FRACTURE MECHANICS OF MATERIALS AND METHODS OF ASSESSMENT OF STRUCTURES SERVICE LIFE-TIME: SUCCESS AND PROSPECTS

V. V. PANASYUK and O. YE. ANDREYKIV
Karpenko Physico-Mechanical Institute,
Lviv, Ukraine

ABSTRACT

The modern methods for prediction of structural elements strength and service life-time on the basis of fracture mechanics have been considered. The calculational models for the analysis of the different stages of fatigue fracture, including crack initiation in the vicinity of the stress concentrators, short fatigue crack growth and macrocrack subcritical growth have been formulated. The possible ways of these models application for the account of the effect of loading conditions (nonregular loading, mixed mode loading) on the fatigue crack growth rate have been considered. A system of calculational dependences for subcritical crack growth period in three-dimensional bodies under general loading conditions have been presented. The effective method for practical assessment of the residual service life-time of structures, using the data of non-destructive testing method, has been proposed.

KEYWORDS

Fatigue, crack initiation and growth, structures life-time estimation.

INTRODUCTION

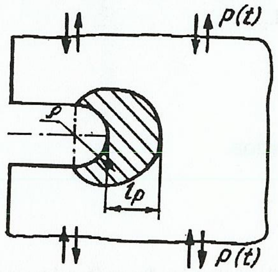
Fatigue of materials is one of the major causes of structure failure that leads, as it is known, to high material and sometimes to human losses. Therefore, the investigation of the fatigue fracture processes and development of the methods for their prevention in practice are the most important problems in science and technology. The investigations in this directions have been performing over more than 150 years. During this period a great progress both in understanding the physical nature of fatigue phenomena and in creation of the methods for their practical analysis, has been achieved. This progress is caused, to a great extent, by the development of fracture mechanics, the latter formed the basis of a new universal interdisciplinary approach to material fatigue problems study. According to this approach (instead of classical postulation of the phenomenological conditions at which fracture occurs) the main attention of the researchers and engineers is paid to the analysis of the fracture process, which is considered as a process of fatigue crack initiation and propagation. In practice this approach became a basis of new principles of provision the engineering structures reliability basing on the safe damage concept. According to this concept all structures (materials) contain defects and sites of fatigue damages initiation. Therefore the predicted resource (service life-time) of the structure is defined by the time or the loading cycles number necessary for subsequent development or accumulation of these damages, macrocrack formation and propagation up to final fracture. In this case, the improvement of structures reliability can be done in two ways: first, by the usage of constructional or technological solutions, which would provide maximum resistance of material to fatigue crack initiation and propagation and second, by introduction of the system of flaw detection aimed at timely detection and removal of the dangerous defects in service conditions

To solve the mentioned problems, the development of the adequate calculational models of fatigue cracks initiation and propagation under different loading conditions, as well as the methods for their practical realization is very important. Some new investigations of this problem are considered in this paper.

MODELLING OF MACROCRACKS INITIATION AT THE STRESS CONCENTRATORS

It is a widely-known fact that in most cases structural elements failure occurs at the stress concentrators. Just in such zones of local overloading of the material the fatigue damages develop. This process consist of two main stages: 1) microstructural short cracks initiation, their growth, coalescence and macrocrack formation; 2)macrocrack propagation. According to the mentioned above the life-time of a body (structural element) N_* can be presented as a sum of two compounds which correspond to the macrocrack initiation period (N_1) and macrocrack subcritical growth period (N_2):

$$N_* = N_1 + N_2 \tag{1}$$



If a body with a stress concentrator which has the form of notch with curvature radius ρ (Fig. 1) is assumed to be th investigated object, the problem of the fatigue macrocrac initiation analysis is reduced to the following: determination o the moment when fatigue macrocrack appears near th concentrator, i.e. establishment of conditions of microcrac transformation into macrocrack; establishment o calculational dependences, which allow to evaluate th durability of macrocrack initiation perid (N_1) for the stres concentrators of the given geometry.

Fig. 1. Process zone in the vicinity of the concentrator tip.

