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EFFECT OF STRESSES ON THE ORIENTATION OF LASER DAMAGE CRACKS IN TRANSPARENT DIELECTRICS

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We consider the effect of focused radiation from a free-running ruby laser of 10 J energy on prestressed organic dielectric samples (polystyrene and polymethylmethacrylate). The crack orientation is found to depend on the nature of the stressed state. A mechanism is proposed to explain the effect. The gas pressures that cause the material to split apart are estimated. The gas pressure in the cracks of the investigated materials does not exceed 100 kg/cm^2.

THE process of development of internal damage in transparent dielectrics under the influence of laser emission is best regarded as consisting of two stages. In the first stage, owing to the induced loss of transparency or the loss already present as a result of microscopic structure defects, the laser energy is absorbed and a brightly glowing gas center is produced.[1] In the second stage, the gas centers continue to absorb energy in the usual manner, and split a layer of medium apart, producing eventually a residual picture of a system of cracks. We consider below the features of the damage produced during the second stage of development. The two stages can be considered separately, because the propagation of the cracks does not depend on the details of the mechanism producing the initial gas center.

We investigated the pattern of internal damage in prestressed transparent samples of polymethylmethacrylate and polystyrene acted upon by radiation from a free-running laser. The orientation of the flat cracks was found to depend on the applied external stress, and the pressure of the gas inside the crack was estimated.

Under the influence of the focused radiation from a free-running laser, a unique damage pattern is produced in transparent materials:[2, 3] saucer-like cracks are produced, the angle between the planes of these saucers and the axis of the beam being close to 45°. In all other respects, the arrangement of such cracks and their orientation along the axis are random, as is natural, since the material is isotropic and is not stressed in the initial state (Fig. 1). It was shown in [1] that the growth of the cracks during the stage of their macroscopic development is due to the splitting action of the heated gas, which initially is produced in the form of small bubbles inside the sample under the influence of the radiation.[1)]

We note now that during the splitting process the gas pressure is practically constant over the entire surface of the crack, and decreases greatly only near the very end of the crack. The rupturing stresses near the end of the crack, on its continuation, are given by the formula[4] $\sigma \sim N/\sqrt{s}$, where s is the distance from the end of the crack to the point where the stress is measured and N is the so-called stress-intensity coefficient, which is proportional to the gas pressure in the absence of external stresses.

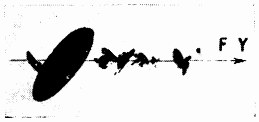

FIG. 1.

In the presence of an external stress p_{ext}, assumed for simplicity to be a spatially-homogeneous uniaxial stress, the value of N is proportional to the algebraic sum of the gas pressure p_g and the projection of the external stress on the direction perpendicular to the plane of the crack. If the normal to the plane of the crack makes an angle φ to the direction of the applied voltage, then

$$N \sim p_g + p_{ext} \cos\varphi$$

(a tensile stress is regarded as positive). It follows from this, in particular, that when compression stresses are applied, N vanishes and reverses sign when $p_g = -p_{ext} \cos \varphi$. The latter denotes that the crack cannot grow in the direction under consideration. (The influence of the cohesion forces acting at the end of the crack can be neglected in the first approximation in the case of sufficiently large cracks.) It is therefore obvious that in the presence of sufficiently large compression stresses the cracks should propagate parallel to the applied stress.

If the number of initial defects randomly disposed in the material is sufficiently large, the crack development should proceed in a direction from which the rupture stresses near the end of the cracks are maximal; more accurately, where the coefficient of stress intensity is maximal. This situation is well illustrated in Figs. 2a and b. Figure 2a shows the damage produced in a free sample, while 2b shows the damage in a sample under tension. It is obvious that the maximum tensile stresses occur in a plane perpendicular to the direction of the tension in the sample; we see that the cracks (Fig. 2b) become oriented near these planes (**Y**—beam direction).

