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Volodymyr PANASYUK*

FRACTURE MECHANICS AND STRENGTH OF MATERIALS: ACHIEVEMENTS AND PROGRESS

MECHANIKA PORUŠENÍ A PEVNOST MATERIÁLŮ: DOSAŽENÍ A PERSPEKTIVY

Abstrakt

V příspěvku je proanalyzován vývoj výzkumu a výsledků v oblasti fyziko-chemické mechanice odolnosti materiálů jako světového trendu. V článku provedeny syntéza hlavních výsledků výzkumu dosažených AV Ukrajiny, deklarováno jejich praktické použití a nastíněny aktuální perspektivy vědeckého výzkumu, zejména v oblasti odolnosti materiálu proti trhlinotvorbě, rozvoji trhlin v pružně-plastických tělesech a vlivu prostředí na tento rozvoj.

Abstract

The main stages of research development into fracture mechanics and strength of materials in the second part of the XX century have been considered.

The principal attention was paid to the analysis of the calculation models of limiting equilibrium ofdeformed solids, containing sharp stress concentrators (cracks), to the development of the methods of the stress intensity factor calculations, to the methods and means of experimental development of the material crack growth resistance, concepts offatigue crack initiation and propagation and also to the processes of materials pitting in the zone of two bodies cyilic contact.

New approaches to establishing the period of fatigul macrocrack initiation at the stress concentrator, using the conventional (ν-K)-curves for the given material have been foimulated. The influence of service environment on corrosion crack growth resistance of structural materials and construction of the basic (calculation) fatigue crack growth curves for the strength assessment of the high-pressure vessels have been considered.

INTRODUCTION

Progress in science and technology, in particular the development of new machines, structures and means of transport ai well as goods production require design of new materials and data on their physicomechanical characteristics (strength, plasticity, hardness, resistance to aggrlssive media effect , the influence of constant or time variable external loading etc.). For a long time people paid much importance to generation of data on such properties and also to such properties change depending on physical structure of the material, mode of loading (static, cyclic, dynamic), the influence of physicomechanical environmental factors and temperature on these characteristics. As a result the science about physico-chemical properties of materials, structural in particular, their integrity and fracture has been created. The theoretical concepts on realisation of deformation processes and fracture of materials and also on strength assessment and prediction of structural elements life time were substantiated.

In the first half of the 20th century in the engineering practice there was already a number of physcimechanical statements (hypotheses,generalisations, postulates) for assessment of the serviceability of the material as well as structural element strength and life time calculations under given service conditions, etc.

In the middle of the 20th century new machines (especially for military purposes) were designed. This put forward new tasks to the science on material strength and fracture, related with establishing the criteria and methods of prediction of strength and life of machines and elements that operate in severe condition, in particular when structural elements contain sharp notches or cracks.

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* Academician of NASU Karpenko Physico-Mechanical Institute of the NASU, Lviv, Ukraine

The solutions of such problems were not obtained from the model charts and statements that were used in classical mechanics of materials. So it was necessary to expand the basic statements of the classical mechanics to expand the basic statements the classical mechanics of materials and to formulate the corresponding calculation models for obtaining the physically sound solutions of the problems on strength of deformed solids with sharp stress concentrators, like cracks.

As a result of theoretical and experimental researches into this problem and using new results, a new direction in the science on materials strength and fracture - fracture mechanics and strength of materials (often called fracture mechanics) was created in the middle of the 20th century.

It is obvious that for the last 50 years the world scientific community, including scientists and engineers of Ukraine, dealing with the problem mentioned above has achieved a significant progless. Now, entering the 21st century it is actual to make a synthesis and analysis of some important results on this problem and to draw prospective problems. This is the aim of the presented report.

GENERAL CHARACTERISATION OF THE PROBLEM

(CLASSICAL AND NONCLASSICAL APPROACHBS)

To understand better the progress of fracture mechanics and the formation of prospective problems in this field of science let us consider the classical and nonclassical approaches to this problem solution.

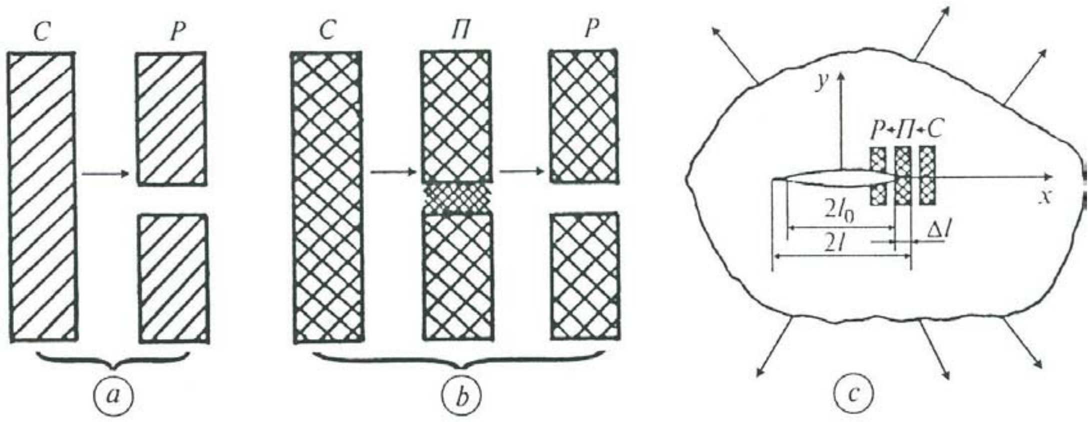

Fig. l. Material fracture: *a* is classical and *b* is non-classical charts;
c is non-classical chart at the crack tip.

