98.25	180,0	--*1*--	+0.83	+177.5	
9	--*1*--	35,5	99,20	177,5	--*1*--	+0.95	+201.1	
10	--*1*--	35,0	99.80	175,0	--*1*--	+0.60	+126.3	

Conclusion

1. From the analysis of literature data it follows that the desire for mandatory removal of residual stresses in many cases is unjustified. The presence of compressive stresses in the surface layer of heavily loaded products significantly increases the resistance to fatigue spalling and their wear and crack resistance.
2. An X-ray study of the distribution of residual stresses on the surface and in the depth of the hardened layer of metal of the wheel showed that the nature of the distribution of residual stresses depends on the power of the plasma jet (arc), the hardening rate, and the initial state of the metal.
3. It is shown that in order to increase the wear and crack resistance, as well as the fatigue strength of the metal when setting the plasma quenching mode, it is necessary to create conditions leading to the maximum value of the residual compressive stresses in the surface and subsurface layer and a change in the sign of the residual stresses at the interface with the initial structure by translating compressive tensile stresses.
4. The results of x-ray studies of the distribution of residual stresses are qualitatively confirmed by the data of the destructive mechanical method, indicating that compressive stresses act in the surface layers of the rim, which in tensile layers of the rim transform into tensile stresses.

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ИССЛЕДОВАНИЕ РАСПРЕДЕЛЕНИЯ ОСТАТОЧНЫХ НАПРЯЖЕНИЙ В ОБОДЕ ТЕРМООБРАБОТАННОГО ЖЕЛЕЗНОДОРОЖНОГО КОЛЕСА

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Резюме

Показано, что при поверхностной плазменной закалке характер распределения остаточных напряжений зависит от мощности плазменной струи (дуги), скорости упрочнения и исходного состояния металла. Отмечено, что для повышения износо и трещиностойкости, а также усталостной прочности металла колеса при назначении режима плазменной закалки необходимо создать условия, приводящие к максимальному значению остаточных сжимающих напряжений в поверхностном и подповерхностном слое и изменению знака остаточных напряжений на границе с исходной структурой путем перевода сжимающих напряжений в растягивающие. Результаты рентгенографических исследований распределения остаточных напряжений качественно подтверждаются данными разрушающего механического метода. Оценка характера распределения остаточных напряжений по изменению длины образца свидетельствует о том, что в поверхностных слоях обода действуют сжимающие напряжения, которые в более глубоких слоях обода переходят в растягивающие напряжения.

Ключевые слова

Плазменная закалка, остаточные напряжения, рентгеновский и механический методы, распределение напряжений, износостойкость, усталостная прочность, обод колеса, плазменная струя, контактная поверхность, упрочненный слой.

ТЕРМИЯЛЫҚ ЖОЛМЕН ӨҢДЕЛГЕН ТЕМІРЖОЛ ДОҢҒАЛАҚТАРЫНЫҢ ОБОДЫНДАҒЫ ҚАЛДЫҚ КЕРНЕУЛЕР

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Түйін

Сыртқы қабаты плазмалық шынықтыру арқылы беріктендірілген теміржол доңғалағының ободындағы ішкі қалдық кернеулердің таралуы зерттелді. Сыртқы қабаты плазмалық шынықтырылғанда қалдық кернеулердің таралуы доғаның қуатына, беріктендіру жылдамдығына және металдың бастапқы жәй күйіне байланысты болатыны көрсетілген. Ободтың тозуға төзімділік пен жарықшақтыққа қарсылығын арттыру, сонымен қатар, доңғалақ металының шаршау беріктігін көтеру үшін плазмалық шынықтырудың кестесін белгілеуде сыртқы және одан төмен қабатта қалдық кернеулердің жоғарғы мәнін қамтамасыз ету үшін және құрылымның бастапқы шегінде қысу қалдық кернеулерінің созу қалдық кернеулерге ауысуына жағдай жасау керектігі атап өтілген. Қалдық кернеулердің таралуын рентгенографиялық әдіспен аныктау нәтижесінде механикалық қирататын әдіспен зерттеу толықтай құптап дәлелдейтіндігі көрсетілген. Қалдық кернеулердің таралуын үлгі ұзындығының өзгеруіне байланысты бағалау доңғалақтың сыртқы қабатында сығу кернеулерінің пайда болуын, ал олардың төменгі қабаттарында созу кернеулеріне ауысатыны көрсетілген.

Кілттік сөздер

Плазмалық шынықтыру, қалдық кернеулер, рентген және механикалық әдістер, қалдық кернеулердің таралуы, тозуға төзімділік, шаршауға беріктік, доңғалақ жиегі, плазмалық ағын, байланыс беті, беріктендіру қабаты.

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Summary

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