PIERCING A METALLIC BARRIER WITH A JET OF A DILUTE POLYMER SOLUTION

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Results are shown pertaining to the action of jets of dilute polymer solutions on solid barriers. The piercing of a barrier is explained by the viscoelastic properties of aggregates which, during an impact, behave like solid particles.

Certain soluble polymers are known, traces of which greatly reduce the turbulent friction drag [1]. In order to explain this phenomenon, it has been suggested in [2] that such polymer solutions contain large supermolecular structures, aggregates, consisting of macromolecules and large amounts of immobilized solvent. This hypothesis evolved from the need to reconcile, at least, the characteristic dimensions of the smallest-scale (Kolmogorovian) eddies in the stream with the size of inhomogeneities generating them in the solvent. A further extension of this hypothesis has led to the concept of macromolecule aggregates as viscoelastic droplets (particles) suspended in the solvent, whereupon their actual existence has been confirmed in experiments [3, 4]. Subsequent research has made it possible to determine the characteristic dimensions as well as the volume concentration of such aggregates [5]. In an aqueous solution containing 0.001% (weight) of polyoxyethylene with a molecular weight of $4 \cdot 10^6$, for example, the dimensions of these aggregates were found to be of the order of 1 mm and their volume concentration up to 3%. The measurements had been based on the analogous behavior of solid particles and viscoelastic aggregates in suspension in a liquid during stagnation at the critical point of a Pitot tube, this behavior resulting in anomalous readings already at a mainstream velocity of 3 m/sec. According to the data obtained from those measurements, aggregates stagnate at a Pitot tube within 10^{-3}-10^{-2} sec, after which time their behavior does not differ from that of undeformable particles. Thus, the relaxation time of aggregates is of the same order of magnitude. During deformation processes with a characteristic time longer than that, aggregates behave like droplets of a plain liquid, while with shorter relaxation times they cannot be deformed yet and, therefore, they behave like solid particles.

Extending this viewpoint to the structure of polymer solutions has led to the following hypothesis: as the mainstream velocity rises appreciably, the ratio of deformation time to relaxation time becomes such that the aggregates will behave like particles sufficiently rigid to be capable of piercing a barrier. This hypothesis has been confirmed experimentally on a test apparatus shown schematically in Fig. 1. The liquid was fed from tank 1 to the inlet of a centrifugal pump 2, which produced a pressure head at the inlet of a piston pump 3. The latter raised the pressure of the liquid to 320 atm total and thus ensured a flow rate of 1.1 liter/sec. The liquid under high pressure was fed to nozzle 4 with an inside diameter of 2 mm. A jet was discharged from this nozzle toward a target specimen 5, a plate of grade St5 carbon steel 2.5 mm thick, perpendicular to the jet axis at a distance of 3 mm from the nozzle throat. During operation with pure water under the top pressure and at the top flow rate, no breakdown of the specimen surface was noted after 1 h. According to [6], a metallic barrier would not be pierced after 40 min by a jet flowing under a pressure of 500 atm total.

When a 0.1% solution of grade AMF polyacrylamide with a molecular weight of $2 \cdot 10^6$ was used under a discharge pressure of 250 atm total and at a flow rate of 0.7-0.8 liter of liquid per second, after a few minutes the jet of liquid had pierced a hole in the plate larger in area than the active nozzle section.

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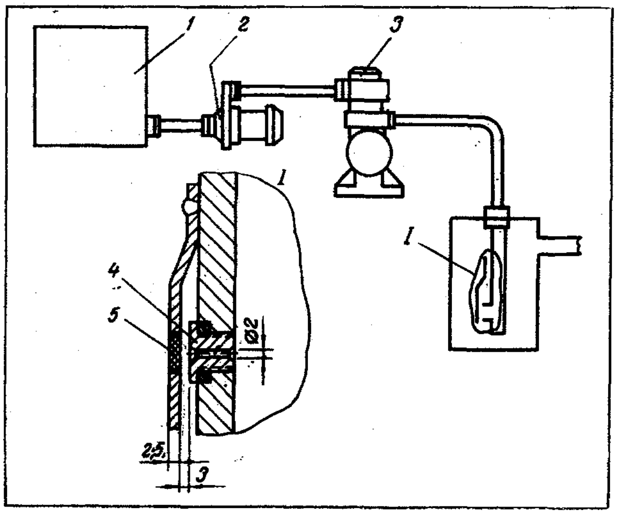

Fig. 1. Schematic diagram of the test apparatus.

Photographs of this hole on both sides of the plate are shown in Fig. 2a, b.

We then studied the initial stage of breakdown in metallic specimens. This was done by repeatedly circulating small volumes of up to 0.01% polyoxyethylene (grade WSR-301 Polyox) solutions in water. Under these conditions such a solution usually degrades fast, which has to do with the comminution of polymer molecules due to shear stresses during flow and during impact, as well as due to the appreciable heating up of the liquid. For this reason, the destructive effect was most pronounced here only during the first few circulations of the solution in the apparatus.

