The Transformation of Structure Steel with Thermal Strengthening of The Disk Railway Wheel

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***Abstract*— On the example of the carbon steel, issues of structuring in the process of accelerated cooling are considered. The emerging gradient of structures at different distances from the surface of the heat transfer is presented in the form of a dependence, which is adequate to the effect of the temperature of individual heating during the release of steel after the quenching. It is shown that after the forced cooling is stopped, the increase of distance from the cooling surface accompany higher the tempering temperature of the metal. In the volumes of the metal, the microstructure close to the middle of the disk wheel is formed by the diffusion mechanism.**

***Keywords* - carbide particle, dislocation, polygonization, martensite, softening, railway wheel**

I. INTRODUCTION

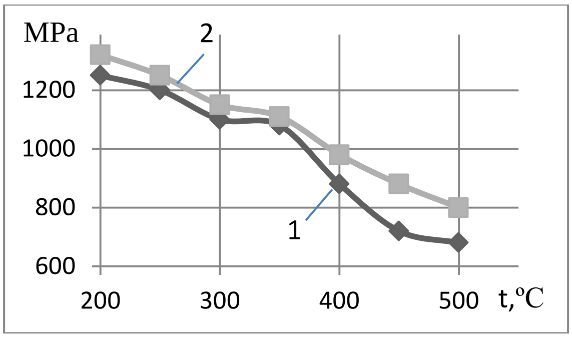
In the process of thermally strengthening the disc of railway wheels, the formation of a gradient of structures from the surface of the forced heat transfer is accompanied by a certain change in the complex of properties [1,2,3,4]. Investigations of the processes of structural transformations on the technology of intermittent accelerated cooling determined that significant influence on the achievement of the level of properties due to the development of processes of self-discharge [6]. Taking into account the continuous nature of the change in the cooling velocity in different metal wheels of a wheel, depending on the distance from the surface of the intense cooling, the structural state of the metal will be adequate for release at a certain temperature [7,8]. In the process of accelerated cooling, the gradient of structures at the intersection of the disk is determined solely by the temperature of the cooling end [9], and the subsequent release of metal near the surface due to heating from the heat of internal, deepened volumes, is accompanied by complex structural changes in the internal structure [2,9]. Purpose. The structural changes in carbon steel after accelerated cooling to determine the resource of increasing the strength of the disk railway wheel are investigation.

II. MATERIAL AND METHODS OF RESEARCH

As a material for research, carbon steel with a chemical composition was used: 0.61% C, 0.37% Si, 0.66% Mn, 0.0021% S, 0.014% P, used for the manufacture of railway wheels. Preparations for samples were made from fragments of the disk drive after accelerated cooling. To determine the effect of the degree of heating the metal, samples for testing were cut from the disk surface and central volumes. Measurement of temperature on the surface and in the middle of the disk in the process of accelerated cooling was carried out using thermocouples of the type chromel-alumin. The specimens in the form of foil were made by pinching in chloro-acetic electrolyte and Morris reagent, and examined under an electron microscope with an acceleration voltage of 100 kV. The level of accumulation of defects in a crystalline structure was estimated by expanding the line by interference (110), using X-ray structural analysis techniques on the DRON-2.0 device, with scintillation pulse recording, in monochromatic $CuK\alpha$ radiation. The complex of properties was determined from the analysis of patterns of stretching of samples on a machine of type "Instron", with a deformation rate of $10^{-3}s^{-1}$, microhardness of steel was measured on the device PMT-3, with a load on the indenter of 0.49 N.