To solve this complicated problem, different approaches were proposed (see Panasyuk, 1991; Shin, 1994). In particular in the studies of Andreykiv (1976, 1982) the physically well substantiated model of fatigue fracture of the material in the stress concentration zone is proposed. This model is based on the hypothesis that the intensity of fatigue fracture processes is fully governed by the material deformation in the prefracture zone and is determined by some dependence, invariant for the given material. This dependence can be written as (Andreykiv, 1982):

$$\frac{dl}{dN}\Phi(\lambda) = 1 , \tag{2}$$

where l is the crack length; N is a number of loading cycles; $\Phi(\lambda) = 1/v$ is the characteristic function of fatigue fracture; v is the fatigue crack growth range; λ is a parameter which defines the deformation value in the prefracture zone.

During stabilized macrocrack growth under quasi-brittle fracture, the parameter λ is expressed by the maximum stress intensity factor (SIF) value in a cycle: $\lambda = 1 - K_{Imax}/K_{fc}$ (K_{fc} is the critical SIF value, that corresponds to the beginning of spontaneous fracture). In this way the concrete form of function $\Phi(\lambda)$ can be determined, proceeding from the standard kinetic curve of fatigue fracture of the material. Besides, since for the macrocrack, the deformation in the prefracture zone is proportional to the crack tip opening displacement (CTOD) (Andreykiv, 1982):

$$\varepsilon_{max}/\varepsilon_{fc} = \delta_{max}/\delta_{fc} = K_{Imax}/K_{fc} \tag{3}$$

(ε_{fc}, δ_{fc} are critical values of deformation and CTOD, respectively), the parameter λ can be expressed immediately by the value of deformation:

$$\lambda = 1 - \sqrt{\varepsilon_{max}/\varepsilon_{fc}} . \tag{4}$$

On the basis of the above hypothesis, dependencies (2), (4) describe also the process of macrocrack initiation, if only we assume that l is the newly-formed crack length (or total length of microcrack) and ε_{max} is the deformation at the tip of these cracks, accounting stress concentrator. By integrating dependence (2), the formula for estimation of the macrocrack initiation period is obtained:

$$N_1 = \int_0^{l_o} \Phi(\lambda)dl . \tag{5}$$

In this case, l_o corresponds to such length of the newly-formed crack, at which it is considered to be a macrocrack. Obviously, to obtain this, the fatigue crack should pass the initial plastic zone of length l_p near the concentrator (Fig. 1) and form its own, typical of macrocrack, prefracture zone. For many cases this condition is necessary and sufficient. Therefore in formula (5) we can take $l_o \approx l_p$.

As to the deformation value at the tip of crack of length $0<l<l_p$, initialing from the concentrator tip, it can be approximately evaluated in the following way. From the results of Panasyuk (1968) the value of CTOD for sufficiently small cracks is proportional to the crack length ($\delta_{max}=Bl$, where B is a constant). Taking into account this fact as well as dependence (3), the deformation at the crack tip can be presented as:

$$\varepsilon_{max} = \varepsilon_0 - B_1 l , \tag{6}$$

where ε_0 is the maximum deformation near the concentrator in the original state (crack is absent), B_1 is unknown coefficient, which is defined from this condition. As soon as the crack length is $l=l_p$, it becomes the macrocrack and than relation (3) is fulfilled, i.e.

$$\left(\varepsilon_0 + B_1 l_p\right)/\varepsilon_{fc} = K_{Imax}/K_{fc}^2 .$$

Hence $\beta_T = \left(\varepsilon_{fc}K_{Imax}/K_{fc}^2 - \varepsilon_0\right)/l_p$ and thus

$$\varepsilon_{max} = \varepsilon_0 + \left(\varepsilon_{fc}K_{Imax}/K_{fc}^2 - \varepsilon_0\right)\left(l/l_p\right) . \tag{7}$$

Andreykiv (1982) had showed that estimates of the macrocrack initiation periods within the framework of this model agree well with the experimental data for certain materials. According to the above mentioned, this model, is expected, to be a good basis for development of engineering problems for assessment of structures life-time.

FATIGUE MACROCRACK GROWTH MODELLING

When investigating fatigue macrocrack propagation the hypothesis, expressed by equation (2), has been used (Andreykiv,1982; Andreykiv and Darchuk, 1992). The general case of a quasi-brittle body which is subjected to the cyclic loading and contains initial macrocrack along the surface $\bar{r} = \bar{r}_0$ $(N = 0)$ is considered. To determine period N_2, the following equations were obtained:

$$\Phi(\lambda)\left|\frac{\partial \bar{r}}{\partial N}\right| = 1\ ;\quad \frac{\partial \bar{r}}{\partial N}\frac{\partial \bar{r}}{\partial \theta}\frac{\partial^2 \bar{r}}{\partial \theta^2} - \left|\frac{\partial \bar{r}}{\partial N}\right|\left|\frac{\partial \bar{r}}{\partial \theta}\right| \times \left|\frac{\partial^2 \bar{r}}{\partial \theta^2}\right| \sin\beta = 0\ ;$$
$$\cos^2\frac{\beta}{2}\left(K_I\cos\frac{\beta}{2} - 3K_{II}\sin\frac{\beta}{2}\right) = K_{fc} \tag{8}$$

