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INVESTIGATION OF THE MECHANISM OF FATIGUE OF COLD-WORKED STEEL ALLOYS

The study of fatigue of cold-worked steel alloys is unknown, although it is known in practice that all metals that have undergone preliminary treatment are subjected to the fatigue process. Therefore, it is of interest to conduct x-ray investigations of the changes in the crystalline structure of superficially cold-worked steels subjected to alternating loads.

EXPERIMENTAL PART

The steel alloy 40X was selected for study. The cold working was produced on a profile grinding arrangement mounted in a lathe. Annealed samples having dimensions of crystal blocks of order 10^{-3} and 10^{-5} cm were preliminarily subjected to grinding. The depth of the grinding layer was determined by means of X-ray of the surface layer of the sample after every layer of electrolytic etching. Etching was produced in aqueous solution of chrome anhydride for constant current of 1 amp. and temperature of 55° C. After removal of a layer of thickness 55 microns, the intensity of the interference line and the width of it had values corresponding to initial annealed sample.

Method of fatigue tests and x-ray photography of the samples are described in work [1].

For samples with various dimensions of blocks, the state of the crystalline structure of the surface layer of thickness 55 microns was identical; however, the basis on which grinding was produced had a significant influence on the fatigue limit. For ground samples with initial dimension of blocks 10^{-3} cm, $\sigma_s = 30$ kg/mm^2; with initial of dimension 10^{-5} cm, $\sigma_s = 42.5$ kg/mm^2. Such a difference of these quantities indicates the fact that not only surface cold working increases the fatigue limit, but also subsurface state of the crystal structure has an important effect on its magnitude, and consequently on the process of destruction also.

EXPERIMENTAL RESULTS

The change in the width of lines (220) as a function number of cycles of load is presented in Fig. 1 for loads 2 kg/mm^2 above the fatigue limit, at the limit, and 2 kg/mm^2 above it. The (220) line width of the initial samples was four times greater than the width of the same line in the standard sample. Consequently, grinding produced significant distortions of the crystal structure in surface layer.

In the process of an alternating load of preliminarily cold-worked (by grinding) 40X steel, a decrease in line width occurs in the initial period. For a load equal to fatigue limit and 2 kg/mm^2 below it, the decreases in line width are identical. At 1×10^5 cycles, the biggest decrease occurs in the line width of (220)--of the order of 20%. Further fatigue testing produces an increase in line width of 10%. After 2×10^5 cycles of alternating load, line width ceases to be changed. For a load 2 kg/mm^2 above the fatigue limit, the decrease in line width becomes sharper. The biggest decrease of initial line width of (220) amounts to 30%. Then, just as for the safe range of loads, the line width is increased and, after 2×10^5 cycles, does not change. On a stabilization section the line width for all three loads is identical.

The dimensions of the crystal blocks and micro-distortion were determined by the method of harmonic analysis of the two lines (220) and (110), (Fig. 2). It turns out that the crystalline blocks, which are crushed during grinding to dimensions of 2.2×10^{-6} cm, are not changed in process of fatigue testing.

The heat which is produced in the process of alternating deformation is expended on removal of only part of those micro-distortions which were obtained during grinding. Grinding produces non-uniform distortion of the crystal structure of the surface layer. Certain shear lines remain undistorted. Therefore, upon further change of sign of the stresses, slipping occurs on undistorted planes. Distortions of the crystalline structure of the metal are smoothed out. This is confirmed by the more equal distribution of dislocations during fatigue loading [2]. The character of the change in micro-distortions as a function of the number of cycles for the three loads considered is analogous to change of line width.

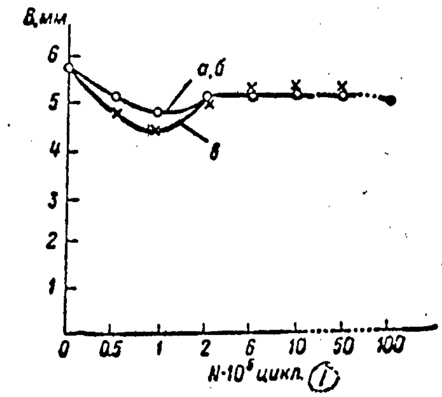

Fig. 1. Dependence of width of lines (220) on number of cycles of load.

a -- σ = 40.5 kg/mm^2, b -- σ = 42.5 kg/mm^2;
c -- σ = 44.5 kg/mm^2; 1) cycles

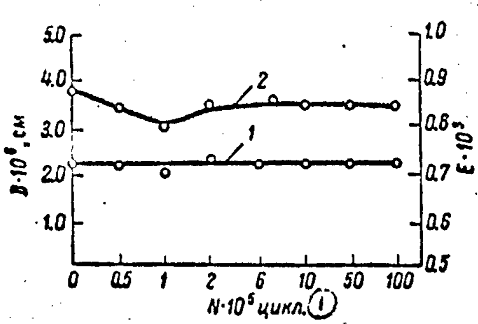

Fig. 2. Dependence of the block character (1) and microdistortions (2) on the number of cycles of load.