In classical approaches and phenomenological criteria, when evaluating the strength of materials and structures, a solid was considered as a continuum with given rheological properties (e.g. an elastic continuum).It is assumed [1,2] that the element of the deformed body is in one of such states (see Fig. 1a): continuous state (*C*-state) or fractured staie (*P*-state). Transition of the element from state *C* to state *P* (fracture process) occurs instantaneously, if the stress-state state calculated by the assumed rheological model attains some critical level (e.g. if tensile stresses at the point of a body reach the material ultimate strength).

Application of the classical approach to the bodies (materials) containing cracks allows to make a conclusion about their strength (e.g. tension of a plate with an elliptical hole, when the elliptical hole transforms into a crack-cut).

This is related with the fact that in the classical approach the special stressstrain state at the tip of a sharp defect-crack is not taken into account during deformation of a body.

The main idea of the nonclassical approach (fracture mechanics) is the following: it is assumed that during transition of the deformed body element from *C*-state to *P*-state a certain intermediate intermediate Π -state is formed (see Fig. 1*b*), which should be considered when solving the problem on strength of the materials with crack-like defects [1, 2].

An important feature of the deformed solid regions, where P-states appearars the fact that the material is always deformed beyond the stress limit. Just in those regions of the material the intensive plastic yield, interaction with the environment, diffusion processes, material damaging occur. They cause local fracture, i.e. $C \to \Pi \to P$-transition.

Thus, nonclassical fracture chart (Fig. 1), incorporated in the modern fracture mechanics, takes into account the Z-state of the material in deformed solids (such states arise mainly at the tips of crack-like defects, Fig. 1c).

In the second half of the 20th century fracture mechanics of materials as a modern science on strength and structural integrity was intensively developed in different countries of the world: in Great Britain, china, Italy, Germany, Poland, Russia, the USA, ukraine, Hungary, France, Japan and other. Speaking about the scientists who lived before 1999 outside the USSR and made a great contribution to the development of fracture mechanics in the late 20th century we should mention the following [1-3]: B. A. Bilby, K. B. Broberg, G. Irwin, T. Yokobory, S. KocSnda, H. LiebJwitz, i. Luca6, F. A. McClintock, A. J. McEvily, K. Miller, Yu . Murakami,J. Knott, R . V . Nickols, J.Petit ,P.C. Paris, A .Pincao, G. Pluvinage, J. Rice, R. O. Ritchie, G. Sih, L. Toth, D. Francois, K-H. Schwalbe, M. O. Spiedel, G. Huchinson, K. Z. Hwang (see ref in [3]).

In East Europe to 1991 the researches into fracture mechanics were successfully developed by the scientists of the former USSR , first of all in Moscow and Leningrad and also in Lviv (Physico-Mechanical Institute), Kyiv (Institute for ProblJms of Strength, Institute of Mechanics, Electric welding institute all of the National Academy of Sciences of Ukraine) and in Dnipropetrovsk (Dnipropetrovsk State University).

In Moscow the fundamental investigations on fracture mechanics were performed by: R. A. Khrystianovych, G. I. Barenblat, R. V. Goldshtein, B. A. Droziovskvi, V. S. lvanova, N. A. Makhutov, Ye. M. Morozov, V. Z. Parton, Yu. M. Rabobrov, S. V. Serensen. G. P. Cherepanov and others, in Leningrad : by V. C. Novozhylov, L. M. Kachanov, G. P. Karzov, N, F. Morozov, L. I. Sliepian and others. In Ukraine, in Lviv in particular, in the second half of the 20th century the first fundamental investigations on the theory of limiting equilibrium of bodies with cracks, in which deformation criteria of limiting equilibrium of bodies with cracks were formulated, were performed (M. Ya. Leonov, V. V. Panasyuk, P. M. Vytvytskyi).

New approaches to solution of the problems of mathematical cracks theory (calculation of the stress intensity factors) and the experimental methods of determination of the materials crack growth resistance (O. Ye. Andreikiv, L. T. Berezhnytskyi, P. M. Vytvytskyi, O. P. Datsyshyn, M. V. Deliavskyi,I. M. Dmytrakh, H. S. Kit, S. Ye. Kovchyk, H. M. Nykyforchyn, O. P. Ostash, V. V. Panasyuk, L. V. Ratych, O. M. Romaniv, M. P. Savruk, B. P. Sylovanyuk, M. M. Stadnyk, M. P. Stashchuk, S. Ya. Yarema and others) were also developed. In Kyiv Research Center on Fracture mechanics the following scientists should be noted: O. M. Guz, A. O. Kaminskyi, A.Ya. Krasovskyi, A. O. Lebedev, L. M. Lobanov, G. S. Pysarenko, , V. T. Troshchenko,V. I. Trufjakov and others (see ref. in [1-8]).

