EFFECT OF THE ORIENTATION OF A BOUNDARY CRACK ON THE PASSAGE OF SURFACE WAVES

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The passage of Rayleigh waves through boundary cracks of various orientation is studied by the method of dynamic photoelasticity. The passage coefficients of a wave are determined, and formation of a stress state in the neighborhood of the crack tip is demonstrated for various positions of the crack. It is shown that a variation in the orientation of the crack leads to a variation not only in the stress concentration but also in the mechanics of its formation. The maximum stress concentration occurs in the case of the crack being positioned at the angle $\alpha = 150°$, while the minimum stress occurs for $\alpha = 90°$.

Investigations into the effect of the surface waves on the development of the boundary cracks broaden the concept of the mechanism of fracture of solids under dynamic loading. In [1, 2] crack growth was demonstrated in the case of Rayleigh waves going out to its vertex. In the present work we consider the effect of the orientation of the crack on the passage of Rayleigh impulses.

The investigations were carried out on testpieces of polymethylmethacrylate with the dimensions $400 \times 250 \times 15$ mm^3, on which by means of a slight tap of a knife, we produced cracks of arbitrary depth and required orientation. Identical dimensions of the cracks were obtained by milling the surface of the testpiece.

The experiments were carried out on testpieces with the length of crack equal to 5, 10, and 15 mm. Rayleigh waves were excited by a point microexplosion at the end of the testpiece. The weight of the microcharge was 40 mg of TENa. The initiation of the microexplosion was effected by means of an exploding wire. A discharge of a capacitor with 2 μF capacitance charged up to 5000 V was produced through a copper wire 5-mm long and 0.05 mm in diameter. The control of the explosion was effected by means of a discharger clamp connected in series with the wire by a high-voltage impulse from the control panel of an SFR-1M camera. This ensured complete safety when setting off the microcharge. The filming of the process of propagation and interaction of the wave and the crack was carried out in polarized light. For the polarization a polariscope with circular polarization was used, while in the role of the light source an ISSh-100-3 vacuum tube, ensuring a flash with duration of 300 μsec, was used. Monochromaticity of the light was achieved by means of an interference light filter with $\lambda = 460$ mμ.

The pattern of interaction of Rayleigh waves and a crack of various orientations is shown on cinegrams obtained with a velocity of filming of 10^6 frames/sec (Fig. 1). A study of them confirms the fact that when the wave passes through the crack, the following phenomena take place: diffraction of the wave on the dihedral angles at the crack tip, reflection of the wave, formation of surface waves and body waves, and separation of the Rayleigh wave into two surface waves that follow one after another.

The phenomena being observed in many aspects is determined by the orientation of the crack and by its dimensions. If the crack is located so that it forms an angle $\alpha > 90°$ with the surface of the half-space, then the passage begins with diffraction of the wave on the dihedral angle α. At the same time the wave is partially reflected, and partially passes through to one of the sides of the crack. The last wave, propagating towards the vertex, having reached it, diffracts, creating a stress concentration in its vicinity. The diffraction phenomenon on the crack is accompanied by formation of surface waves and body waves; this is clearly seen on the cinegrams from the isochromatics propagating into the depth. After diffraction

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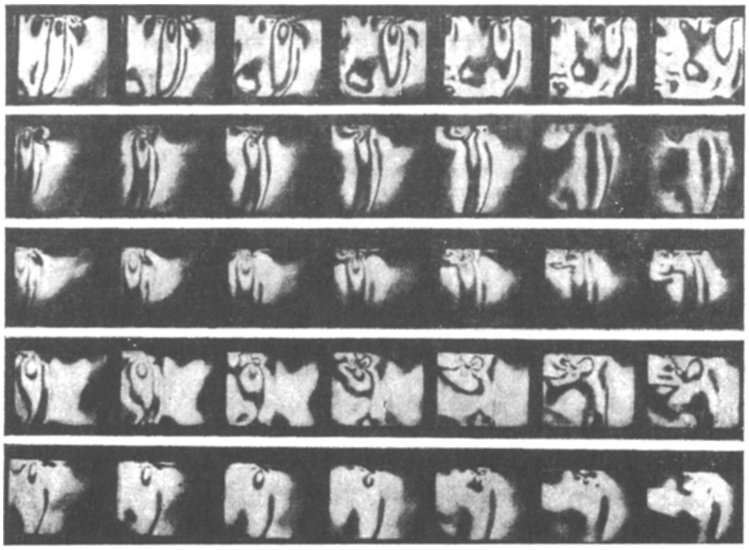

Fig. 1

of the wave at the crack tip its diffraction takes place on the dihedral angle that is adjacent to the angle α.