Here $\bar{r}$ is a radius-vector of the points on the crack surface; r, ϕ, θ are the spherical coordinates; K_I, K_{II} are Mode I and Mode II SIF values; β is an angle of inclination of the direction of its growth. In the case when the fatigue crack propagates in one plane of a body, this system of equations is reduced to the form:

$$\frac{\partial r}{\partial N}\left[1 + \frac{1}{r^2}\left(\frac{\partial r}{\partial \varphi}\right)^2\right]^{-1/2} \Phi(\lambda) = 1\ ;\quad K_I = K_{fc}\ , \tag{9}$$

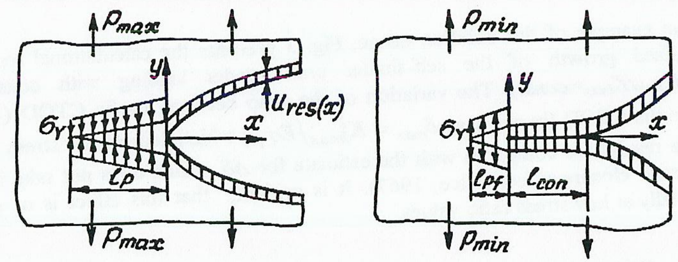
where $r=r(N,\varphi)$ is the unknown radius-vector of the moving crack contour in the polar coordinate system.

The mathematical solution of equations (8) and (9) and the equations of elastic equilibrium of a body (for SIF assessment) for particular elements of the structure is rather difficult. Only a small member of problems was solved (Andreykiv,1982; Andreykiv and Darchuk, 1992). For practical application, a rather effective approximate integral approach, presented below, has been proposed. The $\Phi(\lambda) = v^{-1}$ characteristic is very important in these equations. It is evaluated experimentally and depends on the mode and character of material deformation in the prefracture zone. This section deals with the mentioned problems.

Modelling of the Reverse Plastic Yield and Closure Effects in the Vicinity of the Fatigue Crack Tip.

Fatigue crack growth is related, first of all, with the reverse yield of the material in the prefracture zone in front of the crack. It is very complicated to analyze this process, using the continuum theory of plasticity. However, the main regularities of this process can be described by the known δ_c -model (Dugdale, 1960; Panasyuk, 1968), generalized for the case of cyclic loading. The assumption about the material plastic yield localization in narrow strips, originating from the crack tip , is the basic one for this model. These strips are modelled by the lines of the displacements discontinuity, on which the plastic conditions are fulfilled and outside which the body is considered to be elastic. Thus, the original elasto-plastic problem is reduced

to the elastic problem for a body with a modelled cut, which includes the crack and the modelled plastic zones.



a) b)

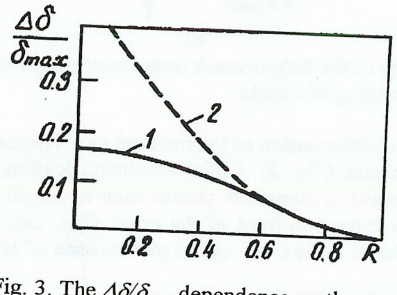
Fig. 2. Deformation of material in the vicinity of the fatigue crack under maximum (a) and minimum (b) loading of a cycle.

In accordance with this model the elasto-plastic deformation of the material near fatigue Mode I crack tip takes place by the following sequence (Fig. 2). Under maximum loading of the cycle, the situation corresponds fully to δ_c -model: a monotone plastic zone of length l_p with stresses equal to material yield strength σ_y is formed in front of the crack (Fig. 2a). During unloading the reverse plastic yield of the material occurs and cyclic plastic zone of length l_{pf} appears.

