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STUDY OF PHYSICAL AND MECHANICAL CHARACTERISTICS OF STRUCTURAL STEELS DURING FATIGUE TESTING

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Keywords: microhardness, operation, reliability, steel, surface hardening, fatigue characteristics, surface roughness, time, temperature.
Abstract. This article examines changes in a number of physical and mechanical properties of structural steel during fatigue testing. The tests were conducted under alternating bending conditions using loading frequencies of 0.3, 3.0, 9.0, and 18.0 kHz on samples surface-hardened by borosilicate coating. It is shown that the microhardness and dislocation density of the studied material increase during the initial stage of testing, indicating the development of a hardening process followed by softening at the final stage.

ИЗУЧЕНИЕ ФИЗИКО-МЕХАНИЧЕСКИХ ХАРАКТЕРИСТИК КОНСТРУКЦИОННЫХ СТАЛЕЙ ПРИ ПРОВЕДЕНИИ УСТАЛОСТНЫХ ИСПЫТАНИЙ

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Ключевые слова: микротвердость, эксплуатация, надежность, сталь, поверхностное упрочнение, усталостные характеристики, шероховатость поверхности, время, температура.
Аннотация. В статье изучены изменения ряда физико-механических характеристик конструкционной стали при проведении усталостных испытаний. Испытания проводились в условиях знакопеременного изгиба с использованием частот нагружения 0,3; 3,0; 9,0 и 18,0 кГц на образцах прошедших поверхностное упрочнение боросилицированием. Показано, что микротвердость и плотность дислокаций исследованного материала на начальном этапе испытаний возрастают, что характеризует развитие процесса упрочнения материала, сменяющегося разупрочнением на заключительном этапе.

Most theoretical and experimental studies of fatigue failure development have been conducted without considering structural and metallurgical factors, including the presence of hardened layers and coatings. This complicates the selection of optimal surface hardening process parameters. The impact of the most common chemical-thermal treatments of steel (carburizing, nitriding, and boriding) on the dislocation structure of surface layers of structural steel components and its transformation during subsequent operation remains insufficiently studied.

Research in this area could lead to improved surface hardening compositions and modes, thereby increasing the service life of components. Experimental determination of the fatigue properties of various structural steels was conducted using a testing equipment complex developed at BSTU [1-3]. For testing, experimental specimens were subjected to bending vibrations. The advantage of this design is that cyclic stresses vary along the specimen axis. This improves the accuracy of determining the physical and mechanical properties of materials. To study the development of the fatigue damage process in structural steel with surface hardening, samples of 25KhGT steel subjected to borosiliconization (temperature 950°C, time 3.0 hours) were used. The test results (Fig. 1, 2) show that at the initial stage (with a test base of up to $2\cdot10^6$ - 10^7 cycles), strengthening processes predominate, accompanied by an increase in both the dislocation density and microhardness [2].

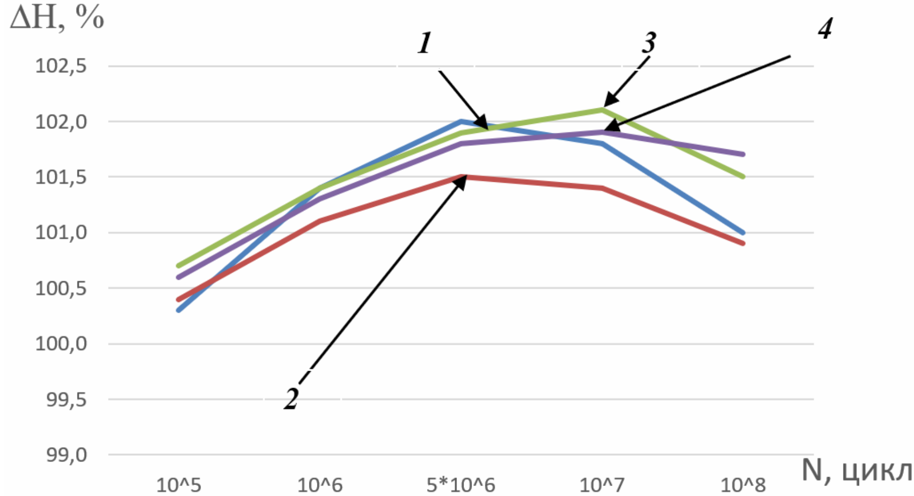

Fig. 1. Change in microhardness of 25KhGT steel samples subjected to surface hardening under loading with mechanical vibrations of varying frequencies (1-0.3 kHz; 2-3.0 kHz; 3-9.0 kHz; 4-18.0 kHz)

