FRACTURE AND WEAR PROCESSES SIMULATING UNDER CYCLIC CONTACT OF SOLID BODIES

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Fatigue propagation paths of the edge cracks are constructed in the elastic half-plane under the action of loading at its boundary. These loading simulate the typical stress distributions under such types of solids contact interaction as rolling, fretting-fatigue, pulsating contact (cyclic indentation). Crack growth paths have been constructed step-by-step using the local fracture criteria and taking into account the characteristics of cyclic crack extension resistance of material. Some regularities of formation of such wide spread form of wear of contact surface under rolling are established.

INTRODUCTION

The cracks, like as other damages, are usually localized in structural elements and machine parts contact zones. This particularly concerned such widely spread types of cyclic contact in technics like rolling, sliding, pulsating contact as well as contacts during fretting-fatigue or friction fatigue. Evolution of one crack or the system of cracks results in more extensive damage in the contact zone or in the main crack formation with complete failure of the structural element. The study of the role of stationary cracks in different types of contact interaction was a subject in a number of experimental and theoretical works (see Lawn B.R. et al., Kolesnikov Yu.V. et al., Panasyuk V.V. et al. [1-4] which contain extensive reviews). But the crack propagation paths have the principal role in research of fracture processes and during the estimation of structural elements durability. They provide the information about the stress-strain state kinetics in contact zone. The information about paths allow to predict the fragmentation sizes of contact surfaces, revile mechanisms and reasons of breakages and wear, including pitting and spalling. In most of known theoretical works the crack

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paths are predicted thenomenologycally (mostly like as rectilinear). In her previous work [4] the author made the attempt of numerical construction of curvilinear crack paths with use of linear fracture mechanics approaches. Presented work is the continuation of these investigations.

SIMULATING OF CRACK PROPAGATION

To calculate the fatigue crack propagation path we can use the theoretical model, described in Datsyshyn's O.P. at al. paper [5]. Here we only touch upon its key moments. We can chose the elastic half-plane weakened by the curvilinear cracks to be the simplest model of the solid. The action of counter-body is modelled either by the action of a stamp or by efforts distributed along the half-plane boundary according the certain law. The fatigue crack propagation can be modelled by step-by-step construction of their paths. Here we take into account the redistribution of stresses in the half-plane, caused both with the crack tip propagation and peculiarities of loading changes within the contact cycle. These changes are accepted to be dependent of the certain parameter λ. It can be bound either with the different types of reciprocal movement of contacting solids, or with the change of the contact intensity in the time, etc. On each step of path construction we find stress intensity factors (SIF) in the crack tips solving numerically in general case the system of singular integral equations (SIE) of the contact problem of the elasticity theory. This allows, with the use of corresponding criterion of the local fracture, to determine the direction of further crack propagation as well as the range of the parameter K in the contact cycle, which controls the stress-strain state in the tip of the crack (e.g., SIF of mixed type).

Suppose, that the crack growth only at those values of λ, which provide the $\max|K|$ in the cycle, and when the range $\Delta K \geq \Delta K_{th}$. Here ΔK_{th} is the threshold value of ΔK, the characteristics of material fatigue crack resistance. More detailed the algorithms of crack growth path of the each step of its construction are described in [4] for rolling. The increments of path propagation we approximate with the polynomials of the 3rd power.

THE NUMERICAL RESULTS

The propagation paths of initially rectilinear edge crack of l length sloped under arbitrary angle β to the half-plane boundary under simplest loading schemes (Fig. 1, 2) have been calculated. These schemes are used by different researchers to model the contact interaction of rolling, fretting-fatigue and pulsating contact. In first three loading cases (Fig. 1a – 1c) the function of its change within cycle supposes either unidirected displacement of concentrated force (Fig. 1a) or eliptically distributed pressure (Fig. 1b, 1c) along the boundary of half-plane directed opposite to actions of tangential efforts. In other cases (Fig. 1d, 2a – 2d) the function of loading change within the cycle is characterized by either even increase of its intensity from 0 to maximum value P (Fig. 1d, 2d) or by intensity p in the first half of a cycle (Fig. 2a – 2c) followed by its drop to zero in the second half of a cycle. In addition, according to loading schemes in Fig. 1b, 1c each passage of contact loading over the crack mouth is supposed to cause the appearance and growth of evenly distributed pressure on the crack edges. Thus we can model the action of incompressible liquid which at rolling under conditions of boundary friction with lubrication is inside the crack and stretches it. In all loading schemes during the cycle the crack can be completely opened, partially opened or completely closed. The crack is assumed to grow according to normal opening mechanism (mode I) and hence we use in calculations σ_θ-criterion of generalized normal opening [4]. Then the controlling parameter K=$K_{I\theta}$. We also supposed, that the crack presence in the compression zone during the cycle slightly affects the character of crack development and $K_{I\theta\min}$=0. Hence $\Delta K_{I\theta} = K_{I\theta\max}$. This allows to use one simple SIE of the first main elastic theory problem for half-plane with the edge curvilinear crack [4, 5].

