INVESTIGATION OF THE PROPAGATION AND INTERACTION OF FAST CRACKS IN PLEXIGLAS

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A considerable amount of attention has been given to the study of the propagation of fast cracks in materials [1-3].

In the present work an explosive method of loading was used to initiate the cracks. This enables the energy introduced into the specimen to be varied fairly easily over a wide range, and enables them to be initiated synchronously at several points in order to study their interaction.

The specimens were made of Plexiglas (in accordance with All-Union State Standard (GOST) 17662-72) in the form of plane disks of diameter d = 120 mm and 160 mm, while the thickness δ was varied from 15 mm to 25 mm. The wedge method was used to initiate the cracks. Wedge-shaped cuts were made in the specimens, from the vertex of which the initial crack emerged. Cylindrical strikers with a wedge-shaped point were inserted into the cuts (in Fig. 1, 1 is the specimen, 2 is the explosive layer, 3 is the detonator, 4 is a damper (plastic foam), and 5 is the striker). The angles of the wedge 2α and the specimen were the same and were 15° and 30°.

We investigated three types of specimens whose parameters are shown in Table 1. The wedge was driven into the specimen using an explosive device (see Fig. 1) as described in [4]. The initial velocity of the striker could be varied by changing the amount of explosive. To study the interaction of the cracks they were initiated in synchronism using two similar strikers. The propagation of the cracks was photographed with an SFR-1M high-speed camera, which operated in a time loop at a frame frequency of up to 675,000 frames/sec. The cinefilms were deciphered using a BMI-1 instrumental microscope.

Investigation of the Propagation of a Single Crack. In these experiments we investigated how the velocity of propagation of a crack depends on the initial velocity of the striker and the effect on the velocity of the crack of the geometrical dimensions of the specimen and the angle of the wedge. The cinefilms obtained in these experiments enabled us to calculate the velocity of propagation of a crack v_T in the specimen. We then time-averaged over a period of 2 μsec and a distance at the base of 0.5 mm. It was shown in the experiments that the velocity of propagation of a crack in each experiment is constant over the length of the specimen and depends on the initial velocity of the striker v_S.

Figure 2 shows the velocity of propagation of the crack as a function of the initial velocity of the striker for different types of specimen (I is a specimen of type 1, II is a specimen of type 2, III is a specimen of type

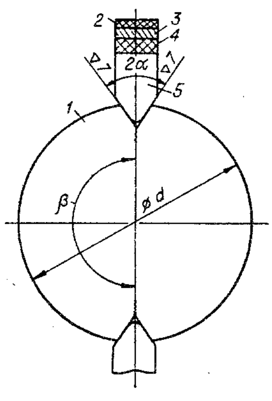

Fig. 1

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TABLE 1

Type of specimen	Diameter d, mm	$2\alpha°$
1	120	30
2	120	15
3	160	30

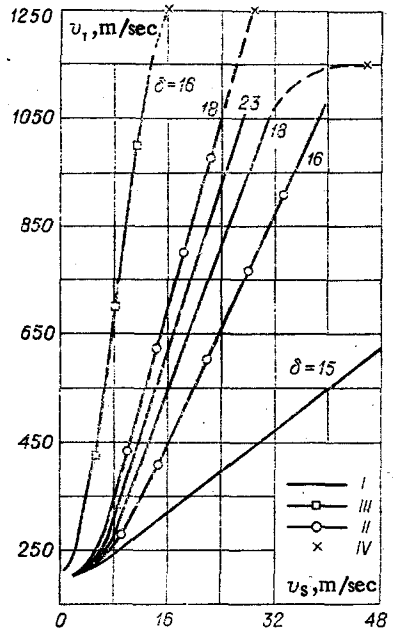

Fig. 2

3, and IV are the experimental crack branching points). With the exception of the initial part and before branching of a single track occurs these relations are linear. The velocity of a crack for a constant initial velocity (energy) of the striker increases as the thickness of the specimen increases. A reduction in the angle of the wedge also leads to an increase in the velocity of propagation of the crack. When the initial velocity of the striker is reduced the dependence of the crack velocity on the striker velocity for all the specimens tested approaches the same value $v_* = 200$ m/sec asymptotically. The maximum velocity of the crack achieved in experiments when the initial velocity of the striker was increased was 1300 m/sec, which corresponds to the velocity of Rayleigh waves c_R in the material of the specimen.

Hence, the results of experiments indicate that upper and lower limits exist for the velocity of steady-state propagation of a crack in the material.

It is well known that branching of the crack usually prevents the limiting velocity being attained. The velocity of branching obtained by many experimenters (see, e.g., [5]) is $v_B = 0.6\ c_2$, where c_2 is the velocity of transverse elastic waves.

In our experiments when the crack had attained a large velocity considerable roughening of the free surface occurred, which appeared as separate short branching cracks arranged along the main crack, while the branching strictly began when the crack had reached a certain length. Estimates showed that the position of the branching point of a single crack corresponds to the instant when it encounters an elastic longitudinal wave reflected from the edge of the specimen in which case the velocity of the crack lies in the limits $0.8c_2 < v_B < c_R$. The attainment of such high velocities by the crack is obviously due to the fact that axial compressing stresses occur in the specimen due to the action of the wedge, which have a stabilizing effect on the trajectory of the crack [6].