[1)] There is a missprint in the formulas of [1] for the volume of the crack; these formulas should read

$$V \approx 0.6\ K^6 / Ep^5 \approx 3.4\, kR^{5/2} / E.$$

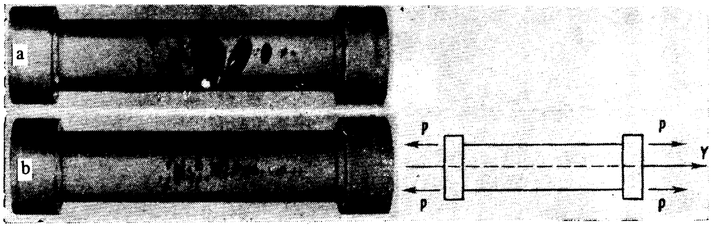

FIG. 2.

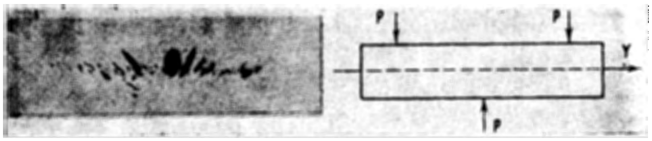

FIG. 3.

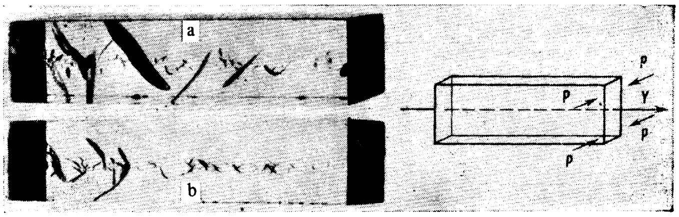

FIG. 4.

A similar situation is seen under different types of load application in Figs. 3–6. The "breakup" of the planes of the cracks from the center of the sample to its edges (Fig. 3) is due to the stressed state characteristic of flexure (the loading schemes are shown alongside the photographs of the samples). In Figs. 4a and 4b the loads are $p \approx 77$ kg/cm^2 and $p \approx 100$ kg/cm^2; Fig. 5a shows the picture of free cracks along the beam direction without external load, and 5b shows the picture under load. The figures show that the orientation of the cracks depends quite clearly on the external load. The latter circumstance can be used to determine the order of magnitude of the gas pressure splitting the crack apart. In fact, if the cracks begin to propagate at a certain value of a compression stress in such a way that their surface becomes cylindrical, with generators parallel to the applied uniaxial external compression stress, this means that the gas pressure in the crack becomes comparable with the external compression stress.

The foregoing is well illustrated in Fig. 2b as compared with Fig. 6b. Figures 2a and 6a show the pattern of damage produced in free samples. In the experiments in accordance with the scheme of Fig. 2b, tensile stresses were applied along the sample axis, while in Fig. 6b compression stresses were applied perpendicular to the sample axis. In either case the effect, naturally, was the same: the cracks developed in a direction for which the rupture stresses near the end of the crack were maximal. The planes of the cracks were oriented perpendicular to the geometrical axis of the cylindrical samples.

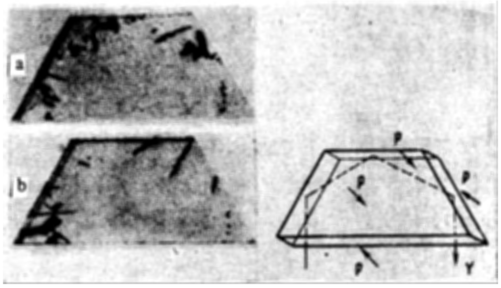

FIG. 5.

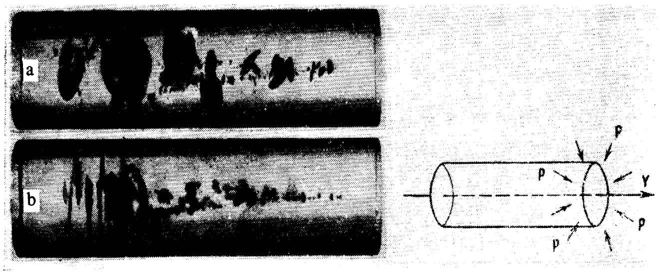

FIG. 6

Analyzing the picture of the damage under gradually increasing external loads, we can conclude that the pressure of the gas in the cracks (when the dimension of the cracks becomes somehow noticeable) does not exceed 100 kg/cm^2.

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