If the angle $\alpha < 90°$, then the sequence of passage of the wave described above is disturbed. At the beginning the fundamental rosette of stresses reaches the vertices of the crack, and then diffraction of the rosette close to the surface takes place on the dihedral angle α, the crack tip, and the angle $180° - \alpha$. The time-based separation between these processes is determined by the angle α and the dimension of the crack. This gives rise to separation of the Rayleigh wave into two surface waves that follow one after another. The excitation of the first surface wave is caused by variation of the stress state at the crack tip as a result of the action of the basic disturbance.

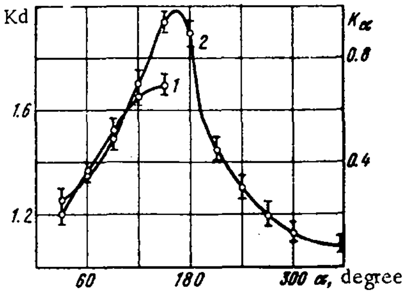

Fig. 2

On the cinegrams we see the effect of the orientation of the crack on the distribution and magnitude of maximum shear stresses at its vertex. They are responsible for the subsequent behavior of the crack, since they determine its magnitude and the trajectory of development. The growth of the crack always takes place along the gradient of tangential stresses. If $\alpha = 90°$, then the crack grows at an angle of 80° to its original position, while in the case $\alpha = 150°$ it takes place at an angle 7-8°. A variation of the parameters of the incident wave is accompanied by a variation in the magnitude of the stress state and has an effect only on the rate of development of the crack.

On the basis of the investigations carried out, we can confirm the existence of a correlation between the magnitude of elastic energy stored at the vertex before fracture and the magnitude of increment of the crack. Regrettably, it is not possible to establish a strict relationship between these parameters on the basis of the experiments carried out, since together with a variation of the orientation of the crack the stress concentration at its vertex also substantially varies. Therefore the action of the wave does not always give rise to a development of the crack. It should be noted that an increment of the crack is also determined by the duration of the Rayleigh wave. The variation of the stress concentration at the crack tip when its orientation is varied, is shown in Fig. 2: an increase of the angle α from 30° to 100° is accompanied by a growth of the dynamic stresses at the crack tip according to a linear law.

The variation of the magnitude of elastic energy at the vertex with time is presented below.

t, μsec		0	4	8	12	16	20	24	28	32	36	40
E_i	90°	0	0.15	0.3	0.48	0.64	0.7	0.64	0.69	0.9	1	0.83
E_{max}	120°	—	—	0.05	0.2	0.4	0.55	0.7	0.67	—	—	—