IRWIN-GRIFFITH CONCEPT

A. A. Gdffith was the first to consider the presence of Π-states in the stressstrained body (material) at the crack tip and to formulate the criterion (condition) of the crack growth and the formation of new surface (fracture) of a body, using not a classical approach but a generalized energy balance of a deformed solid with a crack and the energy that is spent for formation of new surface during crack propagation and formulated a known criterion of crack propagation in a deformed body [9]. The establishment of the structure of asymptotic of the stress field and displacements at the crack--cut in the deformed solid was a very important stage in fracture mechanics development (see ref. in [1-3]). Thus it was shown that the stress tensor components (σ_{ij}, Fig. 2) near the crack tip can be written as:

$$\sigma_{ij} = \frac{1}{\sqrt{2\pi r}}\left\{K_{\mathrm{I}0} f_{1ij}(\theta) + K_{\mathrm{II}0} f_{2ij}(\theta) + K_{\mathrm{III}0} f_{3ij}(\theta)\right\} + 0(1), \qquad (1)$$

where $i,j = x, y, z$ in Cartesian coordinate system or $i,j = r, \Theta, z$, in polar (cylindrical) coordinate system $K_{\mathrm{I}0} = K_{\mathrm{I}0}(p,l)$, $K_{\mathrm{II}0} = K_{\mathrm{II}0}(p, l)$, $K_{\mathrm{III}0} = K_{\mathrm{III}0}(p,l)$ are the stress,intensity factors (SIF) that are the functions of the body configuration, crack dimensions (l) and loading : p,0(1) is a limited value at $r \to 0$;$f_{kij}(\theta)$ are known functions ($k = 1,2,3$).

Considering dependences (1) G. Irwin formulated [10] a new criterion of limiting equilibrium state for a cracked body under quasistatic loading for the case when mode I fracture occurs in the body , i.e. when $K_{\mathrm{I}0} \neq 0$, a $K_{\mathrm{II}0} = 0$; $K_{\mathrm{III}0} = 0$. This criterion is based on the statement that the external loading p will be limiting equilibrium ($p = \mathbf{p}_*$) when for a deformed cracked body the stress intensity factor $K_{\mathrm{I}0}$ (p,l) is equal to K_{Ic}- some constants for the given material i.e.

$$K_{\mathrm{I}0}^{*} = K_{\mathrm{I}0}(p^{*},l) = K_{\mathrm{Ic}} \quad (2)$$

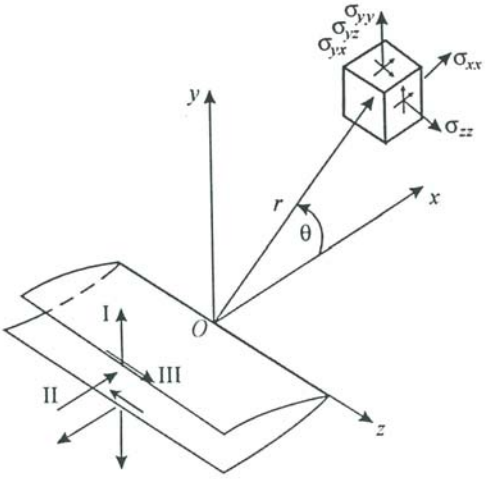

Fig. 2. Local system of coordinates at the crack front (line O_z) and components (I,II,III) of the vector of crack edges displacements

In the brittle fracture conditions that is when $\Delta l << l_o$ (see Fig. lc) G. Irwin proved the equivalency of criterion (2) and the A. Griffith energy concept.

In the 60$^{\mathrm{ies}}$ of the last century the authors of paper [11] generalised criterion (2) for the case when the plate with a crack is in the complex stress state state (twodimensional problem), that is when

$$K_{\mathrm{I}0}(p,l) \neq 0,\ K_{\mathrm{II}0}(p,l) \neq 0,\ K_{\mathrm{III}0}(p,l) = 0.$$

As a condition that determines the direction of the initial crack propagation such a hypothesis (σ_θ -criterion) is accepted [11]: a crack propagates in a plane $\theta = \theta_*$ (in the plane z0r, Fig.2) for which in the small circle of its tip the coefficient of normal tensile stresses intensity $\sigma_{\theta\theta}$ attains the maximum value.

By using this criterion the equations of limiting equilibrium of a body (plate) with an arbitrary oriented crack were established in [11] (Fig. 3).

$$\cos^3\frac{\theta_*}{2}\left[K_{\mathrm{I}0}(p_*,\alpha,l)-3\operatorname{tg}\frac{\theta_*}{2}K_{\mathrm{II}0}(p_*,\alpha,l)\right]=K_{\mathrm{I}c}, \quad (3)$$

$$\theta_*=2\operatorname{arctg}\frac{K_{\mathrm{I}0}-\sqrt{K_{\mathrm{I}0}^2+8K_{\mathrm{II}0}^2}}{4K_{\mathrm{II}0}}, \quad K_{\mathrm{I}0}>0,\ K_{\mathrm{II}0}\neq 0, \quad (4)$$

$$K_{\mathrm{I}0}=p\sqrt{\pi l}\sin^2\alpha,\ K_{\mathrm{II}0}=p\sqrt{\pi l}\sin\alpha\cos\alpha, \quad (5)$$

where θ_* is the angle of the initial crack growth direction; α is the orientation angle of the crack relative to the direction of forces p action.

