ENGINEERING CRITERIA FOR EVALUATION OF RESIDUAL LIFE OF STRUCTURAL ELEMENTS

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The equations for evaluation of the propagating crack area are presented. For the most typical defects they are invariant with respect to the crack geometry. This allows to simplify the calculations and evaluate the residual life of structure by the initial defects area. In this case the criterion of defects tolerance acquire a simple form, convenient for usage in practice. The realization of this approach to the railway rails is considered.

INTRODUCTION

The provision of the required reliability of structures is connected with non-destructive testing aimed at detection of the defects and evaluation of their dangerous effect by the fracture mechanics methods. At present the non-destructive testing used in engineering practice does not give the complete information on the existing defect parameters, particularly on their geometry. For this purpose in order to simplify the calculations, the initial defects are presented as cracks with canonic shape proceeding from the information received in non-destructive testing. It is important to establish and substantiate the rules of this presentation and to generalize the calculation results in the form of the simple criteria of these defects tolerance evaluation. The approximate method of integral evaluation of subcritical plane crack growth (Andreykiv and Darchuk (1), (2), (3), Panasyuk and Andreykiv (4)) can be successfully used for these problems solution. This method uses the crack area as a basic calculation parameter of defects in material and also reduction of the fatigue fracture

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equation to the dependencies which describe the variation of crack area during its growth. Using these dependencies the criteria of failure risk estimation and tolerant defects standard take the form simple and convenient for engineering practice.

This paper presents the basic ideas of this approach. The prospective ways of its usage for improving the methods for non-destructive testing of rails are shown.

METHOD OF INTEGRAL EVALUATION OF THE STRUCTURAL ELEMENTS CONTAINING PLANE CRACKS

Consider a plane crack with smooth contour L, which propagates in a three-dimensional body under cyclic loading σ, perpendicular to the crack plane. Crack growth rate at every contour point depends on the maximum value of SIF in a cycle $v = v(K_{I\max})$. This dependency is determined by the kinetic diagram of fatigue fracture for a given material and loading conditions. In this case variation of crack area S with loading cycles N is described by a differential equation (references (1), (2), (3)):

$$\frac{dS}{dN} = \int_L v(K_{I\max})dt \quad . \tag{1}$$

This equation obtains a more simple form if instead of the crack area we shall consider a parameter a_e , which is a radius of the equivalent circle area ($S = \pi a_e^2$):

$$\frac{da_e}{dN} = v(K_{Ie}) \quad . \tag{2}$$

The value of K_{Ie} is the average value which integrally allows for SIF variation along the crack contour and in the case of $v = CK_I^n$ power function is determined by:

$$K_{Ie} = \left\{ \frac{1}{2\pi a_e} \int_L K_I^n dt \right\}^{1/n} \quad . \tag{3}$$

Fatigue crack growth assessment by the mentioned dependencies has substantial advantages over the conventional method which incorporates subsequent (step-by-step) evaluation of the crack contour and SIF variation along it. These advantages consist in the fact, that for the cracks with most typical smooth convex contours, the value of K_{Ie} depends insignificantly on cracks geometry and is determined , mainly, by its area. Thus, in the case of elliptical cracks of the same area, the value of K_{Ie} is changed not more that by 2% under variation of semiaxes b/a from 0.2 to 1 (reference (1)) and corresponds to the solution of circumferential crack

$$K_{Ie} = \frac{2}{\sqrt{\pi}} \sigma \sqrt{a_e} \; . \tag{4}$$

Thus, the presented equations (2) and (4) describe the variation of crack area in a closed, invariant in respect to the crack geometry, form. Studies (2), (3) show that such method of the approximate prediction of crack growth can be used for the most typical defects of large-scale structures: internal, surface and subsurface defects, a system of defects. In this case the value of K_{Ie} is defined by

$$K_{Ie} = \frac{2}{\sqrt{\pi}} \sigma \sqrt{a_e} F \tag{5}$$

where F is the function, which accounts the influence of the body free surface and/or near-by defects in a system on SIF. This function depends on the integral parameters of defects (defects area, their distance from the surface or the distance between then in a system) and remains almost unchanged during variation of the defects geometry. This allows to evaluate the period of subcritical defects growth only by their integral characteristics:

$$N_* = \int_{a_e^o}^{a_e^*} \frac{da_e}{v(K_{Ie})} \; , \tag{6}$$

where a_e^o and a_e^* are the initial and the critical values of the a_e parameter, respectively.

From these results we obtain the general criterion of equivalency of different defects: they are similarly dangerous if their integral parameters are alike. According to this criterion the defects presented by the non-destructive testing data, can be be replaced by defects of a more simple geometry (for example circumferential), preserving the defects area and their location in a structure. Alongside, when evaluating the defect tolerance it is worth-while to use "defects area - remaining life" dependencies. Firstly, these dependencies are universal with respect to the defects geometry, secondly, crack area belongs to the parameters, which are defined most reliably by the non-destructive testing methods.

