EFFECT OF ELECTRIC CURRENT ON CAVITATION EROSION AND ON THE MICROSCOPIC SUBSTRUCTURE OF METAL

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It may be taken as generally accepted that in many hydraulic machines and apparatus the cavitational breakdown of the working elements results from a combined action of mechanical, electrical, electrochemical, thermal and other factors accompanying the cavitation [1]. Nevertheless, in spite of the increasing attention paid to the phenomenon of cavitation, there exist at the present time no clear ideas either as regards the process and mechanism of corrosion incidence or as regards the effectiveness of different protective methods, including electrical methods. There are publications [2-4] describing the results of X-ray researches on the microstructure in the surface layers of metals undergoing cavitative action with no electric current flowing. The researches here described had as their subject the study of microhardness, microscopic substructure during the incubation period, and intensity of cavitation erosion in the absence and in the presence of electrical action.

The experiments were conducted in an ultrasonic cavitating field of frequency 20 khz excited by the concentrating head *1* of a magnetostrictive emitter in a vessel *2* filled with water (Fig. 1). The concentrating head and the test fluid were cooled by water flowing through coil *3*. The samples were held by a spring *5* in the electrically insulated housing *6*, so that the exposed surface of the sample was at an adjustable distance h from the face of the concentrating head. The distance h was adjusted by means of a micrometer screw *7*. The exposed surface of the sample was immersed 60-65 mm below the surface level of the water in the vessel. The temperature of the water was kept within limits 20-21°C by the cooling apparatus *3*.

The distinctive feature of the method was the investigation of the laws obeyed in the erosion of samples introduced into the cavitation zone but not fastened to the concentrating head and not subjected to oscillatory motion (in which case we should be dealing with the problem of *erosion in a stressed sample*, because of the sample's vibrating with a high frequency and large amplitude).

The test samples were prepared from A_1 aluminum and St3 steel, in 15 × 15 mm size, or diameter 20 mm. The exposed surface was brought to purity ▽9. After mechanical polishing the samples were subjected to heat treatment in order to remove internal stresses. The annealing was carried out in a vacuum of not less than 10^{-2} mm Hg. Before and after each experiment the samples were washed with ethyl alcohol and weighed with a chemical balance. The erosion was calculated from the weight ΔG lost by the sample after any period of testing.

In order to determine the optimal position of the sample relative to the face of the concentrating head we carried out a series of tests to define the influence of h on the intensity of erosion during a constant 5-minute testing period. The test material was aluminum. It was found, in particular, that the function $\Delta G(h)$ had a clearly expressed maximum, the breadth of which varies with change of the sonic field intensity.

The results discussed below were all obtained under identical conditions, with h = 0.5 mm.

The study of the substructural parameters (dimensions of regions of coherent scattering, microstresses, density of dislocations) of the samples subjected to the cavitating field was conducted by X-ray diffraction, using cobalt radiation, in a URS-501 diffractometer. The mosaic block size and the microstresses were calculated by the method of harmonic analysis of the (110) interference line of iron [5]. The density of dislocations was estimated by Khirsh's method [6]. Microhardness was measured by means of a PMT-3 microsclerometer according to the accepted method, with each measurement repeated ten times. Since the penetration depth of plastic deformation is small, the load in the case of the steel was set at 30 g, and in the case of the aluminum at 20 g.

Fig. 2 shows graphs of the microhardness variation in the aluminum and steel samples, versus testing time, and Table 1 shows the principal substructural parameters of the steel samples in the absence of electric current and for the sample used as anode or as cathode.

The duration of the test was decided by the development of erosion pits and by a set limit of weight-loss from the samples during the incubation period.

As the testing time with an unprotected sample is increased, the microhardness of the steel at the end of the testing period almost doubles, a marked rise being observed in the final stage of the incubation period, directly preceding the start of total breakdown, when change in the surface relief of the sample is visually observed. On the basis of X-ray analysis it may be concluded that the mosaic block size decreases, while the microstress and the density of dislocations increases.

When the sample is the cathode, there is a slower increase of the microhardness, dislocation density and microstresses; the mosaic block size also decreases more slowly. If the sample is serving as the anode, an anodic poisoning occurs, that is, the electrochemical processes are predominant and there are insignificant changes of microscopic substructure and microhardness.

In experiments to reveal the influence of electric current on erosion, we determined the relationship between weight-loss and current in aluminum samples subjected to cavitative action for a period of 5 minutes (Fig. 3).

With cathodic protection, cavitation erosion is markedly inhibited, and even with a small density of current it could be noted that the depth of cratering (pitting) was less than in unprotected samples.

With small currents the character of the relationship $\Delta G = f(\pm I)$ is similar to the case of the sample's serving as anode, but upon further increase

of the current there is observed, when the sample is the anode, an increase of the weight-losses, with the cleanness of the surface persisting. When the sample serves as cathode the weight-loss decreases considerably, but a shallow cratering is noted, extending over almost the whole surface. The depth of the craters is a good deal smaller than in the case of an unprotected sample when depressions or pits distributed over the whole surface of the sample are formed by cavitation.

Conclusions. Since the anodic breakdown of metals is markedly increased under the influence of cavitation, while the metal microstructure is little altered, it seems there is a possibility of intensifying certain technological processes by means of a simultaneous action of cavitation and an anodic current.

