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Modeling of the Process of Determining the Speed of the Development of Cracks in a Solid Medium

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***Abstract*—The article is devoted to determining the rate of development of cracks in a solid during a model experiment in a solid medium. At the same time, the rate of crack propagation and its resource development potential for the destruction of solids are substantiated.**

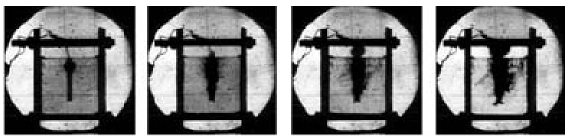
Keywords—crack; development; tension; time; optical material; charging cavity

I. Introduction

At present, the mathematical apparatus of continuum mechanics does not allow to calculate the dynamics of crack development with a given accuracy [1]. Model experiments in solids to determine the rate of crack development are considered and the rationale for the resource potential of the quasistatic fracture process is given.

II. Analysis of the Structure

The process of investigating the rate of crack development in quartz glass models was carried out by the method of high-speed photography using the Teplerovsky installation IAB-451 with a shooting speed of a million frames per second and presents the kinogram of the cracking process in Figure I (a, b, c, d) with a time interval of 18 µs.



a b c d

FIGURE I. KINOGRAMMA EXPLOSION OF AN ELONGATED CYLINDRICAL CHARGE

From the figure of the model experiment, one can see the conic propagation of tension waves along the length of the charging cavity. And thus, the tension waves cause local displacements of the material particles, which create a tension state of the medium, and dark lines (isochromes) appear in the optically active materials, propagating with the speed of longitudinal waves.

During the propagation of tension waves, a crack propagation occurs and the value of which is (0.3 - 0.4) c_p, where c_p is the velocity of the longitudinal wave in the optical glass. On the basis of a graphic picture of the propagation of tension waves in the process of cracking, it is possible to imagine the destruction of a solid medium as follows.

The stepped surface of the plane of the split model of optical glass indicates that the process of the development of cracks is intermittent. The pulsating nature of the movement of a crack due to intermediate relaxation processes of tensions at its tips. The jumps in the development of cracks are due to the required value of tension concentration at the crack tip and also the time needed to feed the required level.

From the film (see Figure I) it can be seen that the detonation velocity of the charge was 6000 m / s, and the flow rate of the gaseous products of the explosion was 700–1000 m / s. The tension waves in the model propagated with the speed of a longitudinal wave of a solid medium. As a result of the interference of stress waves from rigid boundaries (axes of symmetry), directional radial cracks were formed, which determined the split of the model into two equal parts. The average development rate of the main crack was about 2000 m / s, and the process of sample destruction occurred in $25 \cdot 10^{-6}$s.

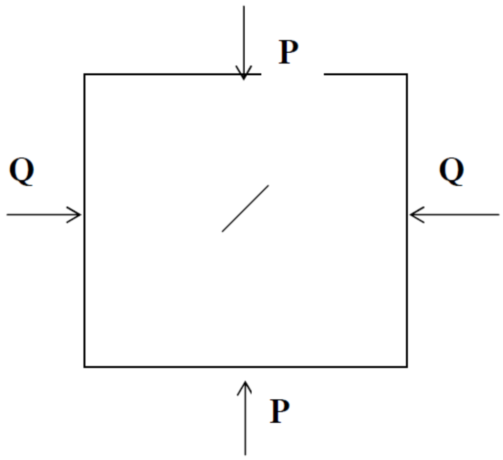


FIGURE II. DIAGRAM OF A MODEL WITH A CRACK

When calculating the tension-strain state of individual parts of machines that operate under loads that vary in time. Such a change in the tensions in the parts of the part determines the process of gradual accumulation of damage that leads to the formation of microcracks. The nuclei of cracks form at the tip due to tension concentrations and develop under the action of operational loads until they reach critical sizes, which are produced to sudden destruction. Moreover, as a rule, breakage occurs at tensions that are significantly lower than the strength of the material. In this case, the physical nature of the destruction of metals exposed to tensions, cyclically varying in time, is accompanied by the final fatigue failure of the part.

Model experiments by the method of photoelasticity consisted in verifying the physical modeling of the process of the development of cracks, that is, to qualitatively show the development of additional cracks by changing the load. A constructive solution to the problem of modeling cyclic loads due to general integrated studies increases the effectiveness of the development of cracks under various types of loading.