III. RESULTS

The nature influence of the temperature end of the accelerated cooling of the surface disk wheel on the complex properties investigated steel is shown in Fig. 1. The analysis of the nature of the dependence between the strength and yielding stresses indicates a complex nature of structural transformations, depending on the temperature of stop accelerated cooling. Indeed, for temperatures of 200-300°C, a decrease in the strength characteristics due to the decrease in the saturation of the solid solution is observed. Almost an equidistant placement of dependences for strength and yield stresses (Fig. 1a) indicates that the main factor of influence should be considered the degree of saturation solid solution of carbon atoms in the process of accelerated cooling, and dispersion hardening a significantly lower value. Moreover, the process of pick out carbon atoms from a solid solution has a double effect on the strength properties of the metal. In addition to reducing the degree of tetragonal crystal lattice ferrite (softening the metal), the pick out of carbon atoms on the dislocation, facilitating their further fixation [7,10], has the effect of strengthening. The reduction of the strength range from 1300 to 800 MPa is accompanied by a corresponding decrease in the expansion of X-ray interference from 9 to 4 mrad.



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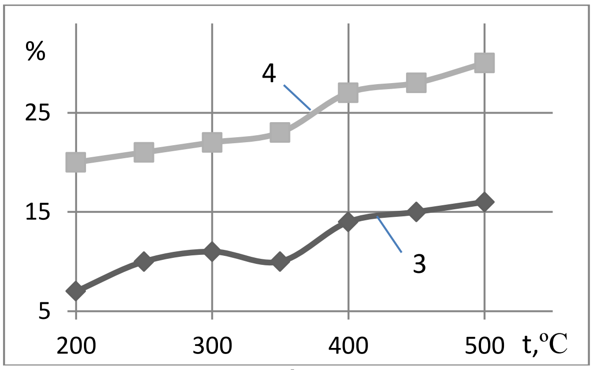


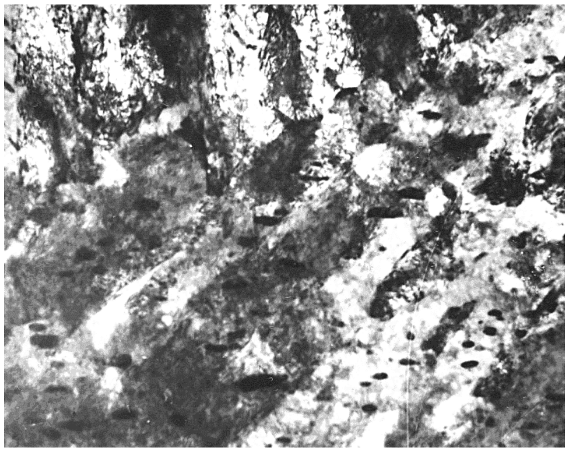
b

Fig. 1 The dependence of the strength (1) and yield stresses (2), elongation (3) and constriction (4) of the metal disk from the temperature end of accelerated cooling

Analysis structure of metal layers near the surface of the heat transfer fluid indicates the existence appearance of bars martensitic after a low temperature tempering (Fig. 2). The thickness of the formed racks of martensite is in the range of 0.1-0.8 μm. On the boundaries of individual rails and packages there are fine particles of carbides with sizes of 0,03-0,04 μm (Fig. 2). In a larger number of broad bars, very small dotted cementite can be observed, with random orientation. The formation of the specified carbide particles was due to the development of the process of release from the heat of deepened volumes of metal after the cessation of accelerated cooling.

With further deepening from the cooling surface, the metal, after the formation of the structures behind the shear or intermediate mechanisms, is released at higher temperatures. Taking into account the lack of qualitative structural changes in the structure of the metal, the difference in the strength of the steel may be due only to the change in the degree of super saturation of the solid solution, the allocation of dispersed carbide particles. Compared with the volumes of metal subjected to the tempering to 200°C, the increase in the temperature of the cooling completion by 100-150°C reduces the strength and increases the plasticity of the steel (Fig. 1).

