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Abstract

Full Text

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Experimental Study of the Distribution of Stresses during the Fracture of Polymers

(Presented by Academician V. A. Kargin, 14 VII 1958)

In the present study, in order to obtain data on the distribution and change of stresses during the growth of the fracture region, a method of high-speed cinematography in polarized light was developed. Polyethylene, polymethyl methacrylate, and vulcanized rubber were chosen as the objects of study. As is known, the investigation of stresses in a deformed specimen of a transparent material in polarized light is based on the fact that, under the influence of stresses, such materials become birefringent. In this case, it is not the stresses themselves that are measured in the specimen; rather, the optical effect arising as a result of birefringence is observed, which makes it possible to judge the stresses appearing at individual points of the specimen. As the light source, a projector with a power of 3000 watts or a dc arc lamp was used. The light sources were adjusted in such a way that, by means of mirrors or a system of lenses, the test specimens could be transilluminated with parallel rays. The specimens were deformed to fracture with the aid of an RMM-60 tensile-testing machine, somewhat modified for these tests. As the polarizer, a herapathite polaroid was used, placed in a mount that allowed the polaroid to be rotated to any angle. The analyzer was likewise a herapathite polaroid. In the case under consideration, the lines connecting points of identical coloration make it possible to judge the normal stresses in the transverse section of the specimen, since the difference of the principal stresses is equal to the normal stress in the transverse section.

Fig. 1. Final frames of a high-speed motion picture of the fracture of a polyethylene specimen, taken in polarized light.

The study of the fracture process of polyethylene, methyl methacrylate, and vulcanized rubber showed that there are substantial differences between the fracture mechanisms of these polymers. In Fig. 1 are shown individual frames

Figure 2

Figure 2: Figure 2

Figure 3

Figure 3: Figure 3

from a high-speed motion picture of the fracture process of polyethylene taken in polarized light. These frames show the final stages of the fracture process of polyethylene stretched at a speed of 500 mm/min at a temperature of 20°. Polyethylene specimens measuring 50 × 60 mm had cuts on both sides of 2 mm each, in order to determine in advance the direction of growth of the fracture region. The film transport speed was 1000 frames/sec. From examination of Fig. 1 it follows that the final stages of the fracture process, proceeding at a comparatively high speed within small fractions of a second, are characterized by the absence of overstresses at the place where the fracture region grows. The period preceding this corresponds to the generally accepted description of the fracture process of polyethylene: at the place where the fracture region grows, characteristic spots are observed, indicating the presence of overstresses. In Fig. 2 are presented frames of high-speed cinematography corresponding to the moment of time preceding the onset of rapid growth of the fracture region and to the moment of the dispr—

spreading of the fracture region at high speed. At the beginning of deformation, a distinctly nonuniform stress distribution is observed in the specimen. At the notch sites there are peaks of overstress.

a *b* *c* *d*

Fig. 2. Frames from a high-speed motion picture of the fracture of polyethylene, taken in polarized light: *a*—onset of deformation, *b*—onset of "neck" formation, *c*—onset of growth of the fracture region, *d*—the moment of rapid propagation of the fracture region.

However, further stretching is accompanied by a smoothing of the overstress peaks. At the same time a characteristic "neck" is formed; as it grows, the dimensions of the region of uniform stress distribution increase and, finally, rapid growth of the fracture region begins. At this stage, in contrast to the results obtained for other polymers, no overstress peaks are observed.

Fig. 3. Frames from a high-speed motion picture of the fracture of polymethyl methacrylate, taken in polarized light.

The fracture of linear polymers in the glassy state has an entirely different character. Figure 3 shows several frames from a high-speed motion picture of polymethyl methacrylate in polarized light. The polarization pattern agrees with existing ideas about the mechanism of fracture of polymers in the glassy state. Immediately after the onset of deformation, an overstress arises at the

Fig. 4. Frames from a high-speed motion picture of the rupture of a vulcanized rubber film, taken in polarized light

Figure 4: Fig. 4. Frames from a high-speed motion picture of the rupture of a vulcanized rubber film, taken in polarized light

notch site, increasing as the specimen is stretched. The increase in overstress is illustrated by the increase in the intensity of darkening at the notch sites of the specimen. A very interesting and, it seems to us, important circumstance is that, as the polymethyl methacrylate specimen is stretched, the dimensions of the dense darkening (in the image of the specimen taken in polarized light) increase, but not equally in all directions. The darkening spreads predominantly in the direction perpendicular to the direction of stretching. Consequently, from one defect to another, as deformation proceeds, regions of overstress spread perpendicular to the direction of stretching. Judging by the intensity of the darkening, the overstress is the smaller the farther the point under consideration, lying in the darkened region, is from the boundaries of the specimen defect (in this case, the notch). Finally, a moment arrives when the darkened regions merge and the density of the darkening is equalized. In

plane perpendicular to the tensile axis of the specimen, overstresses arose, at first different at different points of the most dangerous section (depending on the degree of removal from the boundaries of the defect), and then (Fig. 3c) equal in magnitude. In the unruptured specimen of polymethyl methacrylate there exists a region of equal overstresses. In the case under consideration, the locus of points of equal values of overstress passes along a plane perpendicular to the tensile axis. Along this plane the specimen is divided into two parts.

As an example of polymers with a developed spatial structure, vulcanized rubber films made from natural latex were investigated. These films are characterized by high strength compared with other vulcanizates. Specimens, notched as indicated above, were stretched to rupture by 900–1000%. Overstresses at the notches in the form described earlier were not observed. However, the occurrence of overstress surfaces was observed, located not perpendicular to the tensile axis but parallel to it. In the specimens studied, two overstress surfaces were tangent to the boundaries of the notch. At one stage of the rupture process, along these overstress surfaces the specimen is divided into parts. The remaining part, in the course of further stretching, becomes increasingly nonuniform (in the sense of the stress distribution), and the specimen divides into strands. Because in the case under consideration the notches did not perform their usual function—fixing the place of rupture—and, after delamination of the specimen along surfaces tangent to the notch boundaries, the specimen deformed like an unnotched one and tore at a random place, we were unable to record the pattern of stress distribution at the moment of rapid growth of the rupture region.

Fig. 4. Frames from a high-speed motion picture of the rupture of a vulcanized rubber film, taken in polarized light

However, examination of Fig. 4 gives grounds to believe that rupture occurs in a material homogeneous (in the sense of the stress distribution). Thus, on the basis of an investigation of the rupture process of polymers by high-speed filming in polarized light, fundamental differences have been established in the stress distribution during stretching of polymer specimens. Linear crystallizing polymers of the polyethylene type are characterized by the fact that rapid propagation of the rupture surface occurs in a homogeneous stress zone. Linear polymers in the glassy state, of the polymethyl methacrylate type, rupture along a surface perpendicular to the deformation axis, and this surface at first is the locus of points of equal overstress values. Polymers with a developed spatial structure, of the type of vulcanizates from natural latex films, are characterized by a distribution of stresses in planes located along the tensile axis. Rupture of the specimens occurs along these surfaces when the overstresses reach sufficiently high values.

In conclusion, the authors express their deep gratitude to Academician V. A. Kargin for a number of very valuable suggestions and for the assistance rendered in the course of carrying out the present work, and also to B. M. Kovarskaya for providing specimens for the tests.

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