MICROHARDNESS OF STRUCTURAL MATERIALS UNDER THE INFLUENCE OF CYCLIC STRESSES

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UDC 620.178:620.178.3

Fatigue damage can be determined from microhardness measurements [1]. This method makes it possible to follow the changes occurring in local areas of the metal [2].

We studied the changes in microhardness during cyclic loading of aluminum alloys D16, V95, and AD33, steel 30KhGSA, and M2 copper. The aluminum alloys and copper were studied in the annealed and cold worked conditions, and steel 30KhGSA in the improved condition and after low-temperature tempering. The chemical composition of the materials investigated matched the GOST specifications.

The investigation showed that to obtain comparable results it is necessary to make at least 200 tests and treat the results statistically.

For the measurements of the microhardness the rod samples (9 mm in diameter, 80 mm long) were milled flat along the length (the flat surface was 7.5 mm wide). The microhardness was measured across the flat surface, the direction of each of two lines of imprints (100 measurements in each) lying at an angle of about 20° to the axis of the sample. The load on the diamond pyramid was respectively 50, 100, and 200 g for measurements of the copper, aluminum, and steel samples. The imprints, made arbitrarily with respect to the positions of the structural components of the alloys, were made at distances exceeding twice the diagonal.

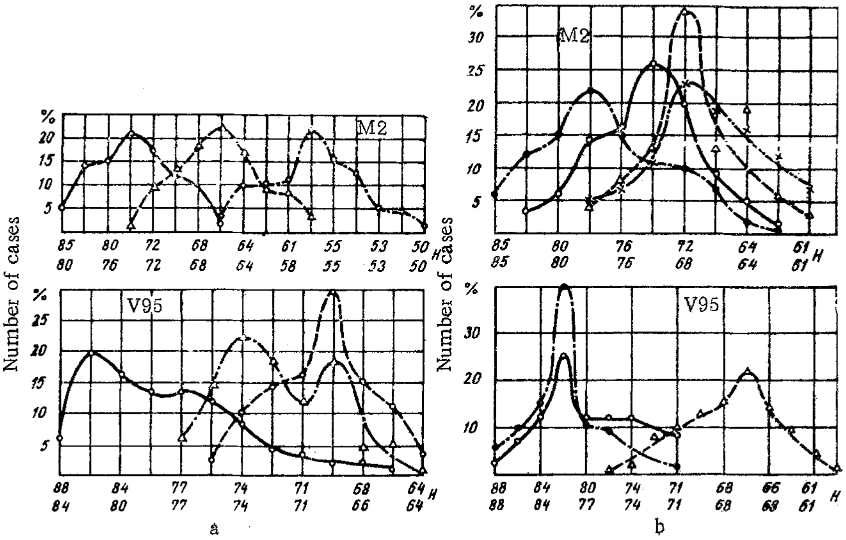

Fig. 1. Variation of microhardness of fatigue samples of M2 copper and V95 alloy. a) Annealed condition; b) cold worked condition. –·–·–) Before loading; ———) one loading cycle; ----) two loading cycles; –··–··) three loading cycles.

All-Union Correspondence Machinebuilding Institute. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 3, pp. 61-64, March, 1969.

Table 1. Microhardness of Steel 30KhGSA after Cyclic Loading

Condition of samples	Loading period	Number of cycles	σ_a, kg/mm^2	Initial microhardness	Change in microhardness
Improved	I	$5\cdot10^{6}$	15	427	−41
			30	400	−14
		$2\cdot10^{5}$		362	−32
	II	10^{7}	15	427	+14
		$5\cdot10^{6}$	30	400	0
		$1.8\cdot10^{6}$		362	+32
	III	$4.13\cdot10^{5}$	40	427	0 (samples failed)
		$8\cdot10^{6}$	30	362	0
Tempered at low-temperature	I	$5\cdot10^{5}$	20	549	−20
		$5\cdot10^{5}$			0
		10^{6}	40		−40
		$2\cdot10^{6}$	25	509	0
	II	10^{6}	20	549	−20
		10^{6}			−20
		$4\cdot10^{6}$	40		+40
		$8\cdot10^{6}$	25	509	0
	III	$8.5\cdot10^{6}$	20	549	0
		$8\cdot5\cdot10^{6}$			−20
		$3.6\cdot10^{6}$	40		+10 (samples failed)
		$10^{7}+6.3\cdot10^{6}$	24+40	509	+40 (samples failed)

Note: The data for each period are for different samples.

The samples were subjected to cyclic loading in a Schenk-Lehr machine at a loading frequency of 30 Hz. The gage length of the sample was subject to pure bending in one plane so that the bending moment was identical throughout the cross section. The microhardness was measured on the surface subjected to pulsating tension.

The measurements for constructing the distribution curves were made before and after the loading cycle. At least 200 measurements were used to draw each curve. The numerical data for drawing the distribution curves were the readings from an ocular micrometer, which made it possible to draw the curves with the highest precision. The conversion of the ocular micrometer readings to imprint diagonals led to values that were too close together making it impossible to obtain frequency curves in a number of cases. The conversion to microhardness led to additional error.

The changes in the microhardness of fatigue samples are due to processes occurring in the metal during the different stages of fatigue. These are due to lattice defects, which determine the course of deformation and subsequent failure.