Besides, on the fatigue crack surfaces there is a layer of plastically deformed material(plastic stretches) of thickness $u_{res}(x)$. They appear when the crack passes the plastically deformed region in front of its tip. These stretches as well as compressive stresses which appear near the crack tip during unloading lead to crack closure: in the particular part of the crack, adjoining the tip, its surfaces link together, interacting between themselves. This situation (Fig. 2b) is modelled by such boundary-value conditions on the surfaces of the modelled cut:
- on the open part of the crack the stresses are equal to zero;
- on the closed part of the crack the conditions of full edges contact operate ($u_{min}(x)=u_{res}(x)$), where $u_{min}(x)$ is displacement of the modelled cut edges under minimum loading in a cycle);
- within the cyclic plastic zone the compressive normal stresses are equal to the material yield strength;
- outside the cyclic plastic region (l_{pf}), within the monotone plastic zone (l_p) the reverse plastic yield does not take place ($u_{min}(x)=u_{max}(x)$).

In this formulation of the generalized δ_c -model, the elasto-plastic deformation of the material near the crack tip has been analyzed in many studies (Budiansky and Hutchinson, 1978; Fuhring and Seeger, 1979; Lo, 1980 et al.). Today the general algorithms for such problems solution by the finite element method (Newmen, 1981) or by the method of weight functions (Wang and Blom, 1991) have been developed. They open new prospects in investigation of fatigue crack growth kinetics with account of plastic behaviour of the material and closure effects in finite bodies (structural elements) under general loading conditions. However, it is rather difficult to realize them. A relatively simple scheme of these solutions construction on the basis of superposition method and singular integral equations is proposed by Panasyuk et al. (1994, 1996a). It allows to obtain a close solution for a rectilinear crack in a plate. This simplifies greatly the analysis of the influence of nonelastic behaviour of material on the fatigue cracks propagation at least in two cases, most interesting from the practical viewpoint: self-similar crack and mechanically short crack. (The first is modelled by semi-infinite crack in a plate and the second - by the rectilinear crack of finite length with large plastic zones near the crack tip).

As an example of this solution usage, Fig. 3 presents the calculational results for the case stabilized growth of the self-similar crack under loading with constant stress ratio ($R=K_{Imin}/K_{Imax}=const$). The variation of the ratio between cyclic CTOD ($\Delta\delta=\delta_{max}-\delta_{min}$) and maximum CTOD (in our case $\delta_{max} = K_{Imax}^2/E\sigma_Y$) which depends on stress ratio is presented. These results are compared with the estimate for $\Delta\delta$, which does not take into consideration the crack closure effect (Rice, 1967). It is evident, that this effect is of great importance, especially at low stress ratio values.



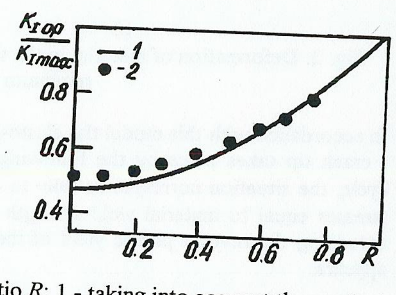


Fig. 3. The $\Delta\delta/\delta_{max}$ dependence on the stress ratio R: 1 - taking into account the crack closure; 2 - without account of the crack closure.

Fig. 4. Dependence of K_{Iop}/K_{Imax} on stress ratio R: 1 - calculational data; 2 - experimental data (Elber, 1970)

It should be noted that the fatigue crack closure effect at first is observed experimentally. (In fact it was revealed at first experimentally by Elber (1970) and only later it was investigatedby different models). It consists in the fact that the fatigue crack surfaces near its tip continue to touch each other for a certain part of a loading cycle; they began to separate when a certain value of SIF K_{Iop} - SIF of crack opening is achieved. Experimental evaluation of K_{Iop} (Elber, 1970) at different stress ratio agree well with calculations within the framework of the given model (Fig. 4).

The crack closure influence on its propagation rate can be evaluated in a most simple way, by using the effective value $\Delta K_{Ief}=\Delta K_{Imax}-K_{Iop}$ and not nominal range of SIF $\Delta K_I=K_{Imax}-K_{Imin}$, as the fatigue crack growth driving force. This fact is proved in practice: kinetic fatigue fracture curves, reconstructed in $v \div \Delta K_{Ief}$ coordinates, depend much less (and in most cases, they are entirely invariant) on the loading conditions (cycle shape, stress ratio, frequency), specimen geometry and sizes and some other factors (Romaniv et al., 1992).