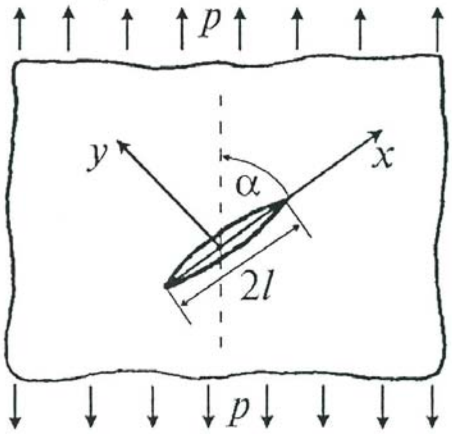

Fig.3

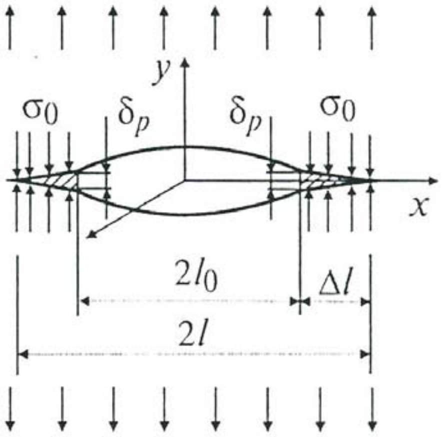

Fig.4

Fig. 3. Tension of a plate with an arbitrary oriented crack

Fig.4.A plate with a central crack ($2l_o$)and model plastic zones (Δl);
δ_p is the displacement of the initial crack edge under loading p.

Equations (3) and (4) were proved experimentally [12] and now are used for establishing the limiting equilibrium (strength) of cracked bodies in the conditions of the complex stress state.

At the beginning of the 80^{ies} O. Ye. Andreikiv, similarly to the above approach, obtained [13] the equations of the type (3)-(4) for a 3-D problem of the crack theory, and also established the correctness conditions of usage of the Griffith-Irwin concepts for finite bodies.

The Griffith-lrwin calculational models and equations (3)-(5) form the basis of the so-called **linear fracture mechanics of solids**. The main peculiarity of this section of fracture mechanics is that the typical dimensions of the region near the crack tip, where material is deformed beyond the elastic limit, are considered to be small to compare with the crack sizes and the body itself. The stress-strain state in this body is determined by solving the corresponding problems of linear theory of elasticity for bodies containing ciacks-cuts (that's why this part is called linear fracture mechanics, LFM). Using the obtained solutions the SIF values are calculated (K_{i0} (p,l),i=I, II,III). Besides, the resistance of the materials to crack propagation, i.e. its crack growth resistance, is calculated. This characteristic is estimated by values of $K_{\mathrm{I}c}$, $K_{\mathrm{II}c}$, $K_{\mathrm{III}c}$, obtained experimentally.

Critical loading is calculated by criterial equations as a functional [1]

$$\left(\frac{K_{\mathrm{I}\theta}}{K_{\mathrm{I}c}}\right)^{n_1}+\left(\frac{K_{\mathrm{II}\theta}}{K_{\mathrm{II}c}}\right)^{n_2}+\left(\frac{K_{\mathrm{III}\theta}}{K_{\mathrm{III}c}}\right)^{n_3}=1 \qquad (6)$$

where n_1, n_2,n_3 and K_{Ic} , K_{IIc} , K_{IIIc} are materials constants determined experimentally (see ref. in [24-16]).

LINEAR FRACTURE MECHANICS

Equations (1)-(6) form the basis of linear fracture mechanics (LFM) of the materials. Development of fracture mechanics concepts is one of the most important conceptual achievements of fracture mechanics of cracked bodies in the second half of the 20th century. It is worth remembering that some components of this direction require experimental verification and theoretical development, first of all it refers to creation and approval of the common standards for determination of crack growth resistance characteristics of structural materials (K_{Ic} , K_{IIc} , K_{IIIc}, n_1, n_2, n_3) . Preparation of technical reference books on these characteristics, calculation of the stress intensity factors (SIF) for particular structural elements and systematisation of these results in the appropriate data bank etc. are necessary. The above mentioned and also some other problems constitute the object of investigations and developments of the 21st century.

NON-LINEAR FRACTURE MECHANICS

It is known that prior to failure of real structural materials the plastic zones at the stress concentrators (crack-like defects, in particular) are formed. The typical linear dimensions of such zones (Π-states) can be commensurable with the defect size or the typical linear size of the deformed body. In such cases the application of the Griffith-Irwin concept (LFM) without additional refinements is not correct. To solve these problems different deformation criteria, in particular the criterion of critical crack tip opening displacement (CTOD criterion) and also the concept of the δ_c-model for evaluation of crack opening displacement near its tip, proposed in [17-19] (1959, 1960) are used. The given concept is the important stage in the development of non-linear fracture mechanics i.e. when typical linear m,dimensions of the region of plastically deformed material at the sharp stress concentrator-crack is commensurable with the typical size of a defect or a body ($\Delta l \approx l_0$, Fig. a).

