

WEAR ON St.5 STEEL DUE TO JETS OF DILUTE
AQUEOUS SOLUTIONS CONTAINING HIGH
POLYMERS OF VARIOUS TYPES

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Wear cavities in St.5 steel samples created by jets of aqueous solutions containing polymers of various kinds are examined; the cavities are evidently formed by an impact mechanism arising as a result of the sudden deceleration of viscoelastic associates of the polymer solutions at the steel surface.

On dissolution in water certain polymers form associates constituting large, supramolecular formations comprising polymer macromolecules and a large number of immobilised molecules of the solvent [1]. The dimensions of the associates in, for example, solutions of polyoxyethylene, with a molecular weight of $4 \cdot 10^6$, are of the order of 1 mm. How much water occurs in the associates may be seen from the fact that the volumetric concentration of the associates of the polymer in question amounts to 3% for a gravimetric concentration of the polymer equal to 10^{-5} [2].

It was shown in [2] that even for a flow rate of 3 m/sec the elastoviscous associates exhibited the properties of solid particles on being retarded at the critical point of a Pitot tube. In this case the characteristic time of retardation of the associates in the Pitot tube was of the order of 10^{-3} - 10^{-2} sec (the relaxation time of the associates is of the same order).

The point of view developed in [1, 2] as to the structure of polymer solutions led to the following proposition in [3]: if the velocity of a flow incident upon a barrier is raised sufficiently, the ratio of the retardation time of the associates to their relaxation time will assume such a value that the associates will behave as fairly rigid particles capable of rupturing the barrier [3]. An experimental verification of this proposition showed that when a jet of a dilute polymer solution with a velocity of ~ 150 m/sec struck a metal sample (carbon steel of the St.5 type) open holes and cavities (caverns) were created on the surface.

We accordingly attempted an analysis of the character and the causes of wear in steel samples attributable to the action of water jets containing traces of polymers.

The samples for the wear tests were made from St.5 steel in the as-supplied state. The microstructure comprised ferrite and pearlite with a clearly-expressed banded structure.

As working liquid we used aqueous solutions of polyacrylamide of the AMD brand (molecular weight $1.5 \cdot 10^6$) or polyoxyethylene — Polyox WSR-301 — with a molecular weight of $4 \cdot 10^6$, the concentrations being varied from 0.1 to 0.001%. As a solvent we used Moscow city water without subjecting this to either physical or chemical treatment.

In order to compare the action of the polymer solution jets on the metal samples we carried out analogous tests without the additives in question and also with the addition of sand.

In order to study the effect of the liquid jet on the metal samples we used the apparatus depicted schematically in Fig. 1. From the vessel 1 the solution was directed by means of the centrifugal pump 2 to the plunger (piston) pump 3, which raised the pressure of the liquid to 320 atm and gave a rate of flow

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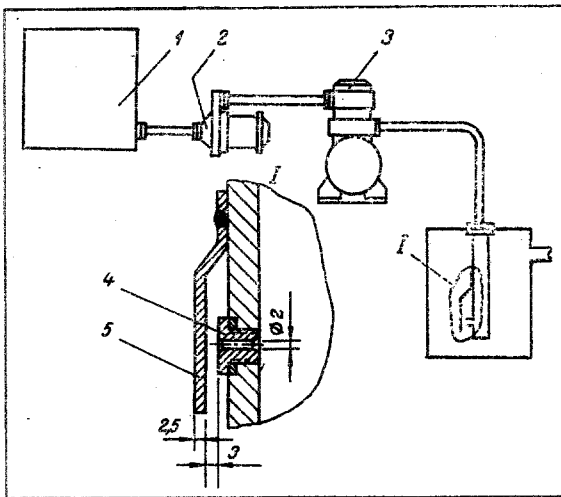


Fig. 1. Arrangement of the apparatus.

equal to 1.1 liter/sec. The high-pressure liquid passed to the nozzle 4 which had an internal diameter of 2 mm. The sample 5 was placed perpendicularly to the jet of liquid, at a distance of 3 mm from the tip of the nozzle.

When the apparatus was operated without circulation of the liquid, using solutions of both polyacrylamide and polyoxyethylene (concentration $10^{-1}\%$, supply pressure 250 atm, volumetric flow rate 0.7–0.8 liter/sec), a hole was created in a steel plate 2.5 mm thick by the jet of solution after only a few minutes. In order to discover the character and causes of the wear due to the jet of polymer solution we studied the initial stages in the wear of the steel samples. This we did by repeated circulation of small volumes of the aqueous polyoxyethylene and polyacrylamide solutions. Under these conditions we observed an intensive degradation of the solution, as-

sociated with the diminution of the associates and the degradation of the polymer molecules by shear stresses in the flow and also impact stresses, as well as the heating of the liquid (up to 50°C). These facts and also the circumstance that the most serious wear only occurs during the first few cycles of circulation of the solution through the apparatus explain the comparatively slight wear suffered by the samples in the time chosen for the experiment (20 min). The period of operation of the apparatus (without circulation) in pure water was 60 min, and with the addition of sand 5 min.