Taking the above mentioned into consideration and methodological complexity and labour-consumption of the procedures of the experimental evaluation of ΔK_{Ief}, it is evident that application of the calculational methods is very important for this problem solution. This increases greatly the possibility of application of this parameter for engineering calculations. The role of calculational methods increases even more in the situations when usage of SIF (i.e.

linear-elastic fracture mechanics) is not rightful, and a direct model experiment for calculational evaluation of cyclic parameters of the stress-strain state in the prefracture zone is extremely complicated or impossible. Some of the typical situations are considered below.

Application of the Generalized δ_c -model for the Analysis of Some Aspects of Fatigue Macrocrack Growth.

Crack growth under nonregular loading. Experimental investigations of fatigue crack propagation under loading with variable amplitude (Robin et al., 1983, f. ex.) show the presence of cycles intereffect: the middle crack growth rate at the given loading cycle depends not on its parameters only (amplitude, stress ratio etc.) but also on history of loading. Usually, crack growth retardation takes place during the change of loading level from the higher to the lover one, while compressive stress accelerate crack propagation. The above mentioned effects can be explained by the proposed model. Thus, for example, a one-time peak overloading causes increase of the plastic strains in front of the crack. As the crack goes through this disturbed region, the elastic stretches value $u_{res}(x)$ on its edges increases; the corresponding growth of the crack closure level is observed and this means, that the driving force of the crack growth ($\Delta\delta$, ΔK_{Ief}) decreases. Later this process gradually stabilized and the preliminary level is reached. As an example, Fig. 5 presents the results of cyclic CTOD calculations depending on crack increment Δl after the body overloading. These calculations

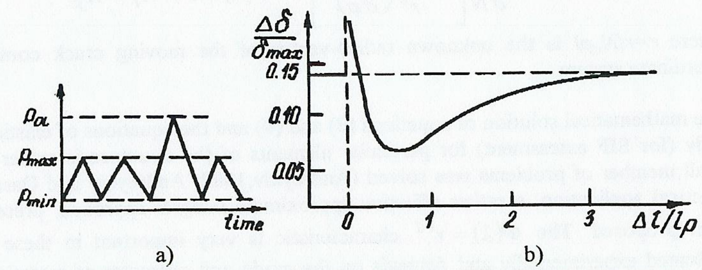


Fig. 5. Cyclic loading with a single overloading (a) and a plot of cyclic CTOD $\Delta\delta$ depending on crack length increment after overloading Δl.

agree well with the known experimental data on the effect of overloading on the crack growth rate (Newman, 1981; Wang and Blom, 1991). Thus, application of the proposed model opens new prospective ways of the cycle-by-cycle analysis of fatigue crack growth at arbitrary variation of the loading amplitude with time. With respect to the random loading, most typical of service conditions, this approach forms the basis when establishing the generalized regularities of crack propagation, depending on loading spectrum characteristics (de Koning, 1988).

Short cracks propagation. The advantage of the proposed model, as compared to the conventional linear fracture mechanics approaches, is that it takes into consideration though in a simplified formulation, the plastic yield of the material in the vicinity of the crack tip (in this case it is not limited by the conditions of small plastic zones). Using this model the propagation of the mechanically short cracks (sizes of which do exceed the dimensions of the structural elements of the material) can be analyzed. The proposed model allows to consider at first the specific manifestation of the crack closure effects, typical of this stage of fatigue fracture. At the same time it is necessary to take into account the fact that initial macrocracks, formed in the material not because of plastic discontinuities, but due to coalescence and spreading of microcracks, macrocracking along the phases boundaries, etc., do not have corresponding residual deformations on their edges (stretches) - the major cause of the crack closure. Only later, when such a crack begins to develop as a fatigue Mode I crack, the residual plastic deformations appear, which lead to crack closure. As a result, cyclic CTOD $\Delta\delta$ at first exceeds the stabilized value, which corresponds to the long cracks, and only with crack growth, these values become similar (Newman, 1981; Wang and Blom, 1991; Panasyuk et al. 1996). This effect additionally explains the known experimental fact (Miller and de los Rios, 1986; Ritchie and Lankford, 1986) that short cracks rate exceed the rate of long cracks at the same SIF values.

Fatigue crack propagation under mixed-mode loading. After certain generalization, the model can be used for prediction of the fatigue cracks behaviour under complex stress-strain state (Panasyuk et al., 1995). These generalizations are reduced to the following.