Fatigue can be divided into three stages. In the first stage the distortion of the crystal lattice increases, the dislocation density increases up to a certain critical value, and the microhardness and strength characteristics of the metal also increase. In the second stage discontinuities occur, with dislocation pile-ups at barriers, and nucleation and development of submicroscopic cracks. The resistance to plastic deformation decreases and the microhardness falls below the original level; the submicroscopic cracks develop into cracks of microscopic size. In the third stage the microcracks unite into cracks of microscopic size and failure occurs.

The materials investigated can be divided into three groups: 1) the thoroughly annealed samples of copper and nonferrous alloys; 2) the samples of copper and nonferrous alloys with some degree of cold working; 3) the samples of steel 30KhGSA in the improved condition and after low-temperature tempering

The variation of the microhardness of copper and the V95 alloy is typical of the first group (Fig. 1). As can be seen in Fig. 1, the microhardness first increases and then decreases in the process of loading. After one loading cycle (5×10^5 cycles) of the V95 alloy at a stress amplitude $\sigma_a = 8$ kg/mm^2 (Fig. 1a) the frequency curve is shifted to the left.* After the second loading period (4.2×10^4 cycles at $\sigma_a = 8$ kg/mm^2)

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* In accordance with the method used to draw the distribution curves from the readings of the ocular micrometer on the PMT-3 apparatus, the microhardness increases from right to left.

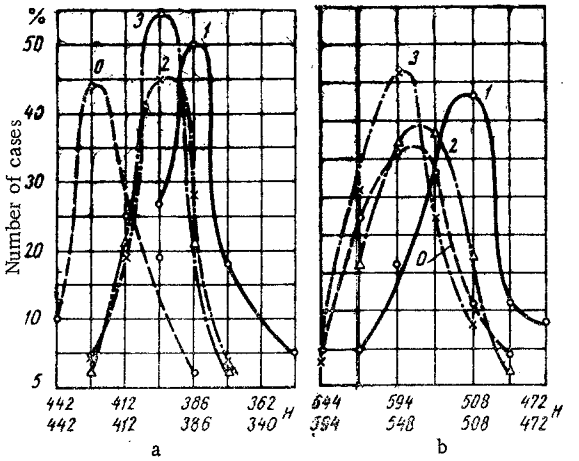

Fig. 2. Variation of microhardness in fatigue samples of heat treated steel 30KhGSA during cyclic loading. a) Improved condition; b) after quenching and low-temperature tempering. The loading periods are given on the curves.

the microhardness drops below the original level (H 159-174), leading to failure.* The microhardness varied in the same way for the copper samples (Fig. 1b). After the first loading period (5×10^6 cycles) the microhardness increased sharply (from 58 to 75). After the second period (10^6 cycles) the microhardness dropped to H 66.

The variation in the microhardness of copper and the V95 alloy was also typical of the second group of materials (Fig. 1b). In these samples the microhardness decreased during cyclic loading. In the original condition the microhardness of the copper samples averaged H 76. In the first loading period (5×10^5 cycles at $\sigma_a = 5$ kg/mm^2) it dropped to 72, while in the second period (5×10^6 cycles at the same stress) it dropped to H 68. After the third period it decreased only slightly (Fig. 1b). The samples of alloy V95 also had a high microhardness in the original condition. In the first loading period (2×10^5 cycles at $\sigma_a = 14$ kg/mm^2) the average microhardness remained almost unchanged, while after the second period (7.5×10^4 cycles) the microhardness decreased considerably and the samples failed.

In the tests of the third group of materials the microhardness of the improved samples of steel 30KhGSA first decreased and then increased (see Table 1). The shift in the frequency curves for the improved and tempered samples can be seen in Fig. 2. In the first loading period (5×10^6 cycles at $\sigma_a = 15$ kg/mm^2) the average microhardness of the sorbite decreased from 427 to 368† in the improved samples. After the second long loading period the microhardness increased to H 400. After the third period (4.14×10^5 cycles at $\sigma_a = 40$ kg/mm^2 the samples failed. In the first loading period of the samples tempered at low temperature (10^6 cycles at $\sigma_a = 40$ kg/mm^2(the microhardness of the martensite dropped from H 549 to H 509. In the second period (4×10^6 cycles) the original microhardness was reestablished. After the third period the microhardness increased still more and the fracture of the samples was brittle.

CONCLUSIONS

1. As the result of cyclic loading of annealed materials the microhardness first increases, then decreases below the original level, followed by failure. It can be assumed that the initial stresses cause an increase of the lattice defects but no damage. Further cyclic loading leads to discontinuities and accumulated damage.

2. In cold worked plastic materials one finds a monotonic reduction of the microhardness with increasing numbers of loading cycles. Evidently because of the high initial dislocation density, the increase in the number of lattice defects with the number of loading cycles leads to loosening of the lattice and damage of the sample.

3. During cyclic loading of thermally hardened structural steel the microhardness first decreases and then increases, failure occurring as the microhardness increases. Probably the drop of the microhardness is due to resorption of the areas of lattice defects because of favorable diffusion conditions at the beginning of cyclic loading [3], while the later increase is due to cold working. The reduction of internal stresses in the first stage must have a favorable effect on the fatigue resistance of thermally hardened steel.

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* The samples fractured at the ends clamped in the machine, since the ends of the samples were not specially reinforced.

† During the measurements of the microhardness of the sorbite the diamond pyramid also came into contact with a large number of particles of both phases in the given structure.

LITERATURE CITED

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