The crater produced in the specimen was an almost circular indentation with a protuberance at the center, the base diameter of the latter being equal to the inside diameter of the nozzle. The surface of the crater was dull. The photograph in Fig. 3 shows the effect of a 0.001%solution of polyoxyethylene in water discharged under a pressure of 300 $\mathrm{kgf/cm^2}$.

It has been found experimentally that the destructive capability of jets of polymer solutions depends on the polymer concentration. This destructive capability was determined from the loss of weight of a specimen plate during the time of treatment with a solution containing definite amounts of polymer material. Under a constant discharge pressure and during equally long periods of jet action, the destructive capability of a jet first increased with increasing polymer concentration C and then, after a maximum at $C = 0.001\%$, began to decrease. This may indicate an analogy between the phenomenon under study here and a sand-blast treatment of materials. Such a dependence of the destructive capability on the polymer concentration in a jet is qualitatively analogous to the well known relation between the destructive effectiveness of water-sand jets and the weight concentration of abrasives in the active liquid — a relation which has been recently established in laboratory tests with metallic plate specimens. According to the data obtained by various authors [6-10], with all other conditions the same, a jet of liquid and sand pierces a barrier fastest when the sand concentration is within 70-120 g/liter. This is equivalent to a volume concentration of quartz grit (density 2.6 g/liter) in the active liquid as high as 2.7-3.8%. In earlier mentioned tests [5] the destructive capability of high-velocity jets of aqueous polyoxyethylene (grade WSR-301 Polyox) solutions was maximum when $C = 0.001\%$. The volume concentration of aggregates in solutions with such a concentration of polyoxyethylene was also 3% [5].

It was noted in [6, 7, 9, 10] that, when the distance from nozzle to specimen plate was short (3 mm or less), the reflected jet with abrasives damaged the piercer-nozzle casing. An analogous effect is, apparently, also produced by a jet of polymer solution, In the lower right-hand corner on the photograph (Fig. 2b) there appears an indentation in the back surface of the plate, caused by a jet of polymer solution after the latter had been reflected from a cylindrical protective case behind that plate. A metallographic analysis revealed that the microhardness of the surface layer within the crater region was higher than within the peripheral zone. A microscopic examination of microcuts under 2000× magnification indicated the existence of a cold-worked layer within the zone of jet action, the thickness of this layer not exceeding two or three grain diameters. Slip zones were distinctly noticeable within the metal structure. An x-ray examination of the crater surface also revealed a layer where plastic deformation had occurred.

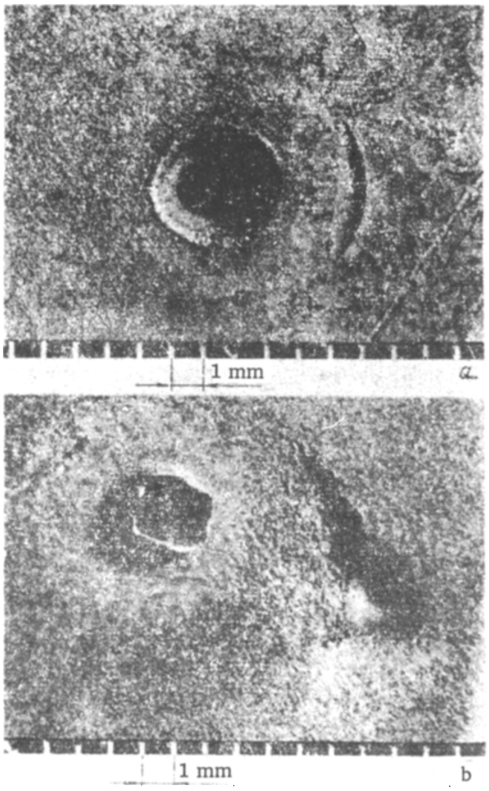

Fig. 2

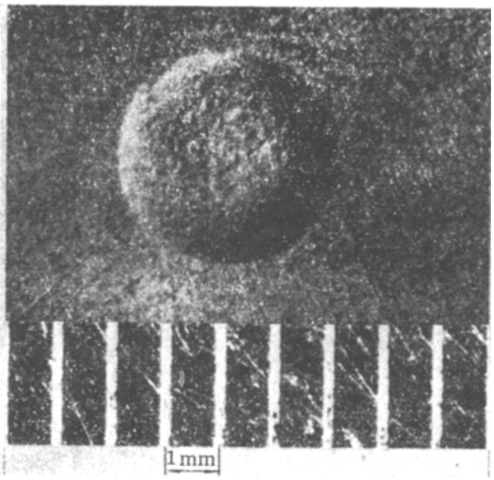

Fig. 3

Fig. 2. Hole made in a steel plate by a jet of polyacrylamide solution (concentration C = 0.1%) flowing at a velocity of 150 m/sec: (a) front view, (b) back view.

Fig. 3. Initial stage of breakdown in a steel plate, caused by a jet of a 0.001% polyoxyethylene solution. Discharge pressure 300 atm total.

Thus, microcut examinations of the crater surface in specimens after treatment with high-velocity jets of polymer solutions indicate an impact-type breakdown.

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