σ = 44.5 kg/mm^2; 1) cycles

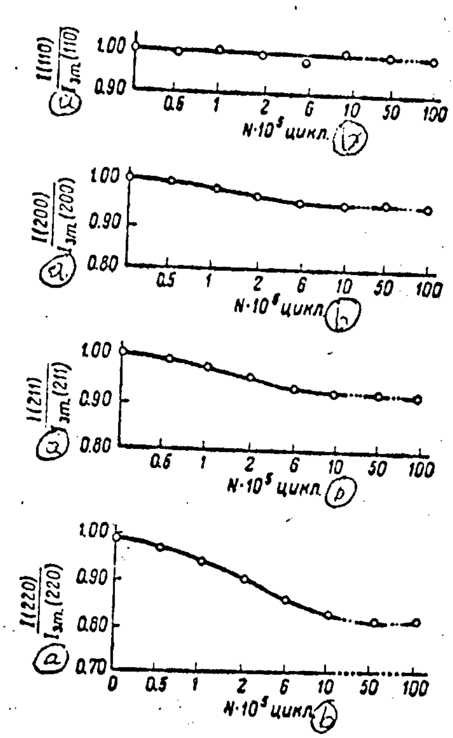

Fig. 3. Dependence of the intensity of interference lines on the number of cycles of load. σ_{-1} = 42.5 kg/mm^2; (a-- I_{st}; b--cycles).

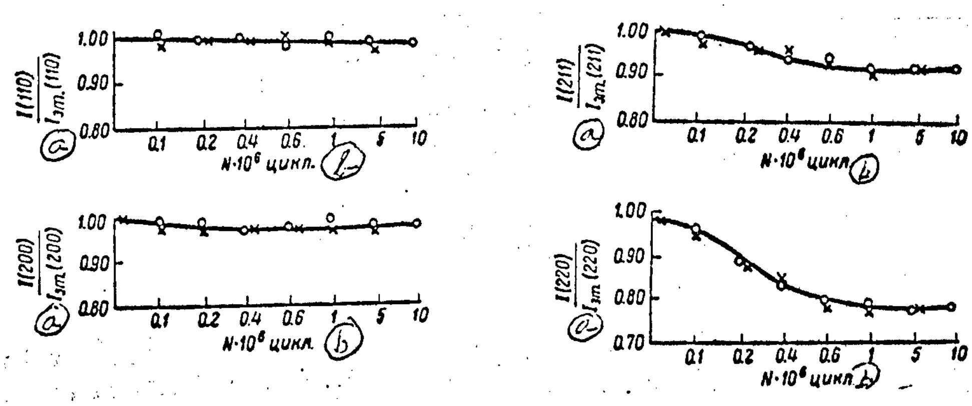

Fig. 4. Dependence of the intensity of interference lines on the number of cycles of load. σ_{-1} = 44.5 kg/mm^2; (a--I_{st}; b--cycles).

Removal of micro-distortions in preliminarily cold-worked (by grinding) samples subjected to alternating deformations, can be explained also from the general representations of dislocation theory. During grinding dislocations of various signs are formed. Analogous dislocations, being repulsed, shift to boundaries and accumulating there, distort the boundaries leading to crushing of the blocks. Opposite dislocations are attracted, and therefore interplanar distance is increased by only a small amount in some places (of the order of 0.001 and, probably, not more than 0.01), and decreases in other as a result of which micro-distortions of the lattice appear. During application of an alternating load, the remaining sources start "to work," emitting dislocations of one sign, which are annihilated with the dislocations formed during grinding, since their advance to the boundaries is hampered by Lomer-Cottrell obstacles. As a result, the density of dislocations decreases. During motion of dislocations in ground, cold-worked steel alloys, just as in annealed, a Cottrell cloud of foreign atoms is formed in which there are "sedentary" dislocations. During application of the corresponding stress, in our case, during a load equal to fatigue limit and above it, internal local stresses appear which wreck the "sedentary" dislocations in the Cottrell cloud, and it becomes a source of dislocations avalanches chaotically located inside the crystalline block. These chaotically distributed dislocations free atoms from the nodes of the lattice and decrease the intensity of x-ray interferences (Figs. 3 and 4).

Decreases in the intensity of interference lines at a load 2 kg/mm^2 below the fatigue limit was not observed. It follows from this that a discrete decrease of the intensity takes place during the transition from the safe interval of loads to the dangerous interval.

The sign-alternating decrease in the intensity of all lines of the spectrum (without significant fluctuations) permits us to consider that the decrease of intensity of x-ray interferences occurs because of the development of distortions of the third kind.

CONCLUSIONS

Investigation of the mechanism of fatigue of 40X steel preliminarily cold-worked by grinding on samples with initial magnitude of crystal blocks 10^{-3} and 10^{-5} cm, showed the following:

1. Initial state of structure of samples on which was produced grinding in significant degree, shows on magnitude of fatigue limit.

2. A surface layer preliminarily cold-worked by grinding turns out to be so much distorted that during further fatigue testing development of effects of second kind does not occur. Conversely, the removal of micro-distortions in the initial period is a confirmation of the existence --for definite fatigue form of the load and for every metal-- of its own maximum distortions of crystal structure.

3. Removal of micro-distortions occurs both for loads above the fatigue limit, also at the limit, and below it, and is produced by the influence of heat arising in deformation. The degree of removal of the micro-distortions can depend on the applied stress, but at loads below or above some definite value, there was no removal of micro-distortions or their further decrease.

4. Decrease of intensity of X-ray interferences occurs only at loads above the fatigue limit and equal to it.

5. The common mechanisms of the fatigue process of annealed and preliminarily cold-worked (volume and surface) metals and alloys are those distortions of crystal structures which produce a decrease in the intensity of X-ray interferences only at loads above the fatigue limit and equal to it. The absence of texture in the fatigue process allows to consider that a change in the degree of the intensity of the X-ray interferences can be attributed to development of distortions of the third kind.

LITERATURE

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