FRACTODIAGNOSTICS—PROBLEMS AND METHODS

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ABSTRACT

In the present paper, the problems of fractodiagnostics have been discussed. Fractodiagnostics is considered as an inter-disciplinary branch of the strength science aimed both qualitatively and quantitatively to describe the loading hystory resulting in fracture by the analysis of fracture surface parameters. There are presented some fractodiagnostics methods allowing one to estimate crack propagation period, critical temperatures of brittleness, critical values of other characteristics controlling the fracture in the range of the ductile -brittle transition and local stress state using fracture surface parameters. A special attention has been payed to the X- ray fractographic methods which enable the estimation of the depth of the plastic deformation zone under the fracture surface and the degree of the crystalline structure distortion in this zone. Based on these characteristics, the methods of the determination of the local stress state and critical fracture parameters have been developed.

KEYWORDS

Fracture surface parameters, fractodiagnostics, X-ray fracto-graphy, plastic deformation zone

The factors affecting the material and in some cases not taken into account result in accident failure. The investigation of the history of such failure and ascertainment of the reasons of the accident enable the optimization of the construction or structure of materials and the basis of the frequency of the periodical control of the construction elements. A lot of information about the fracture history can be obtained by the fracture surface analysis. However, for the development of diagnostics methods on the fracture surface, it is necessary to know the general regularities of the fracture process of different materials tested under different loading conditions. Otherwise, the scientific basis is needed to solve the problems of diagnostics of fracture surfaces. Moreover, it is obviously necessary to create a novel interdisciplinary branch of strength science - fractodiagnostics - with the aim to describe both qualitatively and quantitatively the loading history resulting in fracture using the analysis of fracture surface parameters. It is well-known that similar investigations in other branches of science carried out for the purpose of restoring a history of the process on its finishing have stood out into a separate division of science.

Fractodiagnostics must combine many trends of the strength science- macro- and micromechanics of fracture, material science and physics of solids. It must connect kinetic fracture macrocharacteristics with fracture surface parameters and general regularities of fracture under different loading conditions.

Within the limits of fractodiagnostics, special and general regularities of crack propagation in various materials are

to be established. Based on these regularities, material structure and fracture surface parameters, crack growth rate and plastic deformation zone estimated in laboratory tests must be connected with the characteristics obtained by stand tests or under service conditions.
The new field of science should unite the specialists dealing with the study of fracture surface formation on different scale levels differing by several orders: from microscopic to global, including the rock fracture formation. It seems that general problems of fractodiagnostics are as follows:

- classification of fracture mechanisms and features of fracture surface relief at different scale levels - from microscopic to global, including the fracture formation in rocks
- determination of the main fracture mechanism on each stage of fracture and corresponding parameters of fracture surface relief
- establishment of the relationship between well-known fracture criteria and general parameters of fracture surface of specimens and details, development of physically based criteria of fracture
- study of structure sensitiveness to the parameters of fracture surface relief
- analysis of accident fracture under service conditions
- study of the regularities of the fracture surface relief formation, statistical analysis of fracture surface features
- development of fractodiagnostics methods for different loading conditions and materials
- working out of measures to prevent the accident failure and to increase the reliability of details and constructions
- study of general regularities of fracture under different loading conditions.

Consider some fractodiagnostics methods allowing one to estimate crack propagation period, critical temperatures of brittleness and local stress state.

THE FRACTOGRAPHIC METHOD OF THE ESTIMATION OF FATIGUE CRACK GROWTH PERIOD

The method is based on scanning electron microscope measuring the fatigue striation width corresponding to a certain fatigue crack length and determination of the range where the macrorate of the fatigue crack growth is equal to the microrate determined by the size of striations.

The fatigue striation size has been determined in the direction of maximum removal of the crack front from origin of fracture. Based on the results of measurements, the relationship between the striations size and crack length has been established. The shape of this relationship is determined by the stress level but generally is of the S-character similar to that of the dependence of the striation size on the range of stress intensity coefficient.

