MODEL OF RESIDUAL LIFE OF A PLATE WITH A CRACK SYSTEM UNDER CORROSIVE ENVIRONMENT AND MANEUVER LOADING MODE

IRYNA DOLINSKA, TARAS SKALSKYY

Karpenko Physico-Mechanical Institute of NAS of Ukraine

A computational model is developed to study the kinetics and determine the period of subcritical growth of a system of cracks in a plate under the influence of a corrosive environment and a maneuver loading mode. The computational model is a differential equation with initial and boundary conditions, which describe the rate and direction of crack propagation. Based on the model, the residual life of a plate made of steel St3 with a two-periodic system of cracks was estimated.

Keywords: computational model, system of cracks, residual life, energy approach, corrosive environment

Introduction. Reliability and life of elements of long-term operated structures are of significant importance for various industries. To assess their life, it is necessary to take into account the occurrence of defects in the material, in particular cracks, and their further propagation. Under regular loading and the influence of corrosion-active environments, the fracture of materials and structural elements has been studied in sufficient detail [1]. However, during operation, such elements are subjected to complex-mode loadings, in particular, maneuver ones. Their influence on the residual life of structural elements has not been sufficiently studied [1], especially during the propagation of the system of cracks. In this work, a computational model was developed for studying crack systems and their influence on the residual life of plate under a maneuver loading mode.

Construction of a computational model. Consider a metal plate in which a system m of macroscopic cracks propagates. The plate is subjected to a longterm static load, as well as to the action of an additional time-concentrated dynamic load and a corrosive environment which enters the crack tips. Assume that anodic dissolution and hydrogen embrittlement occur at the crack tips during electrochemical corrosion. The configuration of the plate and the geometric arrangement of the cracks are determined by the linear parameters $a_1,..., a_k$, and the geometric configuration of each crack is determined by the parameters $b_1,...,b_m$. If ($a_g \to \infty$ ($g = 1,2,...,k$), obtain an infinite plate weakened by one crack with the configuration b_j. Next, choose a local coordinate system $O^{(j,z)}\rho^{(j,z)}\theta^{(j,z)}$ at the z-th tip of each crack $L^{(j)}$ and denote by $\Delta l^{(j,z)}$ the increment of the j-th crack at its ends ($z = 1,2$). The force load is described by the parameter p. It is necessary to determine the residual life of the plate.

Apply the well-known hypothesis [1, 2], according to which corrosion-mechanical cracks propagate in the direction of their maximum possible velocities. As a result, the problem of determining the residual life of the plate is reduced to the solution of a system of differential equations:

$$\frac{dl^{(j,z)}}{dt}=\frac{d\left(\Gamma^{(j,z)}\right)}{dt}\left(\gamma_{CC}-\gamma_t^{(j,z)}-\frac{\partial W_{p,2}^{(j,z)}}{\partial l^{(z)}}\right)^{-1}, \qquad (1)$$

$$\frac{\partial}{\partial\theta^{(j,z)}}\left[\frac{d\left(\Gamma^{(j,z)}\right)}{dt}\left(\gamma_{CC}-\gamma_t^{(j,z)}-\frac{\partial W_{p,2}^{(j,z)}}{\partial l^{(z)}}\right)^{-1}\right]_{\theta^{(j,z)}=\theta_t^{(j,z)}}=0$$

under initial and final conditions

$$t=0,\ \ l^{(j,z)}(0)=l_0^{(j,z)},\ t=t_*,\ l^{(e,z)}(t_*)=l_*^{(e,z)},\ (j=1,...,m;\ z=1,2). \qquad (2)$$

The critical crack length is found using the energy criterion:

$$\gamma_t^{(e,z)}\left(l_*^{(e,z)}\right)=\gamma_{CC}; \qquad (3)$$

$$\max_j\left[\gamma_t^{(j,z)}\left(l_*^{(j,z)}\right)(\gamma_{CC})^{-1}\right]=\gamma_t^{(e,z)}\left(l_*^{(e,z)}\right)(\gamma_{CC})^{-1}.$$

Here $\Gamma^{(j,z)}(t)$ is the energy of the plate fracture during an elementary jump of the crack tip $l^{(j,z)}$, which depends on the length of the *z*-th crack L_j, time and corrosive environment; $W_{p,2}^{(j,z)}(l)$ is the part of the work of plastic deformations in the prefracture zone caused by dynamic forces concentrated in time, and which depends on the crack length only; $\gamma_t^{(j,z)}$ is the specific work of plastic deformations in the prefracture zone near the crack tips L_j; γ_{CC} is its critical value; $\theta_t^{(j,z)}$ is the value of the angles $\theta^{(j,z)}$, which determine the direction of propagation of the crack ends L_j; $l_*^{(j,z)}$ is the critical growth of the z-th crack tip L_j under plate fracture.