Fig. 1a presents the paths of crack development for various β angles to the boundary of half-plane under rolling. Friction factors f=0.25; 0.30 correspond, for example, to the friction between metal wheel and rail in dry weather. It is seen from the figure that the direction of further propagation of a crack slightly depends on its initial orientation. After certain transition period it will grow inside the bulk of material along the line directed at certain sharp angle to the boundary and towards the tangential stresses effect. The higher is the friction in the contact the stronger the crack is "attracted" to the boundary. Dash line in Fig. 1a is a path of crack propagation calculated by $\tau_{r\theta}$ criterion (generalized cross shear). Here, taking into account the analysis of $K_{II}(x_0/\beta)$, the known [2] experimental result that surface shear cracks propagate rectilinearly along its extension at angle of 20°–30° to the direction opposite the contact friction forces action has been proved.

Under loading, which models the influence of lubricant during rolling, the propagation paths were calculated for $\pi/2 < \beta < \pi$. These values are the most favorable for the crack filling (pumping, entrapment) by a lubricant at chosen rolling direction. When comparing the paths in Fig. 1b and c we can see that the more crack is inclined to boundary the easier it comes to the surface. Two most typical cracks positions relatively to the counter body have been chosen for numerical analysis: crack mouth is under the center of contact zone $\lambda = x_0/a = 0$ and when $K_{I\theta} = K_{I\theta\max}$ (λ≈0.5). Here the maximum intensity of liquid pressure in the crack was assumed to be equal to the pressure of elliptical loading at the point of the crack appearance on the boundary of half-plane ($p = sp_0$). It can be seen that at similar crack orientations the crack which is outside the center of contact zone has a shorter path. Therefore the most dangerous as for the pitting formation is the moment preceding ((λ≈0,5) the supposition of the center of contact zone on the crack mouth (λ=0). This occurs regardless the fact that inside the crack the pressure is not maximum ($p = 0.87p_0$). The data in Fig. 1b and 1c also show that the decrease of the friction facilitates the crack appearance on the boundary (the paths become shorter). Results in Fig. 1d show the dependence of the character of quasistatic path on the parameter ε of the position of stretching efforts on the crack edges. The closer these efforts are to the mouth of crack the sharper path turns to the boundary of solid. Such loading scheme can be used for modelling of the influence of abrasive or other foreign solid particles penetrating inside the crack. To summarize it should be added that the paths shown in Fig. 1 confirm experimental observations and Way's hypothesis that lubricant plays the main role in appearance of such dangerous wearing form during contact fatigue as pitting [6].

All four loading schemes shown in Fig. 2 are most frequently used [2, 3] to model the contact fretting-fatigue. Fig. 2a, 2b, 2d show the results of influence of counterbody on crack propagation path, whereas Fig. 2c presents the result of the interaction between counterbody and nominal static loading intention. It is clear that with the rise of tension at infinity (drop of r) the path approximates to the normal to tension direction (Fig. 2c). It is seen from Fig. 2a that the reduction of friction in the contact deviate attracts the path to the boundary of half-plane. In Fig. 2b we can see that the initial crack orientation slightly influences on the further direction of its propagation. Paths of differently oriented cracks asymptotically tend to the same direction. From Fig. 2a and 2d we can draw a conclusion that the distance between the mouth of crack and the end of contact zone has the most substantial influence on the path. It should be noted that the character of cracks in Fig. 2a, 2b, 2d confirms available of experimental cracks geometric [1] which appear under the pressing of indentors with flat or rounded base into elastic body.

