# SIMULATING A CRACK BY A NOTCH IN THE SOLUTION OF DYNAMIC PROBLEMS

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In the article the method of dynamic photoelasticity is used to investigate the formation of a state of stress at the apexes of cracks and notches under the action of stress waves. Edge and closed cracks in the case of the action of longitudinal and surface waves are discussed. The investigations show that a crack may be simulated by a notch only under definite conditions.

In the work an attempt was made to justify experimentally the simulation of closed cracks by a notch. The investigations were carried out by the method of photoelasticity in a homogeneous isotropic material – polymethylmethacrylate. Based on the investigations it is shown that a notch can be used only under definite conditions for studying physical phenomena and the formation of a state of stress at the apex of a crack under dynamic loading.

The interaction between longitudinal and surface waves and a notch was examined with a different orientation with respect to the front of an incident wave. The study of the interaction of the longitudinal waves was carried out on samples in the form of disks with a diameter of 200 mm and a thickness of 15 mm. Surface waves were investigated on samples with sizes of $400\times300\times15$ mm. In the first case, notches were sawn along the radius of the disk to the center, while the cracks were generated by a light blow of a knife at the apexes of analogous saw cuts, but did not extend to the center of the sample by a distance of 20-30 mm. Samples were selected with a flat front of the crack, located at the center. Closed cracks were simulated by a notch at the center of the sample. With the loading of such samples by a wave of stresses along a normal to the plane of the notch, there is symmetrical development of cracks at its apex. The cracks forming lie in the plane of the notch and are, in a way, its prolongation. Samples with this type of real closed cracks were subjected to further study. The stress waves were excited by the microexplosion of 20 mg of PETN at the end of the sample. Assuming that all the experimental conditions are identical, the similarity was evaluated from the value and character of the distribution of the maximal tangential stresses in the zones under investigation.

Figure 1a gives cinephotos of the interaction between stress waves and edge notches and cracks. The case of the propagation of a wave along one side of the crack is considered. The frames on the cinephotos, corresponding to identical moments of time (reckoned from the moment of arrival of the wave to the crack), are graphic evidence of the coincidence of the stress distribution at the apexes of the cracks. This is observed not only in the distribution of the tangential stresses, but also in their value. The dynamic coefficient of the concentration is roughly equal to three. This means that, in the case under consideration, this type of simulation is correct. A special characteristic of the recorded stress field is the direction of the gradient of the tangential stresses at an angle of 80-85° to the direction of the crack.

By a comparison of the stress fields obtained with different orientations of the cracks and notches with respect to the front of the incident wave (Fig. 1b, c) it has been established that a change in the angle of incidence of the wave brings about a change in the stress field, both in value and in the character of the distribution of the tangential stresses. A change in the position of a crack or notch within the range 0-80° leads to a change in the stress field only in value. Incidence of the wave along a normal to the plane of the crack brings about a redistribution of the state of stress such that the gradient of the accumulated stresses

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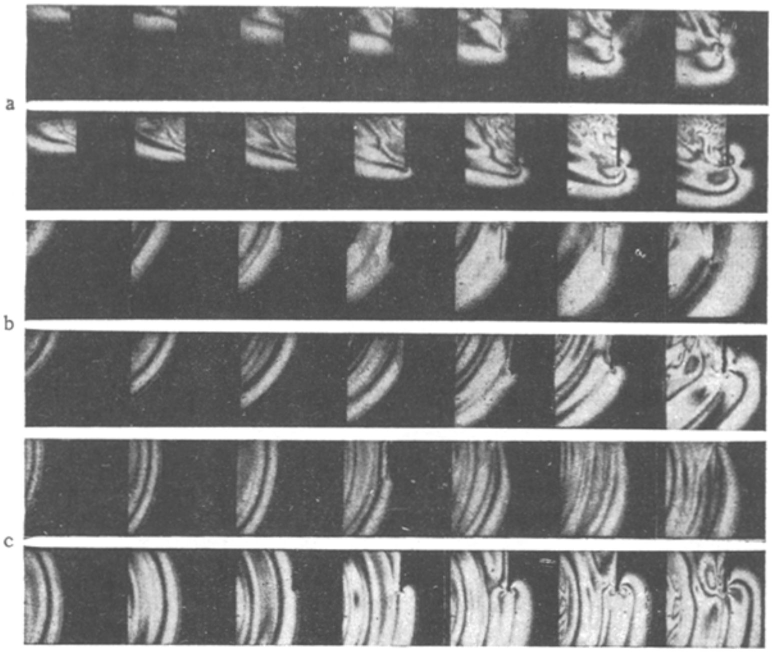