Fig. 3 shows the microstructure for metal layers with a cooling down temperature of approximately 400°C. A detailed analysis of the structure determines the signs of the development initial stages of processes similar to polygonization. Confirmation is the existence of closed and tear dislocation contours. The location of cementite disperse particles in volumes with low dislocation density is an additional indication of the development, and in some places and the completion of polygonation after the cessation of accelerated cooling of steel. The final result is the formation structure similar to a modular one, when separate dislocation cells with a defined dislocation density in the middle are separated by sufficiently wide dislocation walls. The development of the processes of recombination of dislocations, against the background of reducing their total number, leads to the emergence of a dislocation cell structure, which in the form is closer to the polyhedron (Fig. 3a). The body of the dislocation cells themselves has, to a large extent, already been cleared of unbound dislocations. In the volumes of ferrite, there is a certain number of particles of cementite, which by size exaggerate the particles after 200°C (Fig. 2).



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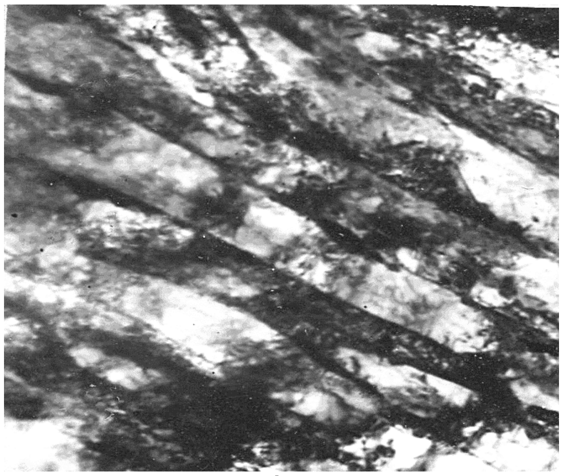


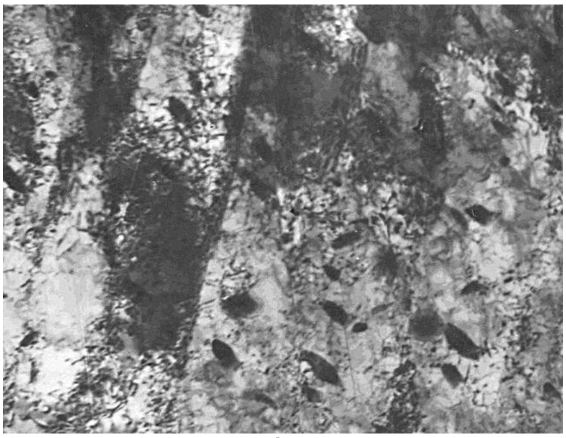
b

Fig. 2 The structure of the steel disk railway wheel after accelerated cooling to 200-250°C (bainite upper – a; bainite lowe - b). Magnification 18000

Thus, after the forced cooling is stopped, the higher the distance from the surface of the main heat transfer, the higher the temperature is, the tempering of the metal. In the metal volumes, which are approaching the middle of the disk wheel, the microstructure is formed by diffusion mechanism. The analysis of the internal structure of accelerated cooled metal shows that the structure consists of a finely differentiated perlite, with the arrangement of small volumes of structurally free ferrite on the doundaries the perlite colony (Fig. 4a). The thickness of the cementite plates in perlite is at the level of 0,02-0,04 μm, and the ferrite layers to 0,15 μm. Detailed studies have determined that grains of a structurally free ferrite, in turn, consist of sub-grains, the size of which varies in the range of values of 1.5-3.5 μm (Fig. 4 b). In this case, the volumes in the middle of sub-grains have an increased density of mutually blocked dislocations. Moreover, in addition to the form of ferrite grains in the form of polyhedra, in separate volumes of metal one can observe the formation of a ferrite of needle shape.

The indicated structural components confirm the existence of a definite difference in the speed of cooling by intersection of the disk. An increase in the temperature of the finish of accelerate cooling of the metal at a different distance from the surface of the disk corresponds to the change in the ratio of the number of martensite, bainite cells with heating from the deepened volumes of the metal, to the perlite with a different morphology of the phase components in the middle (Fig. 2-4). Based on this, the level of strength in the various layers metal disk of the wheel will be determined by the total effect of the saturation of the solid solution and the dispersion of the ferrite from the carbide particles. The character of the change in the microhardness of the ferrite indicates that the continuous reduction of the concentration of carbon atoms in a solid solution, starting at temperatures up to 200°C, is a major factor in reducing the strength of steel (Fig. 5a).