Under the influence of the jets of polymer solutions, round caverns were formed in the samples; they had a rough surface and a diameter of 3.9–4.4 mm, while the depths were varied and nonuniform (0.13–0.51 mm). The character and dimensions of the asperities (rough places) were almost identical in all the samples.

After 60 min under a jet of pure water a cavity was only just noticeable, and was apparently due to cavitation.

In order to prepare a longitudinal microsection, the sample was ground on an emery stone to half the diameter of the cavity. Then the section was flooded with plastic, and emery cloth and diamond pastes were used to prepare microsections. After this the microsection was polished using a cloth coated with a suspension of chromium oxide. Etching was carried out in a 4% solution of nitric acid in alcohol.

On the sample subjected to the jet of polymer solution, the edge of the cavern was characterized by bending of the grains and series of slip bands, indicating plastic deformation (and hence work hardening) in a very narrow zone 1–3 grains thick. Figure 2 clearly shows the branched slip bands characteristic of ferrite. It should be noted that in no case did twins appear in the ferrite grains of the work-hardened layer or in its neighborhood.

The average microhardness (H_{20}) at the edge of the cavern was 227 and at a distance of 0.05 mm from the edge 170 (in the original structure it was 170). The microhardness at the edge of the cavity was



Fig. 2. Slip bands in ferrite grains at the edge of the cavity. $\times 2000$.

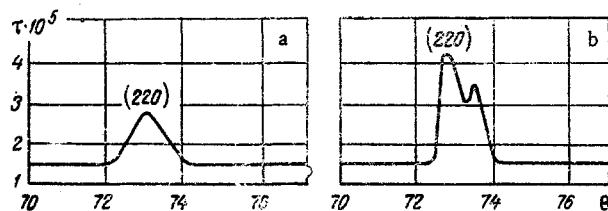


Fig. 3. X-ray recordings of the (220) done before and after removing the work-hardened layer: a) after the action of a jet of polymer solution; b) the same place after removing the work-hardened layer; τ , pulses /min, θ , deg.

clearly higher than in the interior of the sample as a result of work hardening.

The fine crystal structure of the samples was studied by recording x-ray diffraction patterns in a URS-50I instrument, using the radiation of an iron anode and recording the intensities with a scintillation counter.

We used samples previously subjected to metallographic analysis. The x-ray beam was directed toward the bottom of the cavity. The sample was installed in the holder in such a way that the bottom of the cavity coincided with the reference plane of the holder. X-ray diffraction patterns were recorded before and after etching.

In order to avoid errors during the recording of the x-ray diffraction patterns, the cavity was etched in the sample holder, i. e., the latter was not readjusted. After the action of the jet of polymer solution, the (220) lines were broadened and the doublet became diffuse, these effects vanishing after deep etching. There was also a sharp (~50 times) reduction in block size, an increase of an order of magnitude in the microstresses within the steel, and also an increase in the number of crystal-lattice defects, this being a typical result of the plastic deformation of the metal (Fig. 3).

For comparison purposes we made some experiments to determine the effects of a jet of sand-carrying water. The experiments were carried out with samples of St.1 steel. The action of the water jet containing 4 vol. % sand was far more intense than that of the water containing polymer additives with the apparatus working in the circulation mode; after 5 min a cavity 10 mm deep appeared in the sample. In this cavity we found a work-hardened layer and a large number of twins (Fig. 4). The latter indicated a severe impact action of the sand particles.

Thus the samples subjected to the action of a water jet containing polymers acquire a work-hardened layer such as is characteristic of all forms of mechanical wear [4, 5]. For the experimental conditions employed, a water jet without additives produced little wear on the steel.

The intensification of the wear due to the polymer additives is caused by the abrasive action of the associates, which on being sharply decelerated at the steel barrier with a retardation time much shorter than their relaxation period become so hard that they create plastic deformation (work hardening) in the outer layer; the repeated impacts cause fatigue and hence local destruction of the surface.



Fig. 4. Twins in ferrite grains at the edge of the cavern. $\times 400$.

The severe abrasive action of the water jet containing sand is due to the fact that the hardness of the sand particles is greater than the hardness of the steel, as a result of which, in addition to work-hardening, the sand particles cut the surface layers of the barrier.

The absence of twins during the action of the water jet containing polymers shows that in this case the steel barrier is receiving impacts from particles softer than sand. It would appear that the wear of steel by water jets containing soluble polymers constitutes a case of wear by particles with a hardness lower than the hardness of the metal.

These results indicate an abrasive effect of the jets of polymer solution on the hard obstacle, much greater than that of pure water. We might indicate a number of industrial processes in which the wearing properties of a jet constitute the main technological operation, and in which the use of polymer solutions as working media will clearly be desirable: the hydraulic-monitor method of breaking rocks in open working and in deep drilling, the perforation of oil and gas wells, and so on.

The polymer powder itself and its aqueous solutions are harmless in application and have no corrosive effects on the metal. The viscosity and density of the solutions differ very little from the viscosity and density of the solvent.

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