Such a dependence is usually described by the curve of three parts [1, 2]. In the first and third parts, the effect of the crack length on the striation size is negligible, being in the second region limited by a crack length l_s and l_r and a corresponding range of the stress intensity ΔK_s - ΔK_r (Fig.1), where the striation size increases with the crack length and the striation number is equal to that of loading cycles (Botvina and Limar', 1985).

The second and third parts are found in a low-cycle fatigue

region, the first and second one in a high-cycle region. The coincidence of macro-and microrates of crack growth is observed only on the second part of the curve. Therefore it is important to know its limits while estimating the period of fatigue crack growth.
The beginning of the range of macro-and microcracks coincidence can be determined by some fractodiagnostic features.

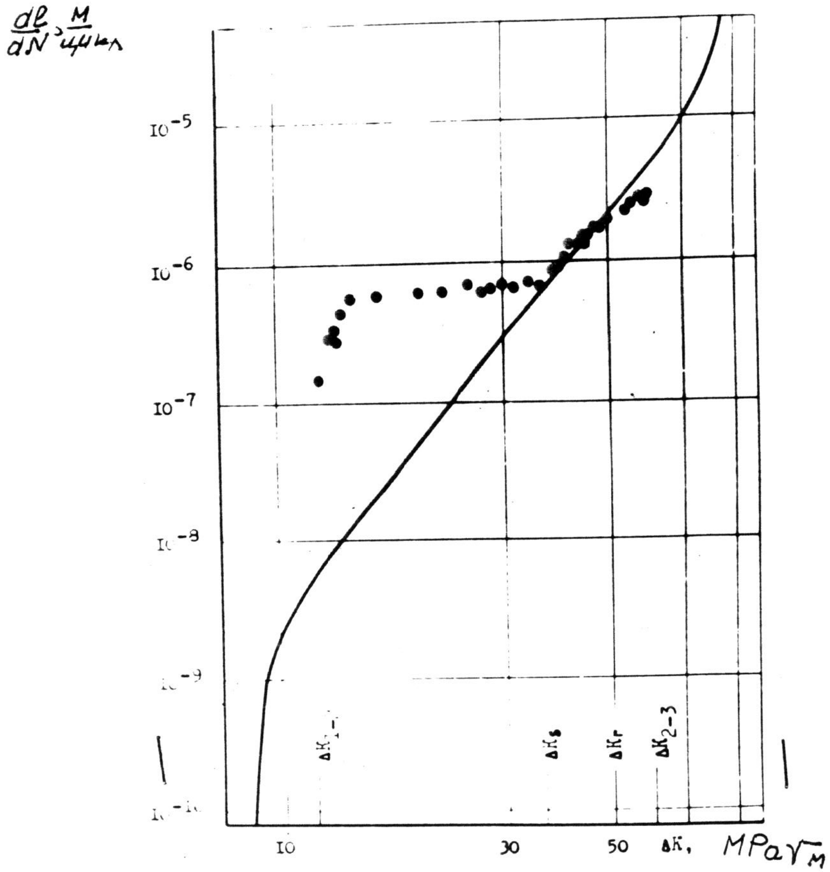

Fig.1. The kinetic diagram of the fatigue fracture for the titanium alloy BT3 tested under cyclic tension

On reaching ΔK_s, static mechanisms of fracture (dimples, cleavage facets) appear on the fracture surface and portion of these mechanisms increases with increasing of ΔK. At ΔK_s, combined striations and shear fracture ranges near the specimen surface and observed.. The shear sections and striation size increase at increasing ΔK. At the end of the coincidence range of macro-and microrates of the crack growth ,the striations size becomes independent on the crack length but static fracture mechanisms continue to develop. The life-time of details is determined by an average striation size in a local range of the fracture surface whithin the coincidence interval of macro- and microrates at a striation per a loading cycle.