APPLICATION OF METHOD FOR ASSESSMENT OF RAIL FLAW DETECTION INTERVALS

The periodic flaw detection of rails is used for revealing of dangerous damages in good time and is performed by the moving devices of flaw detection. The operation of such devices is rather limited: they register only such defects in the rail which exceed certain dimensions. (Particularly, in the case of defects in the rail head they register only these, area of which is greater that 25% of the head area). Therefore, it is necessary to set up the standard of the defect tolerance and intervals of flaw detection control using the integral characteristics of defects. Prediction of crack propagation by the fracture mechanics methods is the important element of this problem. Calculations by integral method are the most reasonable in this case.

The analysis of rail loading during service is the starting point of such calculations. It is based on the solution of the problem on rail bend on the elastic support by a system of forces which simulate the effect of locomotive and cars wheels on the rails. Fig.1 presents the distribution of the bending moment M along the rail length. This curve illustrates the cyclic loading of rails. Besides, during calculations it is necessary to consider the stresses caused by longitudinal forces and temperature variation in rails and residual stresses due to heat treatment. These stresses are quasi-static in character and does not change over a loading cycle.

The SIF value caused by these force factors can be approximately obtained by the boundary interpolation method. Specifically, for internal crack in the rail head we got solution (Andreykiv and Darchuk (5), Andreykiv et al. (6))in the form:

$$K_{Ie} = \frac{2}{\sqrt{\pi}} \sqrt{a_e}\left(\sigma_M F_1(\varepsilon) + \sigma_0 F_2(\varepsilon)\right) , \qquad (7)$$

where σ_M and σ_0 are bending moment stresses and quasi-static stresses in the zone of defect location; $\varepsilon = S/S_0$; S is a crack area; S_0 is the rail head square.

These solutions are verified by the experimental testing of rails with cracks of different size and geometry (Bychkova et al. (7)), which were taken out of service. Three-point bending of the rails sections was performed up to their complete failure. Thus obtained value of breaking loading agrees well with theoretical data (Fig.2). Alongside, these data confirm the correlation of the rail strength with the defect area at least for cracks during fatigue fracture in service conditions.

Fatigue crack growth in rail steels can be presented by the generalized power law:

$$v = C\frac{\Delta K_I^n}{1-R} , \qquad (8)$$

where ΔK_I is SIF range in a cycle; R is stress ratio; C, n are material characteristics.

Basing on equation (6) the period of subcritical crack growth from the initial value, which can be registered by the railway flaw detector ($\varepsilon_0 = 0.25$), to the critical one, when rail breaks due to service loading ($\varepsilon_* = 0.30$) can be defined. The value of N_* was recalculated into total weight freight T_*, which is allowed to be passed for a period between flaw detection control. Fig. 3 shows the dependence of permissible tonnage T_* on the average load on the car axis P, trains speed being 40...50 km/h (dynamic coefficient is $k_d = 1.1$) for P65 type rails made of 75Г steel, bedded on the wood sleeper and gravel (elasticity coefficient is 50 MPa). These results are verified by the data of service inspection and large-scale tests.

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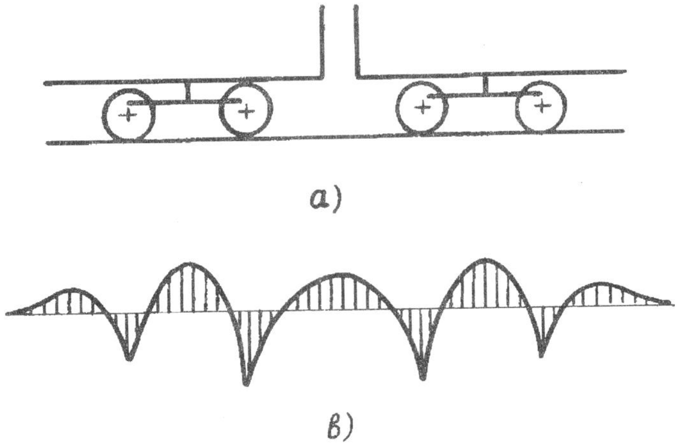
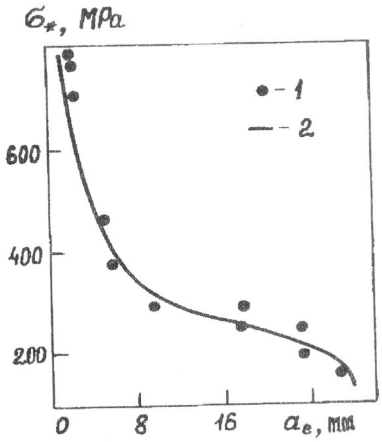
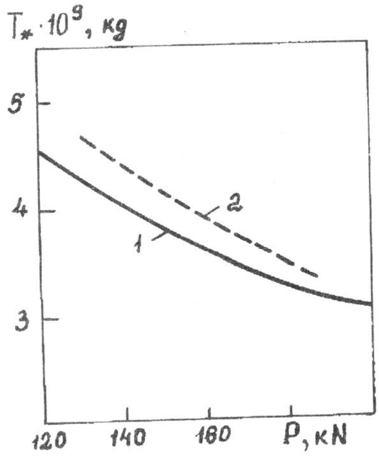


Figure 1 Loading of rails under train wheels (a) and distribution of the bending moment M along the rail (b)



1 - experimental data;
2 - calculation data;

Figure 2 Dependence of the breaking load σ_* on crack size in the rail head



1 - calculation data;
2 - statistic average data;

Figure 3 Dependence of T_* on the car axis loading P