The results shown in figures 1, 2 are obtained together with H.P.Marchenko (Fig. 1a, 1d), A.B.Terletsky (Fig. 1b, 1c, 2d), and R.B.Schur (Fig. 2a–2c).

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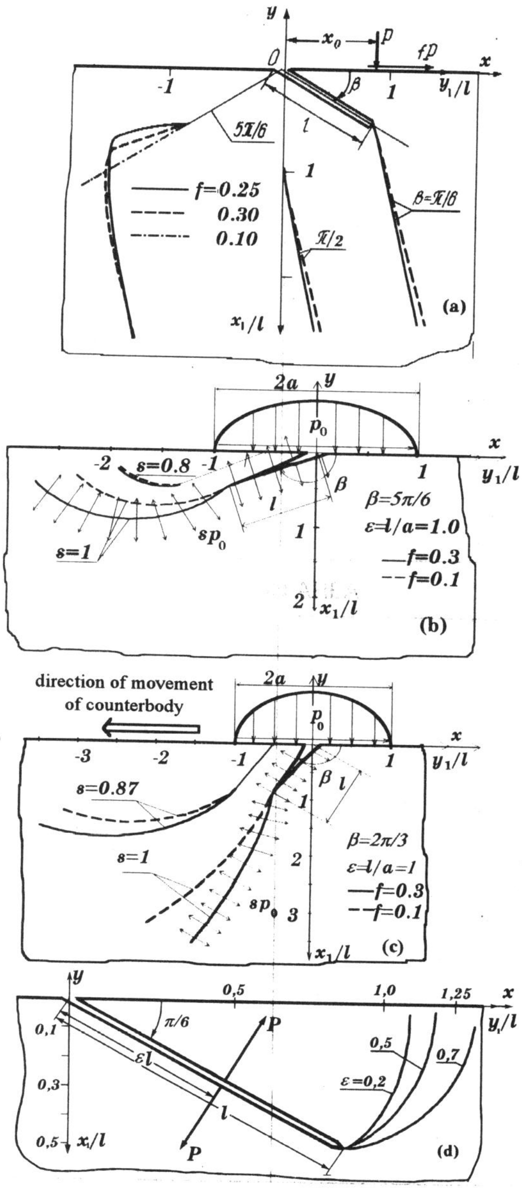

Figure 1 The crack propagation paths during rolling

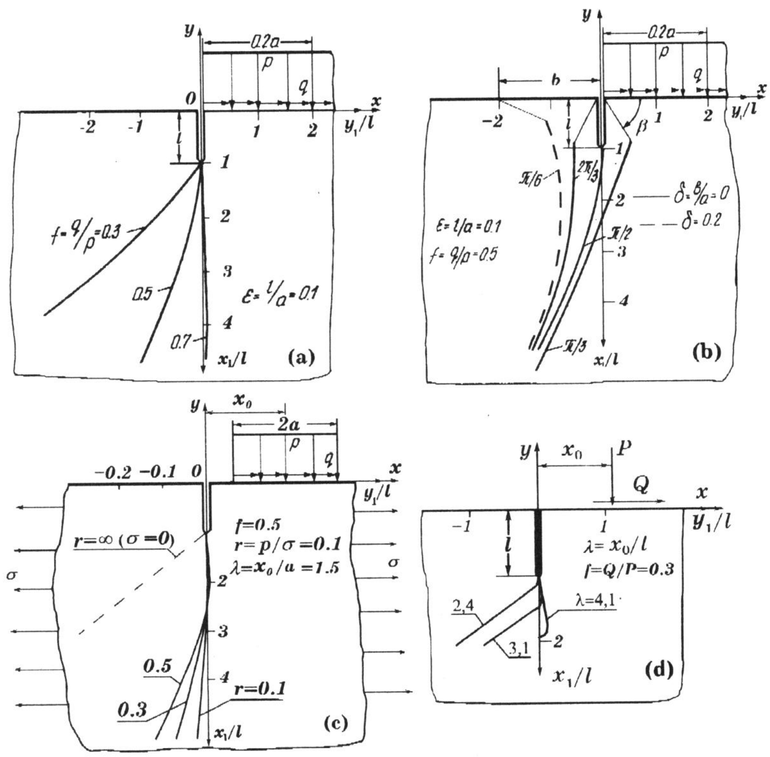

Figure 2 Crack propagation paths under fretting-fatigue and pulsating contact (cyclic indentation)