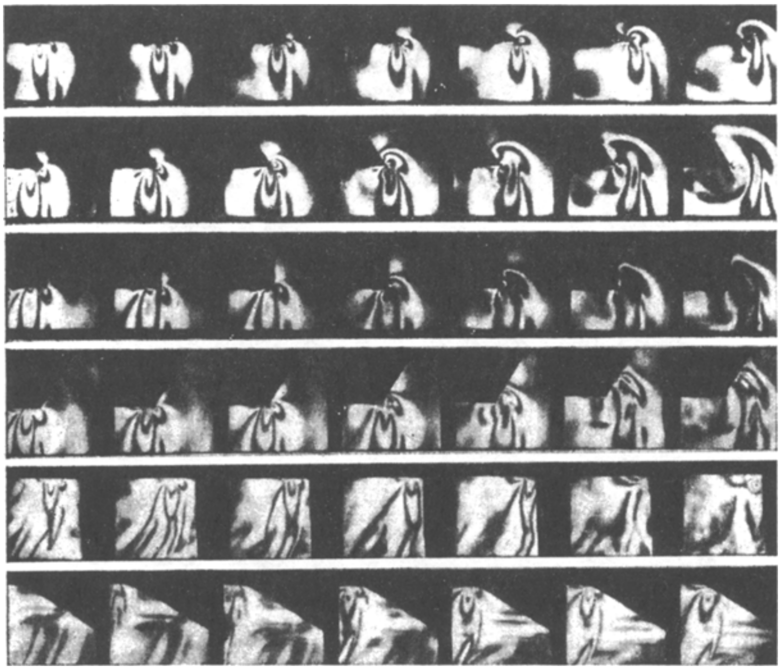

Fig. 2

TABLE 1

$\alpha°$		15	30	45	60	75	90	105	120	135	150	165
K_p	$l/\lambda=1$	0.98	0.97	0.92	0.88	0.84	0.82	0.83	0.84	0.87	0.92	0.95
	$l/\lambda=2$	0.95	0.8	0.58	0.4	0.32	0.28	0.3	0.28	0.3	0.64	0.85
	$l/\lambda=3$	0.7	0.65	0.4	0.25	0.17	0.13	0.15	0.2	0.33	0.52	0.8
K_p^*	$l/\lambda=3$	0.71	0.66	0.42	0.27	0.18	0.14	0.17	0.21	0.34	0.54	0.82

K_p^* –calculated value.

Here E_i, the store of elastic energy, was determined by the methods [1]. When the crack is oriented at the angle $\alpha = 90°$, we observed two extrema which are caused by the diffraction on the crack, respectively, of the basic and the near-surface disturbance in the Rayleigh impulse. This also explains the separation of the Rayleigh wave into two surface waves. The stress fields corresponding to these instants of time are distinguished from one another by the location of the gradient of maximum shear stresses. As a result, a variation in the trajectory of growth of the crack takes place. For certain positions of the crack these variations are so substantial that its direction of development is changed into an opposite one. Processing of experimental data shows that not only the orientation but also the dimension of the crack exerts influence on the passage of the wave. In Table 1 we have given the values of the passage coefficients of the wave for various values of l/λ with the orientation of the crack taken into account.

The maximum passage of the wave is observed when the wave is located at the angles $\alpha = 150$ and 30°; the minimum passage is observed for $\alpha = 90°$. An increase and a decrease in the angle α relative to $\alpha = 90°$ are not equivalent: the passage is considerably reduced when $\alpha \to 180°$. Such a relationship is particularly telling in the case $l/\lambda > 1$, where l is the length of the crack and λ is the depth of the maximum of the transferable energy in the Rayleigh impulse.

The passage coefficients of the wave can be found also in another way. Assuming that the projection of the crack on the z axis would divide the Rayleigh impulse into two parts, one of which contains the energy E_z/E_t and the other contains $1 - E_z/E_t$, where E_t is the total energy stored in the Rayleigh impulse, while E_z is the projection of the crack isolated, we can determine the passage coefficient

$$K_p = \frac{E_z}{E_t} K_\alpha K_T K_{180-\alpha} + \frac{E_{2z} - E_z}{E_t} K_{180+\alpha} K_{180-\alpha} + \frac{E_t - E_{2z}}{E_t}$$

Here the first term takes into account the last part of the energy of the near-surface disturbance, the second is obtained from it with the assumption that not the entire energy of the lower part of the Rayleigh impulse is diffracted, but only the part that can be drawn into the diffraction process, equal to $E_{2Z}-E_Z$. The remaining (third term) part passes through without interacting with the crack.

The results of determining the passage coefficients of the wave obtained according to such a semi-empirical relationship for the case $l/\lambda = 3$ are presented in Table 1. A satisfactory agreement of the calculated and experimental values of K_p is observed.

To find the passage coefficients of the wave by the methods presented here, we must know its passage coefficients through the dihedral angle K_α and through the crack tip K_T. Additional experimental investigations were carried out. In Fig. 3 we have presented the cinegrams of the passage of the wave through various angles (the speed of filming is 10^6 frames/sec); the values of the coefficients are shown in Fig. 2, while the values of K_T for the crack are presented below:

l/λ	0.5	1	1.5	2	2.5	3	3.5	4
K_T	0.98	0.93	0.85	0.7	0.4	0.15	0.05	0.01

LITERATURE CITED

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