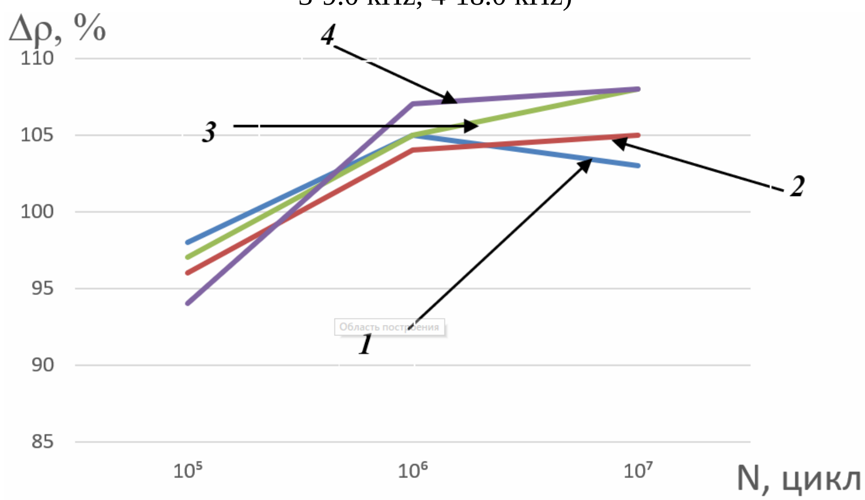

Fig. 2. Change in dislocation density of 25KhGT steel samples subjected to surface hardening under loading with mechanical vibrations of various frequencies (1-0.3 kHz; 2-3.0 kHz; 3-9.0 kHz; 4-18.0 kHz)

Since the value of ρ is more sensitive to the action of cyclic stresses, the dislocation density rapidly increases under loading up to 10^6 cycles. With an increase in the number of cycles, the value of ρ increases more slowly, and when testing at a frequency of 0 kHz, its decrease is noted (fig. 2, curve 1). When testing on large bases, the process of softening is noted, which is especially true for the change in microhardness (fig. 1). Similar relationships with combined strengthening-softening processes were determined for a number of other structural steels without diffusion saturation. However, when testing homogeneous specimens, the increase in dislocation density and microhardness is higher, and the scatter of experimental results is smaller. This is explained by the structural features and stress state of the surface layers of specimens subjected to diffusion saturation.

The obtained test results can be explained by modern concepts of fine structure transformation under cyclic loading. During the initial testing period (approximately up to 10^5 cycles), slight movement of pinned dislocation segments can be expected. As the test period increases, dislocations overcome barriers and move through obstacles, causing plastic deformation of the material. A further increase in the number of cycles leads to an increase in dislocation density due to the action of the Frank-Read source. This also increases the number of vacancies and interstitial atoms [3].

The determining factor is the strengthening process, characterized by an increase in dislocation density with increasing number of loading cycles, as confirmed by X-ray diffraction studies (fig. 2). The increase in dislocation density is explained not only by the translational motion of pinned dislocations but also by their multiplication, primarily due to the action of Frank-Read sources [3]. The cessation of the increase in dislocation density is associated with the action of stresses from previously emitted dislocations.

Annohilation of dislocations of opposite sign is also possible. This suggests the nucleation and propagation of microcracks. Severe plastic deformation leads to an increase in microhardness that lags behind the increase in dislocation density. With a further increase in the number of loading cycles, softening processes develop in the material, characterized by a decrease in microhardness and microstresses. It should be noted that in the considered range of test frequencies, the kinetics of changes in these quantities do not differ significantly. This confirms the potential of fatigue testing using high loading frequencies. As the frequency increases, the strain rate of the material increases for the same number of loading cycles, which also contributes to an increase in the velocity of dislocation movement and the intensity of their proliferation (fig. 2, curve 4). Fatigue testing of surface-hardened steels showed that changes in the kinetics of physical and mechanical properties, and consequently the process of their fatigue failure, are characterized by a combination of hardening and softening of the material. This confirms previously conducted theoretical studies and the fundamental possibility of using accelerated fatigue tests at high loading frequencies and for steels with surface hardening.

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