MECHANISM OF MACROCRACK GENERATION AND PROPAGATION IN LOADED POLYMERS

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The appearance of a large number of submicroscopic cracks is typical in polymer materials under load [1, 2]. These cracks immediately assume definite dimensions due to the structural heterogeneity of polymers [2, 3] and to the molecular-chain mechanism of formation of each crack. The crack concentration may reach high levels (~$10^{12}$-$10^{16}$ cm$^{-3}$), at which dynamic interaction between the submicrocracks is possible. This had led to the hypothesis that macrocrack generation and development are based on the coalescence and enlargement of submicrocracks [2].

The present work is devoted to the experimental confirmation of this hypothesis. The submicrocracks were studied by the light-scattering method with recording of the scattering on cinefilm and subsequent photometric measurement, and by small-angle x-ray diffraction using a BSV-7 fine-focus x-ray tube. Diffraction from microsectors of the testpiece at the macrocrack tip can be studied by virtue of the small cross section of the primary x-ray beam (40 × 100 μ). The testpiece was loaded in a special diffractometer device in which the testpiece sector that was of interest could be brought under the beam. The kinetics of macrocrack growth were studied by filming, using a Konvas-avtomat unit.

The subjects of study were pieces of PK-4 oriented Capron film and of nonoriented triacetate film. For a qualitative assessment of the role of submicrocracks in macrocrack generation, it is convenient to use subjects in which submicrocrack formation leads to appreciable light scattering, which is apparent in clouding of the testpiece sector with an increased submicrocrack concentration. In this case the intensity of clouding is proportional to the submicrocrack concentration. The kinetics of submicrocrack accumulation can therefore be assessed by recording the clouding and making a quantitative evaluation of it.

The experiment was conducted as follows. A triacetate film testpiece was cut out with shaped blades (Fig. 1) to such a shape that the point of fracture was predetermined. The testpiece experienced a constant tensile load $\sigma$ and was heated by a current of hot air to 60°C; at this temperature a large number of submicrocracks forms in this material under load. The testpiece sector in which the macrocrack then developed was filmed continuously at a speed of 32 frames/sec. As a rule, clouding occurs soon after loading at the edge of the testpiece - at the point of minimum cross section - gradually increasing in magnitude and intensity. After some time a visible crack forms at the point of maximum clouding, grows, and splits the testpiece. As the macrocrack grows, the clouding moves with it.

The kinetics of submicrocrack accumulation in the sector where the macrocrack subsequently appears and at the tip of the macrocrack are shown in Fig. 1 (curve 1). The curve was obtained by photometric measurement of the cinefilm. Figure 1 also shows the initial sector of macrocrack growth kinetics (curve 2). It is apparent that the speed of growth remains constant initially; this justifies the determination of the time of macrocrack occurrence $t$ by extrapolation of the $I(t)$ relationship onto the time axis. Let us note that the macrocrack is generated on a fairly remote sector of the submicrocrack accumulation curve. Consequently, a process of bulk fracture due to the high concentration of submicrocracks precedes the appearance of the macrocrack.

Experiments with a testpiece which already has an evident defect, for example, a notch, provide more convincing confirmation of this conclusion. One would think that if the notch can increase independently


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of bulk fracture, the latter should not affect the kinetics of its growth. An experiment was mounted as follows to determine the effect of submicrocracks on notch growth. A PK-4 Capron film testpiece about 80 μ thick and up to 10 mm wide was placed under tensile load and a notch of about 0.5 mm was made in it with a razor blade. The x-ray beam was directed at the tip of the notch, and the kinetics of submicrocrack formation and the growth of the notch was observed simultaneously. It was discovered that initially the notch remains practically the same as regards growth, whereas submicrocracks quickly accumulate at its tip (Fig. 2). The notch begins to grow when the submicrocrack concentration becomes high enough, i.e., when bulk fracture has occurred in the testpiece microvolume in front of the notch tip. The impression is created in these circumstances that the notch cannot grow through the "unplowed" testpiece in spite of the fact that it is a stress concentrator and it is essential that submicrocracks have developed at its tip.

The notched testpiece differs from a testpiece without a perceptible defect only in that the notch localizes the fracture process by its stress concentration field; nevertheless the patterns of fracture are the same in both testpieces, i.e., rupture in a microsector (the appearance of a crack in the latter and notch growth in the former) occurs after the process of bulk fracture in that microsector due to the generation of submicrocracks, which ensure the rupture of that sector.

It is now natural to ask the following question: what is the course of fracture development from the generation of the submicrocracks to the appearance of the macrocrack? It is apparent from Fig. 1 that the macrocrack forms in the gently sloping sector of the submicrocrack accumulation curve. This is even more clearly shown in oriented crystalline polymers.

In this case the testpiece was cut to the same shape as in Fig. 1 and the x-ray beam was directed at the instant of loading at the point near the edge of the testpiece at which the macrocrack subsequently appeared in PK-4 oriented Capron film under a constant tensile load σ = 20 kgf/mm². The submicrocrack accumulation curve slows down sharply; practically all the submicrocracks are formed in the first 10% of the life of the testpiece (t₁). However, an appreciable macrocrack (~100 μ) becomes apparently shortly before the testpiece breaks (t₂): Fig. 3.

Consequently, the maximum possible number of submicrocracks for a given material is insufficient by itself for a macrocrack to develop and for the testpiece to break. There is apparently still some process of submicrocrack development which leads to the appearance of macrocracks. Let us therefore follow what happens to the submicrocracks in the time t₁−t₂.

Let us analyze the scattering curves in the two extreme positions, i.e., shortly after the accumulation curve reaches saturation (t₁) and at the instant of macrocrack formation (t₂).

The scattering curves measured transversely to the axis of loading are given in the coordinates logI − σ² in Fig. 4; these can be used to assess the transverse dimensions of the submicrocracks. It is apparent that the scattering curves diverge sharply at very small angles and practically coincide over the remaining