FRACTOGRAFIC METHOD TO ESTIMATE CRITICAL FRACTURE PARAMETERS

Due to the analysis of fracture surfaces carried out on notch specimens tested in static and impact loading in the range of the ductile-brittle transition, three fracture ranges have been established: an initial range of shear fracture at the notch or fatigue crack tip (θ), ductile fracture zone ($l_c-\theta$), and a zone of instable brittle fracture. The zones of shear and ductile rupture fracture form a zone of the stable crack propagation (l_c).

The zone sizes change with the factors which cause a ductile- brittle transition. The characteristics of the fracture process change too. Measurements of the zone sizes at different temperatures have allowed one to determine critical temperatures of brittleness as follows:

T_A - temperature at which the fracture surface is fully ductile

T_C - critical temperature of brittleness at ratio of ductile zone length to specimen width of about 0.25

T_θ - temperature of the ductile zone disappearance at decreasing test temperature when only a shear fracture range is observed on the fracture surface

T_B - temperature at which the fracture surface is fully brittle.

Besides the crtical temperatures of brittleness, other critical parameters (P) may be determined on the fracture surface character which correspond to the complete ductile fracture (P_A), brittle fracture (P_B), and semi-brittle fracture (P_C). As such parameters may be considered: specimen width, structure element size, loading rate, heat treatment regime, etc.. Critical parameters T_θ, B_θ, d_θ, (P_θ) correspond in their increasing to a ductile rupture zone appearing on the fracture surface. At the appearance of this zone, fracture mechanics characteristics can not be considered valid. Therefore these parameters may be used as criteria of a valid estimation of fracture toughness.

The ratio of a stable crack length to the specimen width may be used as a parameter of fracture mechanisms similarity determining:

1) fracture mechanism and critical characteristics, determining the acting factor
2) regions of the valid application of fracture mechanics characteristics
3) region of strong ($P_B < P < P_A$) and slight ($P < P_B$ and $P > P_A$) effect of various factors
4) opportunity to compare materials under similar conditions on the stress state and to choose a material with optimum properties
5) opportunity to predict the workability of materials in

changing operating factor in ranges determined by critical parameters (Botvina and Kolokolov, 1976; Botvina, 1989).

THE X-RAY METHOD TO DETERMINE CRITICAL FRACTURE PARAMETERS

The X-ray method seems perspective both from the point of view of basic and applied material science. Indeed, this method makes it possible to evaluate the depth of plastic zones under the fracture surface and structural distortions in the zones. This is important for the understanding of regularities of crack growth process under various loading conditions. On the other side, the information obtained by this method may be used for the analysis of reasons of accidental fractures.

The X-ray method has been first proposed by Felbeck and Orowan (1955). Then it was developed by Yokobory et al. (1976) who revealed two plastic zones under fatigue fracture surface: highly deformed cyclic zone and low-deformed monotonous plastic zone. The depth of these zones and their structural distortions depend on the crack length and stress intensity factor.

The method to determine critical fracture parameters is based on the kinetics of plastic deformation zones under the fracture surface of bcc and fcc materials. The investigation of the development of plastic deformation zones under different loading conditions has shown the number of zones at the crack tip and the degree of the crystalline structure distortion of the material in the zone depend on the stress state.

If the plane strain state occurs at the crack tip, a local highly deformed microzone forms near the crack tip and a larger low-deformed zone forms with decreasing plastic constraint (Botvina et al., 1982). Therefore, there are two plastic zones in the plane stress state. Hence critical fracture parameters (for example, temperatures of brittleness) corresponding either to the plane strain state or plane stress state may be estimated on the number of plastic deformation zones . Moreover, two other parameters to determine a local stress state at the crack tip and critical fracture characteristics may be used: ratio of the maximum plastic zone depth to specimen thickness (h_{max}/t) and ratio of physical widening of diffraction lines on the fracture surface to its initial value for a undeformed material (β/β_o).