According to the δ_c-model the regions of the body where plastic zones have appeared can be replaced by a cut (cuts) the opposite sides of which are attracted with stresses, which are the averaged local stresses arising in the plastic zone of the material; for materials without hardening we can assume that $\sigma_0 \approx \sigma_T$ (where σ is yield stress of the material); at all points of the deformed body (outside the cuts) the deformations are elastic. Crack opening (mutual displacement of edges) δ_p near the initial crack tip at the moment of the crack start is equal to constant (δ_c) of the material (Fig. a). Within the framework of the accepted model for elasoplastic material there exists an equality $\sigma_0\delta_c=2\gamma$ between values δ_c, σ_0 and density of material fracture γ, where γ is the average value of the energy necessary for formation of the surface unity in the given material.

Similar approaches (however partial and developed somewhat later) were proposed by D. S. Dugdale [20] (1960) and A. A.Wells [21] (1961). The concept of the δ_c -model was realized for the first time by M. Ya. Leonov and V. V. Panasyuk [17, 18], M. Ya. Leonov and P. V. Vytvytskyi [22] on the example of the generalized problem of Griffith; M. Ya. Leonov and V. V. Panasyuk using the Sack's generalized problem (see ref in [19]). For the generalized Griffith problem (for the plate under tension with an arbitrary number of plastic zones Δl) in terms of the δ_c -model the value of the limiting loading $p = p_*$ was established for the first time (1960) (see ref in [19]) as

$$p_* = \left(\frac{2}{\pi}\right)\sigma_0 \arccos\exp\left(-\frac{d_*}{l_0}\right), \quad d_* = (\pi E\delta_c)/(8\sigma_0), \tag{7}$$

where E is Young's modular.

The size of the area of inelastic (plastic) deformations in the crack plane in this case is determined by the equality

$$\Delta l = l - l_0 = l_0\left[\sec\frac{\pi p}{2\sigma_0} - 1\right]. \tag{8}$$

Formula (7) can be used for the crack of any initial length lo($0 \le l_0 < \infty$). According to this formula the critical loading p_* is always finite and (when $l_0 \to 0$) tends to the value σ_0. This physically sound result is not realized in Griffith-Irwin theory.

In the 80ies O. Ye. Andreikiv, V. V. Panasyuk et al. (see ref. in [5]) broadened the concept of the δ_c -model for mode II and mode III cracks and proposed the methods of experimental determination of critical opening displacement (δ_{Ic}) and critical crack edges displacement (δ_{IIc}, δ_{IIIc}).

At the beginning of the 90ies M. P. savruk et al. [23] used the δ_c -model for plastic bands, initiating from the crack tip at arbitrary angle. Another generalizations of the δ_c -model, in particular for description of the fatigue crack propagation were given in [24], and for the case-of retarded crack propagation in the paper by A. O. Kaminskyi [25].

The concept of the δ_c -model and its modification aimed at more effective account of the peculiarities of the stress state near the sharp stress concentratorcrack tip form the bases of non-linear fracture mechanics. This branch of science about materials fracture has not yet obtained its full conceptual formulation. It is being developed now. The fundamental and applied investigations of the limiting equilibrium of bodies with sharp stress concentrators-cracks, and also the development of the effective models of process zones (Δl) are important for this direction. In this respect it is important to perform investigatlons of the character of interaction between the edges of the model cut of *П*-states zone near the concentrator-crack tip and to carry out corresponding experiments in order to prove the theoretical predictions of failure of elastoplastic bodies with cracks (an example of such a problem is considered).

A very important and perspective task in the implementation of the theory and the methods of fracture mechanics into engineering practice is the preparation and publication of a course oflectures intended for engineers and students.

In the field of non-linear fracture mechanics the problem of study of the processes of material elasoplastic deformation near the sharp stress concentrator tip as well as the development of the effective calculation models for evaluation of the limiting equilibrium states of a body, when the deformation zone is commensurable with the typical dimensions of the defect and the body, applying for this purpose the deformation, force and energy approaches, remains actual.

MATERIALS FATIGUE: CRACK IMTIATION AND PROPAGATION

The problem of materials fatigue is one of the central problems of fracture mechanics and prediction of structural elements life time (durability).Great efforts have been spent for solution of this problem since the 19th century, when this phenomenon was considered for the first time. This problem was the topic of special plenary report by J. Schijve[*] at the 14th European Conference on Fracture (ECF-14) on September, 9 in Cracow. In this problem solution the concepts of fracture mechanics are very important. They are the following. For fatigue fracture of the material two periods are determining: the macrocrack initiation period (N_1) and its propagation period (N_2). Determination of these periods is the main task of the science on materials fatigue and durability (life time) of structural elements. When periods N_1 and N_2 are known, the total life time (N_*) is determlned by formula

$$N_* = N_1 + N_2 . \tag{9}$$

The material ability to resist crack initiation and propagation is characterized by its fatigue crack growth resistance. This characteristics is evaluated experimentally. It is the diagram of dependence of crack growth rate (ν) on the stress intensity factor (K_1) or deformation amplitude of the material at the crack tip (Fig. 5).