Fig. 1

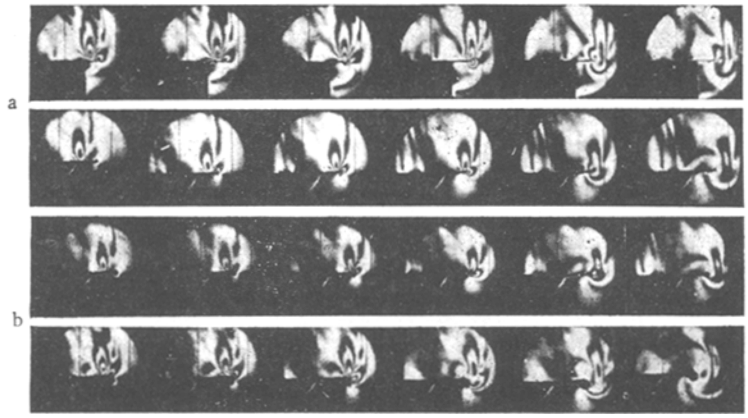

Fig. 2

coincides with the direction of the crack. This points to a change in the mechanism of formation of the state of stress [1, 2].

In this case, the condition for simulation breaks down. As a result of the presence of an acoustical contact between the edges of the crack, the propagating wave is easily transformed through it, with only a weak effect on the breakdown of the continuity. As a result, a weak diffraction stress field is set up at the apex of the crack which, in a first approximation, coincides with the field at the apex of a notch. Spreading of the crack decreases this lack of agreement, but does not eliminate it completely, since it is not possible to eliminate acoustical contact at the mouth of the crack, resulting from its forward movement. A further increase in the angle of incidence of the wave again yields a coincidence of the results. The dependence of the concentration coefficients on the angle of incidence of the wave is shown below.

| $\beta°$ | 0 | 30 | 60 | 90 | 120 | 150 |
|---|---|---|---|---|---|---|
| $K_d$ for a crack | 3.1 | 2.7 | 2 | 1.1 | 1.9 | 2.5 |
| $K_d$ for a notch | 3 | 2.5 | 1.8 | 1.5 | 1.7 | 2.4 |

Here $K_d = K_{max}/K'_{max} K_{max}$ is the maximal concentration of the elastic energy at the mouth of the crack as a result of the action of the wave; $K'_{max}$ is the maximal concentration of energy at the front of the incident wave before its interaction with the crack.

These quantities were determined in an identical volume using a method set forth in [1]. In this case damping of the wave can be neglected, since the distance between the zones in which the value of the elastic energy was determined is very small.

Thus, a lack of agreement is observed only with an orientation of the crack along a normal to the direction of propagation of the wave. With quantitative measurements on a model, in this case there arises an error, i.e., the values obtained are found to be somewhat too high.

It is of interest to investigate the interaction between Rayleigh waves and cracks and notches. These waves, like the volumetric waves, were excited by a concentrated microexplosion, which was carried out at a distance of 200 mm from the apex of the crack. This distance was selected from the condition that, at the moment of the arrival of the Rayleigh wave at the apex of the crack, it would be completely separated from the transverse wave.

Cinephotos of the interaction between a Rayleigh wave and a crack and a notch are shown in Fig. 2a. An analysis of these results (determination of the change in the value of the elastic energy at the apex, and of the transmission and reflection coefficients of the Rayleigh wave) shows that in the case of a notch with a radius of its apex less than 0.5 mm, there is an almost complete analogy between the processes taking place and the state of stress with a crack. With radii greater than this value, some lack of agreement is observed. To evaluate the effect of the radius of the apex on the passage of surface waves, supplementary investigations were made (Fig. 2b). An analysis of the results showed that the transmission coefficient of a Rayleigh wave $K_R$ depends on the radius only when the radius is increased to 1 mm. A further rise in the value of the radius does not lead to any substantial change in $K_R$. Its value was determined in the following manner:

$$K_R = K_R' / K_{max}$$

where $K_R'$ is the value of the elastic energy passing through the apex into the shadow zone, determined by analogy with $K_{max}$.

The dependence of the transmission coefficient of a Rayleigh wave on the radius of the apex is shown below.

| $r$, mm | Crack | 0.25 | 0.5 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|
| $K_R$ | 0.08 | 0.23 | 0.4 | 0.41 | 0.42 | 0.42 | 0.43 |

A comparison between the change in $K_R$ with the time and the form of the load shows that, with radii of the apex greater than 1 mm, they are identical, i.e., there is a linear dependence between the supply of energy into the shadow region and the form of the load.

An investigation was also made of the interaction between stress waves and closed cracks. A notch simulating a crack and a notch with real cracks at its apexes were studied with different angles of incidence of the wave (Fig. 3). The results bear witness to the fact that, as in the case of an edge crack, a change in the angle of incidence of the wave entrains a redistribution of the state of stress at the apex of a notch or a crack. With incidence of the wave along a normal to a notch (Fig. 3a), there first arises a uniform stress field along the upper plane of the notch, due to interference between the incident and reflected waves and, analogously, to that arising with the reflection of a wave from a free surface.