The analysis of the interdependence of these parameters enables the conclusion about a unique relationship h_{max}/t - β/β_o by all investigated materials and loading types of the S- character associated with the transition from plane stress to plane strain state at the crack tip (Klevtsov et al., 1991).

Therefore, the material structure and loading conditions affect only the realization of a definite local stress state being found by an approximately constant ratio h_{max}/t. In different materials, the transition from plane stress to plane strain occurs at a critical ratio $\beta/\beta \cong 2$ (Fig.2).

ANALYSIS OF THE FRACTURE SURFACE OF ROCKS

Some more important applications of fractodiagnostics to the rocks should be discussed. The available information about tectonic processes occurred in the earth crust many years ago could be obtained due to the fracture surface. It is, for example, known that the ductile-brittle transition occurs in rocks under definite conditions similar to metallic materials. Such a transition is connected with the intensity of the tectonic strain.

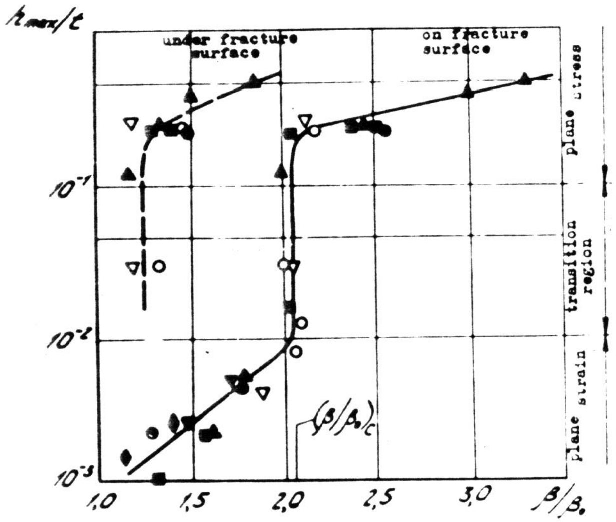

Fig.2.Relative values of maximum depth of plastic deformation zone vs relative values of physical widening of diffraction lines:
▲ -steel 20,static loading, ▼ -steel 40, static loading, ● -steel 15X2MФA, static loading, O -aluminium alloy D16, static loading; ■ - steel 45,impact loading, ∇ -steel 40X4Г18, impact loading; ◆ -steel 3, dynamic loading, ◐ - steel 45,dynamic loading .

Ascertaining of the ductile-brittle transition on the fracture surface of rocks enables the receipt of an information about geological phenomena caused by changing of tectonic strain, in particular, by changing seismicity.

Some structures observed in rock breaks are connected to a local bend of stratum. Each of them forms as a result of local buckling. These instabilities often observed in active seismic zones characterize the past seismic activity, for example, seismic impact.

Circular periodic lines on the fracture surfaces of rocks are similar to those revealed on the fatigue fracture surfaces of details from metallic materials and are formed as a result of shear-rupture transtion. According to some

investigations (Bahat D., 1987) of the formation of circular lines in rock breaks is connected with changing stress state and combination of the I and II loading modes. in consequence of local periodical change of pore pressure in the rocks.

Besides circular line, striations appeared as a result of shear and rupture loading have been observed on the rock fracture surfaces. The information about the loading hystory, i.e. tectonic processes may be also found out by the study of the shear zones observed in rocks.

The results of the use of a fractographic approach in tectonophysics are more novel than those in the material science:the terminology is being verified, fracture mechanisms are being classified, possible hypotheses are being developed. But the problem of these studies is the same: restoring a hystory of the process on its finishing using fracture surface parameters.

Thus, the development of fractodiagnostics of different scale objects must allow one to understand general regularities of the fracture process and to establish the correlation between calculated, predicted and real material characteristics under various loading conditions. It will promote the development both the material science and the tectonophysics, and the understanding of the fundamental properties of the nature.

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