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TABLE 1. Changes in microscopic substructure of St3 during incubation period.

Time exposed to cavitating field (min)	Sample with zero current			Sample as cathode i = 0.079 a/cm^2			Sample as anode i = 0.079 a/cm^2		
	D, Å	ε	ρ, cm^{-2}	D, Å	ε	ρ, cm^{-2}	D, Å	ε	ρ, cm^{-2}
0	1300	$0.9\cdot10^{-3}$	$6\cdot10^{8}$	1300	$0.9\cdot10^{-3}$	$6\cdot10^{8}$	1300	$0.9\cdot10^{-3}$	$6\cdot10^{8}$
6	1380	$0.8\cdot10^{-3}$	$9\cdot10^{8}$	1370	$0.8\cdot10^{-3}$	$7\cdot10^{8}$	1290	$0.8\cdot10^{-3}$	$7\cdot10^{8}$
15	1240	$0.9\cdot10^{-3}$	$5\cdot10^{9}$	1280	$0.9\cdot10^{-3}$	$2\cdot10^{9}$	1310	$0.9\cdot10^{-3}$	$6\cdot10^{8}$
30	1170	$0.7\cdot10^{-3}$	$9\cdot10^{9}$	1130	$0.6\cdot10^{-3}$	$7\cdot10^{9}$	1330	$0.9\cdot10^{-3}$	$9\cdot10^{8}$
45	1100	$0.5\cdot10^{-3}$	$1\cdot10^{10}$	1120	$0.4\cdot10^{-3}$	$2\cdot10^{10}$	1350	$0.9\cdot10^{-3}$	$10\cdot10^{8}$
60	1050	$0.1\cdot10^{-3}$	$8\cdot10^{10}$	1070	$0.1\cdot10^{-3}$	$7\cdot10^{10}$	1350	$0.9\cdot10^{-3}$	$10\cdot10^{8}$
75	980	$0.7\cdot10^{-2}$	$5\cdot10^{11}$	1010	$0.4\cdot10^{-2}$	$2\cdot10^{11}$	Breakdown		
90	910	$0.5\cdot10^{-2}$	$7\cdot10^{12}$	960	$0.5\cdot10^{-2}$	$6\cdot10^{12}$			
105	Breakdown			900	$0.4\cdot10^{-2}$	$7\cdot10^{12}$			
120				Breakdown					

N.B.: D — mosaic block size;
ε — microstress;
ρ — density of dislocations.

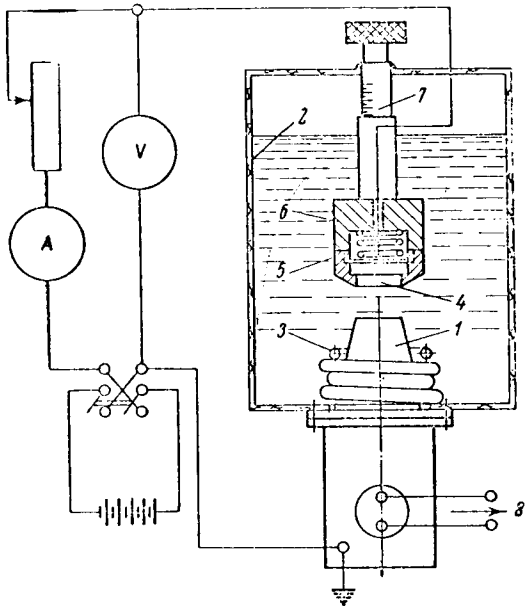

Fig.1. Diagram of experimental set-up.

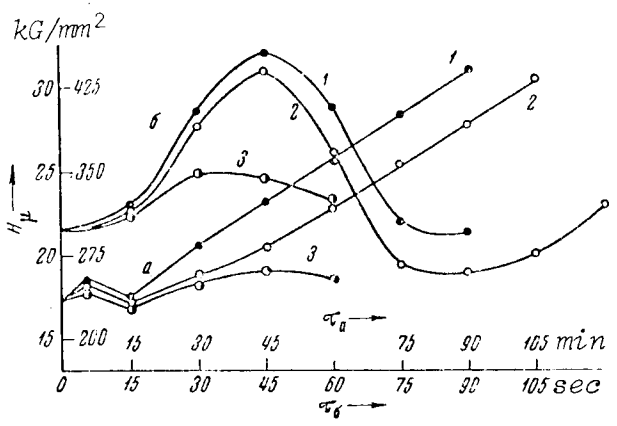

Fig.2. Change in microhardness of steel (a) and of aluminum (b) during incubation period. 1 - in absence of current; 2 - with sample as cathode; 3 - with sample as anode.

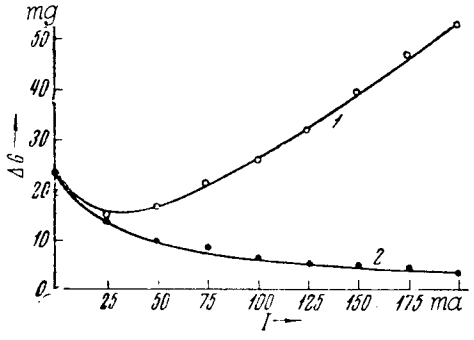

Fig.3. Effect of electric current on intensity of cavitation erosion in aluminum. 1 - with sample as anode; 2 - with sample as cathode.