At a certain distance from the plane of the notch, there is formed a region of maximal stress concentration; these stresses can lead to splitting-off phenomena. The value of the maximal tangential stresses is 400-500 kg/cm$^2$. As a result of diffraction symmetrical stress rosettes are formed at the apexes, whose gradient is directed along the notch. There is then a reinforcement of the interference picture at the upper plane of the notch, and diffraction of the wave into the shadow region, where there arises a concentration of stresses resulting from the compounding of waves coming from right and left. The outflow of energy into the shadow zone obviously takes place as the result of both longitudinal and surface waves. When a concentration of stresses is attained which exceeds the dynamic tensile strength, a crack develops in the direction of the gradient of the tangential stresses.

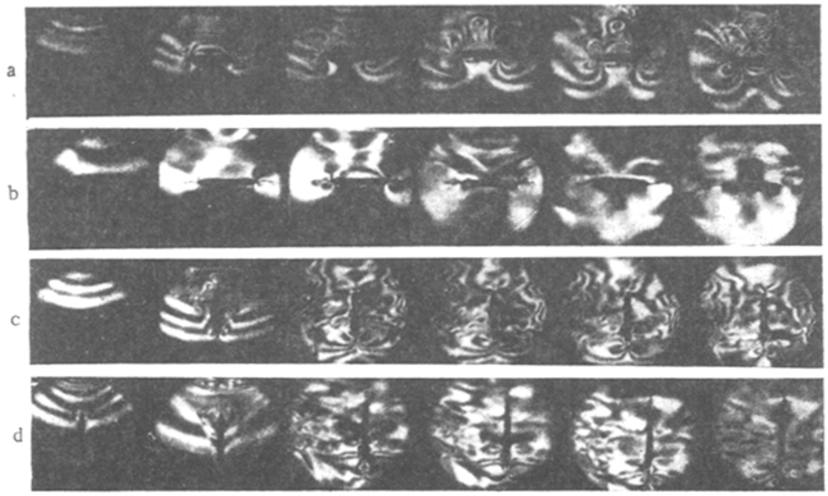


Fig. 3

It is worthy of note that, with the action of a wave, there is a deflection of the upper plane of the crack. Under definite conditions, the deflection has a magnitude sufficient for the formation and development of a crack in the middle part of the notch. Its development proceeds at a rate of 30-40 m/sec. in a direction opposite to the incident wave. The small rate of growth of the crack is probably explained by the fact that its development takes place in the compressing field of the incident wave, which partially compensates the elongational stresses at the apex of the crack. An increase in the intensity of the incident wave does not lead to a rise in the rate of growth of this crack.

When the directions of the notch and of the propagation of the wave coincide (Fig. 3c), there is first formed a stress rosette at the nearest apex of the notch; the rosette is then somewhat modified and is transformed into surface waves, propagating along the plane of the notch. The arrival of these perturbations at the opposite apex sets up a state of stress in its vicinity, capable of bringing about the development of a crack. It is characteristic that, in the cases under consideration, the process of the formation of a dynamic stress field at the apexes of the notch differs in its physical nature: in the first case, the concentration of stresses is due to the diffraction of the longitudinal wave, while in the second case, it is connected with the propagation of surface waves. In spite of this, the direction of the gradient of the combined stresses coincides in these cases. As a result of this, the trajectories of the motion of the cracks coincide.

With the incidence of a wave at an angle of 30-60°, the distribution of the stresses differs from the first two cases considered. The difference consists in a change in the gradient of the tangential stresses and in their alternating reinforcement and relaxation at the apexes. These pulsations are connected with the excitation of surface waves along the sides of the notch. As a result of the state of stress of the sample, no propagation of these perturbations is observed; however, studies of Rayleigh waves [3] show that the character of the stress distribution at the apexes corresponds to the action of this type of waves.

A further study was made of the interaction between waves and a notch having real cracks at its apexes (Fig. 3b, d). The cine-frames obtained point to the presence of certain special characteristics in the formation of the stresses: in the case of the incidence of the wave along a normal to the plane of the crack, the same type of concentration is not set up as in a notch. The observed phenomena are analogous to those observed in the study of the interaction between a wave and an edge crack. The wave is easily transformed through breakdown of the continuity if the distance between its sides is commensurate with the value of the elastic deformation at the front of the incident wave. The critical distance (the distance at which transmission of the wave is not observed) is determined by the intensity of the incident wave.

If the direction of the crack and of the propagation of the wave coincide (Fig. 3d), this case practically does not differ from the interaction between a wave and a notch. The maximal stress concentration is connected with the arrival of a Rayleigh wave at the apex of the crack. In this case, the development of the crack is sharply accelerated if the influx of elastic energy exceeds that expended for breakdown, approaching the velocity of the Rayleigh waves.

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