EFFECT OF FREQUENCY ON PLASTIC ZONE KINETICS AHEAD OF A FATIGUE CRACK

A. D. Volkov

UDC 539.214:539.374:539.375

In order to make it possible to study the main fatigue mechanisms, it is necessary to exclude the effect of a potentially large number of parameters and to carry out experiments under simple controlled conditions. In order to build up a physically valid theory for crack growth, it is very important to have a clear idea about the nature, mechanism, and degree of the effect of each excluded parameter. This is particularly necessary in studying crack kinetics in actual structures and components due to the effect of a whole collection of loading parameters, material structure, and its operating conditions.

It is well known that with an increase in loading frequency, material endurance generally increases, and this dependence develops particularly clearly at high frequencies [1]. The level of the effect of a fatigue loading parameter in each specific case is currently only determined by experiment. Unceasing attempts to explain the mechanism of the effect of this factor on endurance characteristics in any of the existing fatigue theories does not lead to a positive result and it only creates premises for criticizing the theories themselves (see, e.g., [2]).

The effect of loading frequency on fatigue crack growth may be (in our view it is necessarily) explained in terms of the sensitivity of the plastic zone to a form of loading. This belief is based on two facts confirmed by experiment: first, both plastic deformation and microfailure ahead of a crack are realized by mechanisms having a single dislocation nature and, second, the region of prefailure is as a whole in extensive and intensive regions of plastic deformation.

The author has suggested a supplement to the closed set of equations for plastic deformation based on a similar set of equations developed in [3, 4]. Distribution of plastic deformation $\varepsilon_{p\ell}$ and the boundaries of its zone are found as a result of stepwise solution of the following system:

$$\dot{\varepsilon}(\mathbf{r}) = \dot{\varepsilon}_0 \exp\left\{-\frac{U_0 - v\tau_e(\mathbf{r})}{kT}\right\}; \quad (1)$$

$$\tau_e(\mathbf{r}) = \tau_y(\mathbf{r}) - \tau_0 - \tau_f(\mathbf{r}) + \tau_l(\mathbf{r}); \quad (2)$$

$$\tau_l(\mathbf{r}) = \sum_i \int_s F_i(\mathbf{r} - \mathbf{r}')\,\Delta\rho(\mathbf{r}')\,d\mathbf{r}'; \quad (3)$$

$$\Delta\rho(\mathbf{r}) = b^{-1}(\nabla\varepsilon(\mathbf{r})). \quad (4)$$

Here $\varepsilon(\mathbf{r})$ is plastic strain at the point with radius-vector $\mathbf{r}$; τ_y is stress from the solution with a crack; τ_f describes interaction with dislocations of a "forest"; τ_ℓ is total stress due to unlike dislocations of the plastic zone S; $F_i(\mathbf{r} - \mathbf{r}')$ are tangential stresses at point $\mathbf{r}$ due to a single dislocation of the i-th slip system at point $\mathbf{r}'$; τ_e is effective tangential stress in the slip plane; $\Delta\rho$ is density of unlike dislocations; T is temperature; $\dot{\varepsilon}_0$, U_0, v, k, b, and τ_0 are constants. The difference in this system from that used in [3, 4] involves considering the reaction of dislocations from different systems intersecting the slip plane [Eq. (3)]. In addition, Eq. (4) acquires a vector sense.

In order to study specific problems of plastic deformation for a material with a crack, an algorithm has been developed for solving set (1)-(4) realized in a package of programs. As variable starting parameters, loading parameters (length of sinusoidal cycle T_c, amplitude σ^{in}, average stress of the cycle, displacement of the cycle), structure, and state of the materials (angle between the base of slip and a crack, crack length, size of dislocation

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 155-158, May-June, 1989. Original article submitted April 13, 1987; revision submitted October 19, 1987.