The experiments on the models make it possible to illustrate the mechanism of the formation of tension dislocations and the process of the development of cracks and expand the qualitative picture of the destruction of a solid body. The application of the photoelasticity method, if it is difficult to theoretically state the solution of the problem, to conduct full-scale experiments and analytical and numerical methods for calculating the process of crack development have not been developed.

The method of photoelasticity qualitatively shows the process of crack development and serves as the basic principle of experimental continuum mechanics, in which it is necessary to identify the main factors determining the course of research on the development of cracks and minor nonessential factors to be reasonably discarded. Compliance with this requirement allows you to perform the physical nature and patterns of deformation of the models, not only within the limits of elasticity, but also during fracture.

In the first approximation, it is possible to limit oneself to the consideration of two kinds of forces (loading and unloading) arising from cyclically varying loads during operation of machine parts.

The development of cracks stops with a change in the external load, and the process of the development of cracks from one (or several) centers is the most interesting, i.e. the quasi-timeliness of the destruction process in the presence of very many internal foci.

Thus, the transition to its hypothetical destruction of solids is carried out after the introduction of some additional provisions on the mechanism of destruction, that is, taking into account the tension concentration for the crack systems under consideration.

In model studies of the development of a crack, samples were created by calcining with a special tool, when the material was in a heated state, in this case the crack is obtained with closed shores.

For modeling in optical material with a size of 100×100 mm with a diagonal crack of 10 mm in size located in the center of the sample and the crack is directed along the diagonal of the model (see Figure II).

The experiment suggests that cracks in the loaded material can develop not only with increasing load, but also when removing it. As a rule, the process of crack development takes place along the border of the elastic and elastic-plastic region.

With a comprehensive loading of the sample model with a crack (P = Q = 1.2n), the development of cracks was not observed, i.e. the equilibrium state is preserved and as the load decreases Q = 0.4n, the asymmetry of tensions is formed in the vicinity of the crack tip, which causes the start of crack development (see Figure II).

The interference pattern of a band in polarized white light shows isochromes.

The interference pattern of the formation bands in the model, which, as known, characterizes the magnitude of the maximum tangential stresses (τ_{max}), is shown in Figure III. Figure III shows the interference pattern of the bands in polarized monochrome light, which indicates the highest concentrations of maximum tangential stresses under such loading at the end of cracks and is 7 orders of fringes. The size of the crack has not changed.

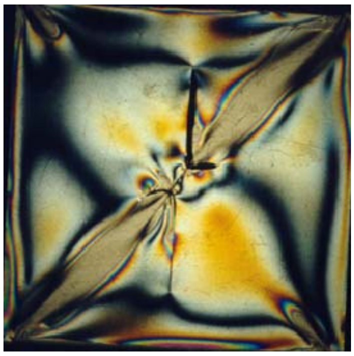


FIGURE III. INTERFERENCE PATTERN OF BANDS IN POLARIZED LIGHT

From this experiment, the same conclusion follows that when removing loads from a material with cracks, if the material was under loads that created large concentrations of tension on the tip of the cracks, which led to the formation of plastic zones, the cracks could sprout or open.

This is explained by the fact that a large stress concentration occurs around the tip of the crack during loading, which leads to the formation of plastic (irreversible) deformations near its zone, and the material is in an elastic state at the periphery of the crack.

When removing the load, the elastic region of the sample is deformed, but the plastic zone does not. And on the border of these zones, new cracks are formed, or the material that has already formed under the load of a crack grows in an elastic state. When removing the load from the model, the elastic region deforms, but plastic zones do not. Along the border of these zones (elastic and plastic) new cracks are formed or the cracks already formed during the load are growing.

Thus, the experiments performed on optically sensitive materials show that the removal of the load from the material with a crack leads to the process of crack development. The magnitude of the tension intensity at the crack tip, which is necessary for its further growth, was determined by the time of feeding a sufficient critical tension level. It should also be noted the effect of asymmetry around tension concentrators on the nature of the stress distribution in the process of crack development.

III. Conclusion

Model experiments from optically sensitive material show a qualitative picture of the development of cracks in a solid medium when tension asymmetries occur in the vicinity of the crack tip and the start of its development. The results of the experiments can be used for comparative analysis and testing the adequacy of the constructed mathematical models.

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