A. Plastic zones. For the mixed-mode cracks the plastic zone is assumed to be a strip, originated from the crack tip at some angle to the crack line. These strips are considered to be the cuts, at which sides the normal (σ_n) and tangential (σ_t) stresses operate, which satisfy the material plasticity conditions (for example, the Mises plasticity condition: $\sigma_n^2 + 3\sigma_t^2 = \sigma_Y^2$). Thus, the problem is reduced to the elastic problem for a body with curvilinear model cut (a crack and additional cuts - plastic zones). The method of singular integral equations is the effective method of such problems solution (Panasyuk and Savruk, 1992). The solution result is, first of all, the determination of the normal (δ_n) and tangential (δ_t) components of CTOD, which characterize the corresponding plastic deformation components.

B. Crack closure effect. The crack closure caused by the crack edges roughness is considered together with the plastic-induced crack closure. The contribution of the first one is very pronounced when the shear component of the crack edges displacement is available. The boundary conditions within the contact region also vary: alongside with the condition of complete junction of the crack edges (displacement condition) it is assumed that the stress components are related between themselves by the dry friction law $\sigma_t = f\sigma_n$, where f is the friction coefficient.

C. Fracture criterion. The value of specific energy of the reverse plastic deformations Δw_p , which is defined in terms of the CTOD and stress components in the plastic region is assumed to be a criterial parameter:

$$\Delta w_p = \sigma_n \Delta\delta_n + \sigma_t \Delta\delta_t \ .$$

In this case, assume that crack propagates in the direction, where Δw_p achieves its maximum value, and crack growth rate depends on the Δw_p value. This dependence is a universal characteristics of material and is evaluated from the kinetic curve of fatigue fracture.

Preliminary verification of this model proved that it allows to analyze the fatigue mixed-mode crack propagation (Panasyuk et al., 1995).

PREDICTION OF FATIGUE CRACK PROPAGATION AND EVALUATION OF RESIDUAL LIFE-TIME OF STRUCTURES

Direct solution of the boundary-value problem (9) in a general case is complicated, first of all, due to the absence of universal calculational dependences for SIF estimation along the contour of noncanonical cracks. Direct calculations by the bulky numerical methods are low-effective, because the crack geometry and sizes constantly change with time and procedure of SIF calculation should be repeated many times.

Besides, the initial defect contour is not always known with a necessary accuracy. The industrial non-destructive testing methods usually give only the defect sizes and do not determine their geometry. Using the data on non-destructive testing, the available defects in the elements are given the canonical geometry (in most cases - elliptical). Therefore, it is important to establish and substantiate the regularities of such simplification as well as to generalize the results of life-time calculations in the form of the simple engineering criteria of the defects hazard assessment. The application of the approximate method, proposed by Andreykiv and Darchuk (1992, 1993, 1994), of integral evaluation of the plane cracks subcritical growth period is rather promissing. It is based on the usage of the crack area as a main calculational parameter of material defectness and on the reduction of the fatigue fracture equation to the relations which immediately describe the variation of the crack area with its growth.

In particular, for the internal plane crack, area of which is described by the dependence $S(N) = (1/2)\int_0^{2\pi} r^2(N,\varphi)d\varphi$, this relation (taking into consideration (9)) has the form:

$$\frac{dS}{dN} = \int_0^{2\pi} r(N,\varphi)d\varphi = \int_L v(\Delta K_I)ds \ , \qquad (10)$$

where $ds = \sqrt{r^2 + (\partial r/\partial\varphi)^2}\, d\varphi$ is the element of the crack contour L arc. In practice it is more convenient to use instead of the area S , the linear parameter a_e - a radius of a circle with the same area as that of the crack ($S = \pi a_e^2$). In this case formula (10) is written as:

$$\frac{da_e}{dN} = v(\Delta \overline{K}_I) \ , \qquad (11)$$

where $\Delta \overline{K}_I$ is the average value, which integrally considers the variation of the SIF range ΔK_I along the crack contour. In the case of power dependence between v and ΔK_I ($v = C\Delta K_I^n$) this value is defined by following relation:

$$\Delta \overline{K}_I = \left\{ \frac{1}{2\pi a_e} \int_L (\Delta K_I)^n ds \right\}^{1/n} \ . \qquad (12)$$

Presentation of the crack growth relations in the form (12) has some advantages: for the crack with smooth convex contours (most typical in practice) the $\Delta \overline{K}_I$ value slightly depends on the defects shape and is determined mainly by their area. Thus, in the case of elliptical cracks of the same area the $\Delta \overline{K}_I$ value changes not greater than by 2% with variation of semiaxes b/a ratio in the range from 1 to 0.2 and corresponds to the solution for a circular crack

$$\Delta K_I = \frac{2}{\sqrt{\pi}} \Delta\sigma\sqrt{a_e} \ , \tag{13}$$

where $\Delta\sigma$ is the nominal stresses range in the defect location zone.