Investigation of the Interaction between Cracks. We simultaneously initiated two cracks in the specimen which propagated at a certain angle β with respect to one another (see Fig. 1) with the same initial velocity, and we recorded their interaction pattern. For the case of opposite tracks ($\beta = 180°$) the following kind of interaction was noted: The cracks propagate rectilinearly until the distance between their ends reaches a certain

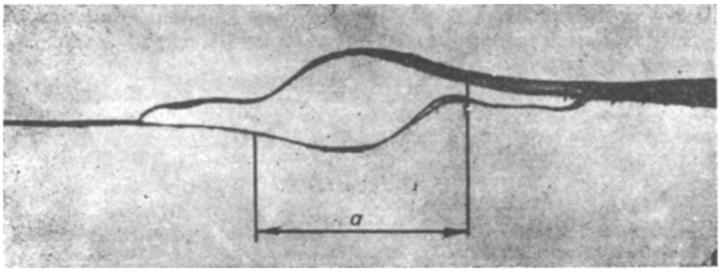

Fig. 3

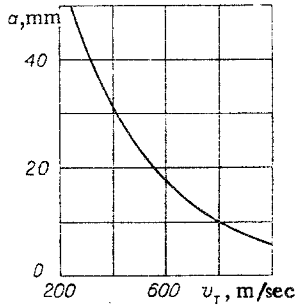

Fig. 4

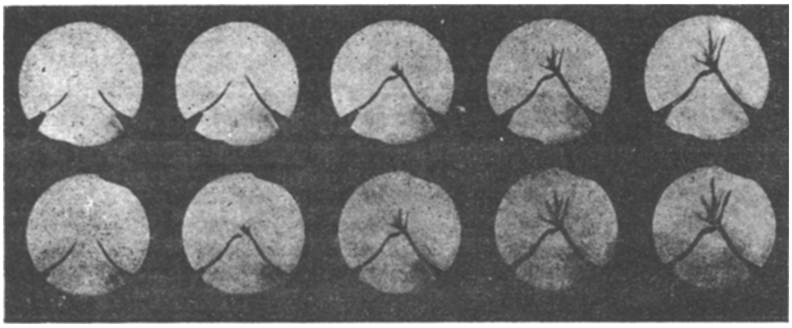

Fig. 5

value a; on reaching the distance a the tracks change their trajectory sharply, deviating from rectilinear propagation, as a rule, asymmetrically (on different sides). On reaching the frontal plane of symmetry the cracks again change their trajectory sharply, they begin to approach one another, and merge. As a result of this interaction a lens-shaped pattern is formed in the central part (Fig. 3). The dimension a represents the region of strong interaction between fast cracks and decreases as the velocity of the cracks increases. For specimens of type 3 the dependence $a = f(v)$ is shown in Fig. 4 (δ = 30 mm). A similar interaction zone also occurs when the cracks encounter a rigid obstacle. At high velocities of the interacting cracks secondary cracks are formed in the frontal plane of symmetry.

Figure 5 shows a fragment of a cinefilm of the interaction between the cracks with large velocity at a sharp angle (the interval between frames of the cinefilm μ_t = 5.2 μsec/frame). As a result of the collision, branching occurs from one of the cracks. The branching cracks are situated symmetrically with respect to the crack which has traveled in the frontal plane. For β = 180° the secondary cracks in the frontal plane propagate symmetrically on both sides. This kind of interaction between fast cracks may be responsible for the appearance of a disintegration region on cleavage and the appearance of cracks perpendicular to the surface of the cleavage which have been observed by many authors who have investigated this phenomenon.

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BRITTLE FRACTURE OF A CORE WHEN DRILLING IN A COMPRESSED MEDIUM

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When drilling with core sampling in a medium compressed by mountain pressure, fracture of the core into separate disks is usually observed [1]. The thickness of the disks formed is related to the value of the mountain pressure, and an increase in the pressure causes a reduction in the thickness of the core disks which have split off. This experimentally established relationship is the basis of one of the methods used to determine impact-dangerous parts in mines [2].

In this paper this phenomenon is investigated theoretically using the model of an ideally elastic medium, fractured in a brittle manner. The following assumptions are made: a) The thickness of the walls of the drilling instrument is assumed to be zero, as also the distance between the edges of the cylindricals cavity drilled out by the drill in the rock; b) the action of the drill on the core during drilling is described by a distributed tangential stress which twists the core. The normal stresses on the sides of the cut are assumed to be zero; c) uniform compression stresses act at infinity, perpendicular to the axis of the cylindrical crack.

With these assumptions the problem of the fracture of a core in this model reduces to an analysis of the stressed state in the region of the edge of the cylindrical cut produced, and, more accurately, to a determination of the intensity coefficients of the stress field K_I, K_{II}, and K_{III} [3].

The simplest problem of the equilibrium in an infinite isotropic elastic space of a cylindrical cut of radius a and length $2l$ whose axis is along the z axis, as shown in Fig. 1, is considered. Two cases of loading are considered: compression transverse to the z axis by a pressure equal to p_0 at infinity, and twisting along the axis by a stress applied to the surface of the core.

1. The Axisymmetric Case. We will assume that the displacement vector is independent of the angle φ and has the form $\mathbf{u} = u\cdot\mathbf{r} + w\cdot\mathbf{z}$. We will introduce dimensionless quantities by the equations (henceforth, for simplicity, the primes will be omitted)

$$\langle u, w, z, r, a\rangle' = \frac{\langle u, w, z, r, a\rangle}{l},$$

$$\sigma'_{ij} = \sigma_{ij}/\mu, \quad \langle p_0, \tau_0\rangle' = \langle p_0, \tau_0\rangle/\mu.$$

Then the equations of equilibrium and the components of the stress tensor can be written in the form

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