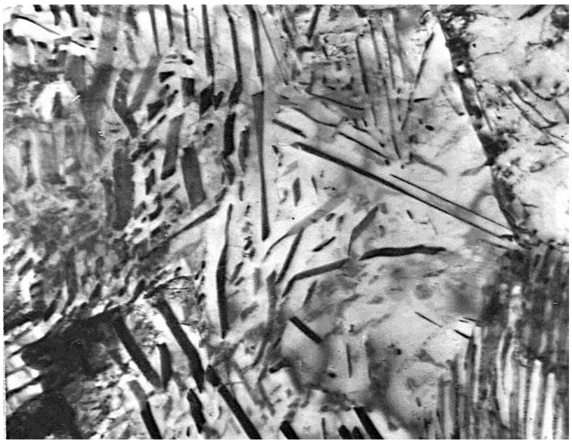
a



b

Fig. 3 Structure of the investigated steel after accelerated cooling to 400°C. Magnification 18000

Thus, the general level of strength of steel with increasing temperature of finish accelerated cooling will be determined by the measure of compensation from the preservation of high concentration of blocked dislocations of continuous softening from the decrease in the degree of saturation solid solution. Starting at temperatures of 300-350°C, a significant pick out of carbon atoms is achieved at the dislocation, and the preservation of their high quantity slows down the rate of decrease, as evidenced by violations of the monotonic curve movement (Fig. 5). In addition, the dispersion hardening of the carbide particles acquires a definite influence on the strength of the steel. Indeed, as shown in [8,9,10], starting from temperatures 350°C in carbon steels after quenching on martensite, there is already a definite amount of fine particles of the carbide phase.

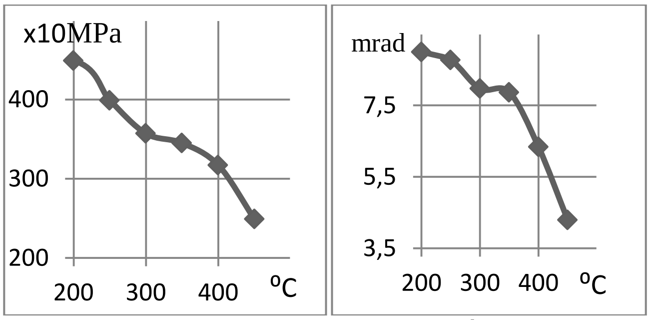


a

b

Fig.4 The structure in the middle of the disk railway wheel after accelerated cooling. Magnification 18000

Based on this, the depletion of the solid solution on carbon will occur due to the direct diffusion of carbon atoms from the solid solution to the carbide particles, which to a certain extent is confirmed by an accelerated decrease in the expansion of X-ray interference (110) (Fig. 5b). The interrelation between the two main processes of structural transformations in acceleratedly cooled carbon steel is determined solely by the temperature of the ended forced cooling and confirmed by the corresponding change in the complex of properties (Fig. 1a).



a b

Fig. 5 Change of microhardness (a) and expansion of X-ray interference (110) of the ferrite (b) from the temperature of ended the accelerated cooling disk wheel

With an increase in the temperature of tempering to 400°C, structural investigations revealed signs of the beginning of redistribution of dislocations and associated with this slight decrease in their density. The jointly development of these processes explains the permanent effect of softening carbon steel with an increase in the temperature of ended accelerated cooling. Analysis of the dependence of the properties of the strength of carbon steel (Fig. 1) shows that in purpose to increase the crack resistance of the wheel, the surface of the disk can be subjected to accelerated cooling up to 350°C, without the appearance of metal areas in a fragile state.

IV. Conclusions

After the completion of the hot plastic deformation in the manufacture of the wheel, accelerated cooling of the surface of the disk can adjust the degree of increase in the complex of properties higher than the requirements of the standard documentation for the railway wheels.

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