This specific feature of $\Delta \overline{K}_I$ parameter is correct (within the engineering calculations accuracy) also for the surface and subsurface defects (Andreykiv and Darchuk, 1993). In the first case, the value of $\Delta \overline{K}_I$ in (13) should be additionally multiplied by coefficient 1.1 which integrally takes into account the effect of the free surface on the SIF distribution:

$$\Delta K_I = 1{,}1 \frac{2}{\sqrt{\pi}} \Delta\sigma\sqrt{a_e} \ . \tag{14}$$

In the second case the effect of the surface is taken into consideration by the correction function F, which depends on the integral parameters of the defect (crack area and depth of its location h):

$$\Delta K_I = \frac{2}{\sqrt{\pi}} \Delta\sigma\sqrt{a_e}\, F(h/a_e) \ . \tag{15}$$

Thus the proposed dependences (11), (13)-(15) in the invariant form, with respect to the crack geometry, describe the crack area variation for the most typical cracks. This allows to evaluate the subcritical cracks growth period N_2 only by their integral characteristics:

$$N_2 = \int_{a_e^0}^{a_e^*} \frac{da_e}{v(\Delta \overline{K}_I)} \ , \tag{16}$$

where a_e^0 is the initial, a_e^* is the critical value of a_e parameter.

The general criterion of equivalency of different defects follows from these results: they are similarly dangerous if their integral parameters are the equal. According to this criterion, during calculations on the basis of the data of non-destructive testing, the real defects should be replaced by the defects of the more simple geometry, the defects area and their location in the structure being the same. Still, when establishing the permissible defect value, it is worth while to use the "defect area - residual life-time" dependences. First, these dependences are universal as to the defects geometry, and, second, the crack area belongs to the parameters, which are most reliably evaluated by the non-destructive testing method.

The efficiency of this approach was verified, in particular, by Andreykiv and Darchuk (1992) and Panasyuk et al. (1996b), during assessment of the best inspection periods of flaw detection of the railway rails under operation.

CONCLUSIONS

The fracture mechanics methods which are based on the analysis of cracks initiation and propagation, occupy the important place in the practical calculations of engineering structures strength and life-time. The recent development of these methods has opened both the new

prospects and revealed new problems. In particular, it is obvious that it is necessary to perform further development of the methods for prediction of fatigue fracture near stress concentrations. They should present more adequately the physical features of this process, and, especially, its stage-like character. However, it is also possible to develop common approach, from the methodological viewpoint, which uses one and the same set of standard characteristics of the material for these stages description.

The difficulties also arise during application of the traditional linear fracture mechanics parameter - SIF range (ΔK_I), as a universal value of the fatigue crack growth driving force, that determines its growth rate. (This assumption is used as a basis in the practical methods of calculation of the subcritical fatigue crack growth and estimation of the residual life-time of structures). The restrictions of this approach are evident not only under violation of the condition of the small plastic zone in the vicinity of the crack tip (mechanically short cracks growth) but also during self-similar crack propagation under particular loading conditions (nonregular loading, complex stress-strain state and other). The correct estimate of the crack propagation rate under these conditions should take into account, first of all, the elasto-plastic deformation of the material in the prefracture zone and the crack closure effect. The model of thin strips, generalized for the case of cyclic loading, forms a good basis for these effects account. The results, obtained within the scope of this approach, allow to explain and quantitatively describe the known peculiarities of the fatigue crack behaviour, observed during experiments.

When performing the practical analysis of fatigue cracks growth in structures, it is worth while to use the integral approach according to which the kinetic relation are reduced to the dependences which directly describe the variation of crack area during its propagation. In this case the relations for evaluation of residual service life-time of structures and criteria of defects danger assessment obtain simple and convenient form for practical usage and are based on such parameters of the defects, which are most reliably described by the existing non-destructive testing methods. Such approaches open new prospective ways in the study of material fatigue fracture and in prediction of the structural elements integrity.

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