As a result of experimental investigations it was shown that such curves ((ν-K)-curves) are of S-shape and in a certain region 2 (Fig. 5) they can be considered rectilinear and can be described [5] by Paris equation

$$\nu = CK_I^n \text{ or } \nu = 10^{-7} (K_I/K^*)^n \tag{10}$$

where K^* is the value of K_1 at which the crack growth rate in the given material is 10^{-7} m/cycle (Fig. 5); C and n are material constants.

To construct the (ν-K)-curve the range of the stress intensity factor ΔK($\Delta K = K_{Imax} - K_{Imin}$ and $\Delta K = K_{Imax}$ when $K_{Imin} < 0$) is used and not the value of $K_I = K_{max}$.

Every (ν-K)-curve is bounded on the left by the threshold value of K_{th}, i.e. by such value of K_1 or ΔK_1 that for $K_{Imax} < K_{th}$ (or $\Delta K_{Imax} < \Delta K_{th}$,) the crack does not propagate (ν= 0). On the right this curve is bounded by the value of K_{fc} , i.e. by such SIF value at which spontaneous failure occurs ($\nu \to \infty$) .

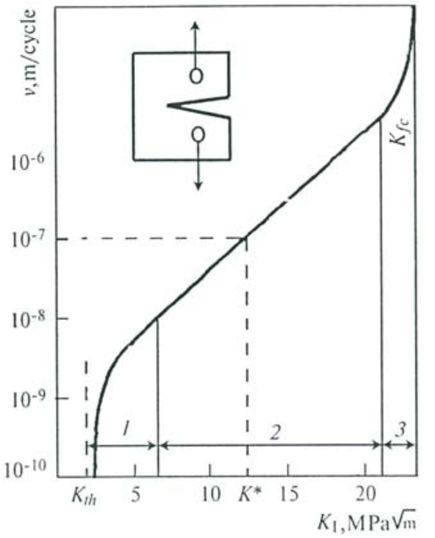

Fig. 5. Diagram of fatigue crack growth resistance (or (ν-*K*)-curve: *1* is the region close to threshold K_{th}; *2* is practically rectilinear region; *3* is the region of rapid crack growth and entire failure under condition $K_{Imax} = K_{fc}$.

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[*] J.Schilve. Fatigue of structures and materials in the 20th century: state of the art. In this paper the detailed list of references on the above problem is given, however the author did not consider the investigation results of the East European scientists. This was done only as a supplement in the Ukrainian translation of this paper by the scientific editor (Journal "Physicochemical Mechanics of Materials". - 2003. - No 3. - P.7 -27 .

So for fatigue fracture we have the following basic fatigue crack growth resistance characteristics : K_{th}, K^*, K_{fc}, m .

In [26] for description of (ν-K)-diagram a simple formula was proposed:

$$\nu = \nu_0 \left[(K_I - K_{th})/(K_{fc} - K_I)\right]^q, \qquad (11)$$

where ν_0, K_{th}, K_{fc} ,q are material constants, obtained experimentally.

If one takes into consideration that the plastic deformations zone at the fatigue crack tip is small to compare with the crack length, i. e. in the case of macrocrack ($\Delta l << l_0$ and $l_0 \cong l$), it is possible to establish the relationship between K_{Imax} and $\delta_p^{(max)}$) (Fig. 5). Having such relationship or by measuring the value of $\delta_p^{(max)}$) immediately in the given deformation conditions of the cracked body, it is possible to construct the fatigue fracture diagram in coordinates $\nu 0\delta_p$, that is (ν-δ_p)-diagrams. The advantages of such diagrams are that the value of δ_p can be measured immediately during experiment. This forms new prospects concerning construction of the important characteristics of fatigue crack growth resistance of structural materials and calculation of residual life time (N_2) of structural elements.

In papers by O.P.Ostash and others [27-28] a unified model of fatigue macrocrack initiation and propagation during cyclic deformation of the materials was formulated. Within the framework of this model a procedure of measuring the macrocrack initiation period (N_1) in the given material when the fatigue crack growth resistance diagram of materials with a macrocnack is known, that is the (ν-K)- or (ν-δ_p)-curve, is proposed. **Investigation.of these aspects of fatigue fracture of structural materials is of a great theoretical and practical importance and is an object of further investigations.**

Let us note the important investigations on fracture mechanics of materials and welded joints, performed in the late 20^{ies} by the scientists of Kyiv school of mechanics and materials science researchers. In particular in Paton Electric Welding Institute, in Pysarenko Institute for Problems of Strength. In Tymoshenko Institute of Mechanic of the National academy of Sciences of Ukraine. The results of their scientific and applied developments were given in the monographs [29-34].