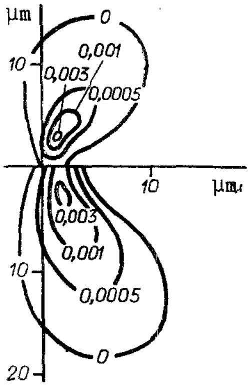

Fig. 1

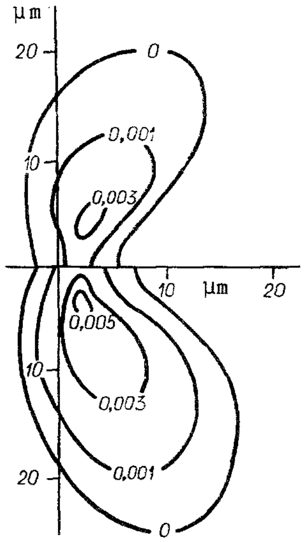

Fig. 2

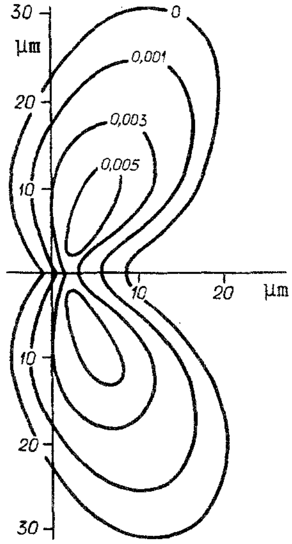

Fig. 3

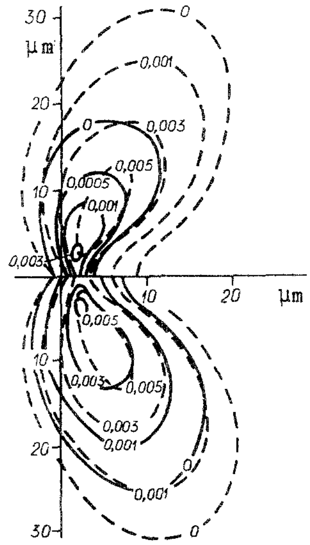

Fig. 4

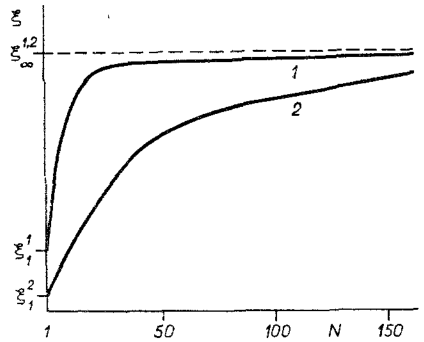

Fig. 5

cells, temperature, etc.) are taken. Presented below are results in the form of a map of $\varepsilon_{p\ell}$ distribution for crack tests in steel for normal breaking with different loading frequencies (Figs. 1-3). A change in loading frequency is achieved as a result of changing T_c from 0.01 to 100 sec with a constant cycle asymmetry coefficient ($\rho = 0$) and spread of stress intensity factor ($\Delta K_1 = 25$ kg/mm$^{3/2}$). Maps of $\varepsilon_{p\ell}$ in the first cycle are given in these pictures: in the upper part with $T_c = 0.01$, 1.0, and 100 sec and in the lower part with $T_c = 0.1$, 10, and 100 sec, respectively. By comparing the maps it can be seen that the most complete plastic strain occurred in 100 sec, and with a reduction in the duration of external load operation its area and intensity decreases.

These tendencies are also observed with prolonged tests. Presented in Fig. 4 are pictures of plastic strain with different test frequency (solid lines in the upper part are 100 Hz, in the lower part 1 Hz, and broken lines are limiting maps for $\varepsilon_{p\ell}$) for five loading cycles. The spread of ΔK and asymmetry coefficient were selected the same as in the previous problems. With this loading no reverse plastic strain arises and, therefore, the limiting map for $\varepsilon_{p\ell}$ is the same for all frequencies and it governs K_{1max}. However, even in this case, as can be seen by comparing maps in Fig. 4, a difference exists in dynamics for plastic-zone formation: with high loading frequency a greater number of cycles N is required in order to achieve a specific level of deformation than with a low frequency. This is seen even more clearly from the curve in Fig. 5, where the level of plastic deformation for the material ahead of the crack for each frequency is presented in the form of a function on the number of loading cycles (lines 1 and 2 are 1 and 100 Hz). As material deformation characteristic ξ here we nominally take the integral of the distribution function $\varepsilon_{p\ell}$ over the whole area S.

Significant progress in fracture mechanics and comparatively slow development of methods of plasticity theory describing formation of a plastic zone ahead of a fatigue crack leads to an attempt to use new approaches to solving the problem of deformation of a material with a crack. The effect of loading-cycle length on plastic-zone kinetics obtained by means of the dislocation model for plastic deformation described in the work agrees on the whole with observations in direct experiments. In addition, the closed system occurring in the process of solution for intermediate results of the map for unlike dislocation density $\Delta\delta(\mathbf{r})$ and maps for the overall dislocation density taking part in the plastic deformation process, and also distribution of operating residual stresses (which are distantly operating stress fields for an assembly of unlike dislocations) may be used in building physically equiprobable dislocation models of fatigue crack growth.

The difference in the approach suggested for studying fatigue failure from semiempirical theories existing in linear fracture mechanics includes the following. Absence of a physical base in mathematical models of semiempirical theories induces mechanical engineers to limit themselves to one or two parameters of the number which affect crack extension rate. In the opposite case the number of empirical constants in resulting expressions increases nonlinearly. The approach described in this work makes it possible to build on the basis of a dislocation model a multiparameter relationship for da/dN with a limited number of empirical constants.

LITERATURE CITED

1. R. Honeycombe, Plastic Deformation of Metals [Russian translation], Mir, Moscow (1972).
2. V. R. Regel', A. I. Slutsker, and É. E. Tomashevskii, Kinetic Strength Theory for Solids [in Russian], Nauka, Moscow (1974).
3. V. I. Vladimirov, A. N. Karpinskii, et al., "Modeling in a computer deformation kinetics in the plastic zone at a crack tip," Probl. Prochn., No. 12 (1983).
4. V. I. Vladimirov, The Physical Nature of Metal Failure [in Russian], Metallurgiya, Moscow (1984).

THREE-DIMENSIONAL BENDING GRAVITATIONAL OSCILLATIONS NEAR MOVING PRESSURE REGIONS

A. E. Bukatov and V. V. Zharkov

UDC 532.593:539.3:624.131

Three-dimensional bending gravitational waves, excited in the near zone during the motion of constant pressure regions over a uniformly compressed thin elastic film, floating on the surface of a homogeneous ideal incompressible fluid of finite depth, are investigated within the linear theory. The dependence of the structure of oscillations on the velocity of the displaced pressure region, film thickness, and magnitude of compressing force is analyzed.

The asymptotic analysis of development of bending gravitational waves was carried out in [1, 2] for motion of a planar pressure front, and in [1, 3-5] for motion of an axially symmetric pressure region. Analysis of dynamic deflection under a lumped load in shallow water was carried out in [6].

1. Let a thin elastic uniformly compressed film float on the surface of a homogeneous ideal incompressible fluid of thickness H = const. A pressure region is displaced over the film with constant velocity v

$$p = p_0 f(x_1, y),\ x_1 = x + vt,\ v = \text{const}. \tag{1.1}$$

We consider the bending gravitational film oscillations excited in this case and the fluid wave perturbations in the near zone of the pressure region.

Under the assumptions of the linear theory the problem consists of solving the Laplace equation

Sevastopol'. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 158-166, May-June, 1989. Original article submitted February 2, 1988.