It is believed that the rate of anodic dissolution is much lower than the rate of mechanical crack growth under conditions of force loading and local hydrogenation at its tip. Then the unknown values in the system of Eq. (1) will be:

$$\gamma_t^{(j,z)} = \delta_{\mathrm{I}\theta}^{(j,z)} \sigma_{0f}^{(j,z)} + \delta_{\mathrm{II}\theta}^{(j,z)} \tau_{0f}^{(j,z)}. \qquad (4)$$

$$\Gamma^{(j,z)} = \beta \delta_{CC} \left(\delta_{\mathrm{I}\theta}^{(j,z)} \sigma_{0f}^{(j,z)} + \delta_{\mathrm{II}\theta}^{(j,z)} \tau_{0f}^{(j,z)} \right). \qquad (5)$$

$$\frac{\partial W_{p,2}^{(j,z)}}{\partial l^{(z)}} = 0,25 \left(1 - R_t\right)^2 \alpha \sum_{i=1}^{n} \delta \left(l^{(j,z)} - l_i^{(j,z)} \right) \times$$
$$\times \left[\left(\delta_{\mathrm{I}\theta}^{(j,z)} \sigma_{0f}^{(j,z)} + \delta_{\mathrm{II}\theta}^{(j,z)} \tau_{0f}^{(j,z)} \right)^2 - \left(\delta_{\mathrm{I}scc\theta}^{(j,z)} \sigma_{0f}^{(j,z)} + \delta_{\mathrm{II}scc}^{(j,z)} \tau_{0f}^{(j,z)} \right)^2 \right], \qquad (6)$$

where $\delta_{\mathrm{I}\theta}^{(j,z)}$, $\delta_{\mathrm{II}\theta}^{(j,z)}$ are the projections of the crack opening displacement $\delta_t^{(j,z)}$ onto the direction axes of the polar coordinate system $O^{(j,z)}\rho^{(j,z)}\theta^{(j,z)}$; $\sigma_t^{(j,z)}$ are the averaged stresses in the prefracture zone near the z-th crack tip L_j; $\sigma_{0f}^{(j,z)}$, $\tau_{0f}^{(j,z)}$ are their corresponding projections.

Plate with a two-periodic crack system. Consider an infinite plate weakened by a two-periodic system of rectilinear cracks of length $2l_0$ (Fig. 1). At infinity, a long-term static tensile load of intensity p_s, is applied to the plate, which creates a symmetric stress strain state relative to the crack location lines, and also acts an additional time-concentrated dynamic load of intensity q_{id}. The plate is in contact with a corrosive-aggressive environment, which, getting into the tips of cracks under the action of the load, causes their propagation, leading to the plate fracture. It is necessary to determine the residual life of the plate.

To solve the problem, the mathematical model (1) – (2) was used, taking into account the ratios (4) – (6). It is assumed that the plate is made of steel St3 and is subjected to static p_s = 230 MPa and time-concentrated dynamic p_{id} = 340 MPa loads (it is assumed that n = 900). The solution was presented as a graphical dependence of the residual life of the plate on the initial crack size (Fig. 1, curve *1*). It was found that with increasing crack length, the life of the plate decreases. At the same time, curve *2* in this figure illustrates the dependence of the residual life of a plate with one crack on its initial size. Comparing these dependences, we can conclude that a system of cracks is more dangerous for the residual life of the plate than a single crack.

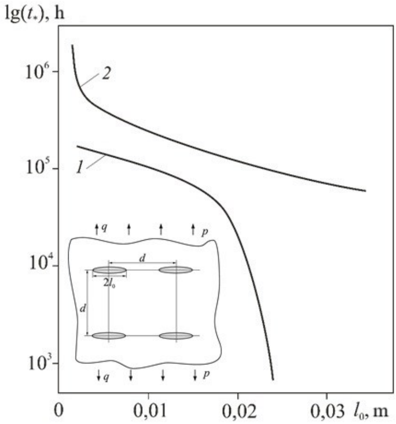

Fig. 1. Dependence of the period of subcritical crack growth in the plate on its initial length.

Conclusions. Based on the constructed computational model, the residual life of a plate with a two-period crack system under the action of a corrosive environment and a maneuver loading mode was calculated. It has been established that the system of cracks reduces the residual life of the plate significantly more than a single crack.

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