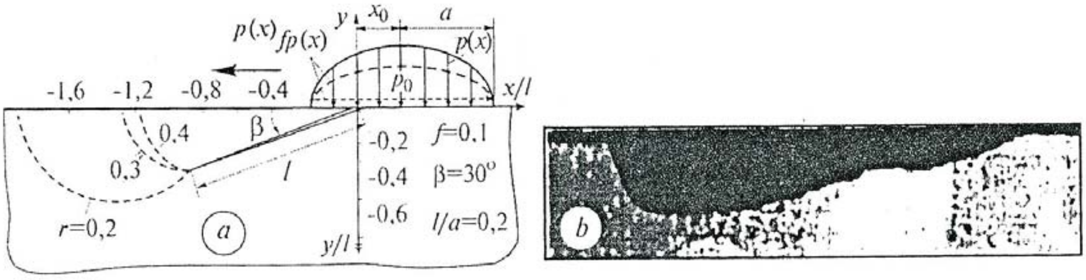

Fig. 6. Damage of the surface contact zone under rolling: *a* are the paths (dashed lines) of an edge crack growth in conditions of boundary lubrication, depending on the oil pressure intensity ($q = rp_0$, r – numerical coefficient) on the crack edges;*b* is the pitting cross-section on the surface of contacting bodies (see ref. in [37]).

The investigation of fatigue crack propagation in the region of cyclic contact of two bodies form a separate part in facture mechanics. For example, in the systém „wheel-rail“ these are rolls, roller bearing, bases of drill bits, etc. This section of fracture mechanics started its intensive development not long ago (see ref in Proc.

of World Congress, Vienna, 2001).

In Ukraine in papers by O. P. Datsyshyn et al [36-37] new important results have been obtained on fatigue crack propagation kinetics in the zone of cyclic contact of two bodies. In particular the appropriate calculation models and calculation algorithms of fatigue crack propagation depending on loading conditions of the bodies and the character or friction forces between them were formulated. As an example Fig. 6 presents the results of paper [37] about the paths of fatigue crack propagation (dashed line) depending on the maximum contact pressure (p_0) between the bodies and caused by them lubricant pressure ($q = rp_0$) on the crack edges where r is a numerical coefficient. The obtained results agree well with experimental data (Fig. 6*b*) and allow to predict the residual life of the contacting bodies systém (pair) when in the zone of their cyclic contact a damage (a crack) appears. Further development of the above researches is very important from the theoretical and practical point of view for calculations of reliability and durability of tribosystems, especially their life time.

THE INFLUENCE OF ENVIRONMENT ON CRACK GROWTH RESISTANCE OF MATERIALS

The establishment of regularities of corrosion environment influence on peculiarities of diagrams (ν-K_1) is the important achievement of the science on material strength. At the beginning of the 80ies it was established that (ν-K_1) diagrams (at stable characteristics of external environment) depend on the initial value of SIF i.e. $K_I^{(i)}$ (where I = 1, 2, 3,). For example, when $K_I^{(1)} < K_I^{(2)} < K_I^{(3)}$ from which the diagrams (ν-K) begin to be constructed, then the SIF values are different (see Fig. 7) though the external environment was similar. These results show that the (ν-K) diagrams for the material in corrosive environment are not the invariant characteristics of the material crack growth resistance in the system material-corrosion environment.

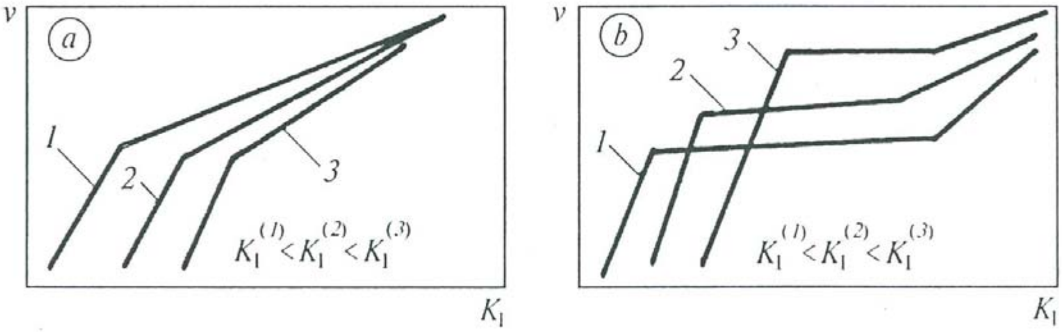

Fig. 7. Dependences (ν-K curves) of crack growth rate (ν) on value (K_1) under simultaneous effect of loading and environment, constructed at different initial $K_I^{(i)}$ values, i = 1,2,3 : *a* is cyclic loading; *b* is long-term static loading [38].

In the 80ies it was established in papers by I. M. Dmytrakh, V. V. Panasyuk and V. L. Ratych (see ref. in [38]) that the invariance of such diagrams is caused by the fact that the crack growth rate in deformed metals depends not only on K_{Imax} but also on physicochemical properties of the environment and metal just at the crack tip and not on the metal surface. If, for example, for a given "metal-environment" system we take the characteristic parameters, the hydrogen index of environment (pH) and electrode potential φ, the values of these indexes on the metal surface (pH_s and φ_s) and at the crack tip (pH, and φ_t) will differ though pH_t and φ_t depend on pH_s and φ_s . At the same time pH_t and φ_t depend on the crack length, environment effect time and physicochemical properties of the material. Proceeding form these conditions a new physical model of physicochemical situation at the corrosion crack tip in a metallic material was proposed in paper [39] (Fig. 8). This model presupposed that the crack growth rate (ν) in such a case depends on K_I and also on pH_t and φ_t i.e.for ν we have the following equality:

$$\nu = F (K_I, pH_t, \varphi_t). \quad (12)$$

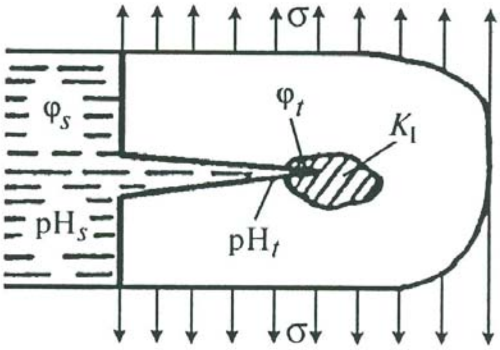

Fig. 8. Physicochemical situation at the crack tip.

The methods of measuring and regulation of pH_t and φ_t at the crack tip were developed [39].

It proceeds from this model that for construction of invariant diagrams of corrosion crack growth resistance it is necessary to ensure the non-variance (stability) of pH_t and φ_t values. Under such conditions we will have invariant diagrams of corrosion fatigue fracture of metals. Experiments proved this calculational model. In such a way a new tool for study of the effect of surfaceactive and corrosion media on physicochemical characteristics of cracked materials appeared. The values (minimum) of $\varphi_t = \varphi_t^*$ and $pH_t = pH_t^*$ at which in the given system "metal-corrosive environment" the crack growth rate ν in the metal gets the maximum value were established. Diagrams (ν-K_I) plotted at φ_t^* and pH_t^* envelop all other diagrams (ν-K_I) e.g. they are basic for estimation of the durability (life time) of structural elements in the given corrosion environment.

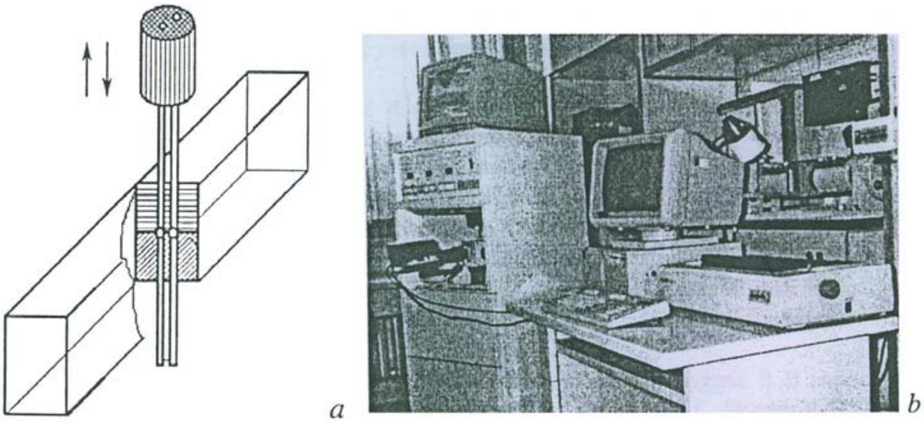

Fig. 9. Equipment for evaluation of the material fatigue fracture characteristics, considering the parameters of electrochemical processes in the prefracture zone: *a* is a scheme of location of the gauges-microelectrodes in the specimen for local electrochemical investigations; *b* is a general view of the equipment.

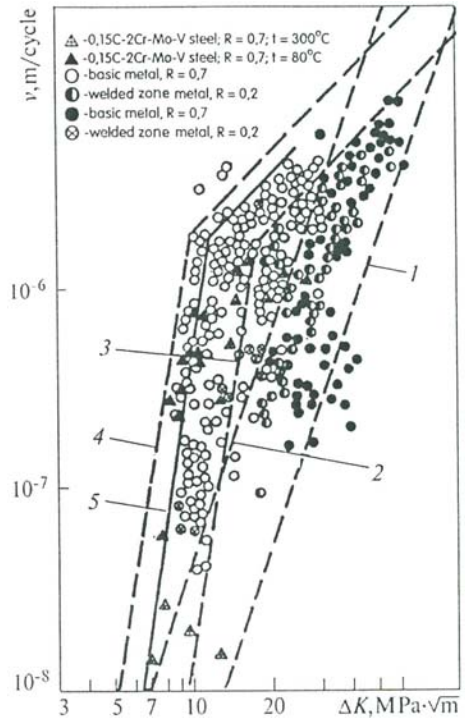

Fig. 10. Fatigue crack growth resistance diagrams ((ν-*K*) -curves) for pressure vessels metal:

1, *2* is according to ASTM Test Method;
3, *4* is according to Bamford [40] (generalized experimental data);
5 is a basic diagram plotted in terms of the proposed concept.

Physico-Mechanical Institute has developed the methods, special test specimens and necessary tools for measuring the parameters pH_t and φ_t and also the methodology of regulation of these parameters (Fig. 9). Thus, at the end of the last century new tools for assessment of the structural elements life time in corrosion environment were created. A typical example of this approach application for estimation of serviceability of structural materials used in high pressure vessels is presented in Fig. 10.

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Reviewer : prof. Ing. Michail Lembák, CSc.