THE GENERAL REGULARITIES OF THE FRACTURE OF STRUCTURAL MATERIALS

L.R.Botvina *

The present work is an attempt to extract general regularities of fracture from an analysis of fracture process of steels, aluminum and titanium alloys under various loading conditions by use of the fractography and X-ray diffraction methods and similarity principles.

INTRODUCTION

The consideration of general features of the fracture development processes on the initiation stage as well as on the stage of crack growth seems to be worthwhile both from the point of view of basic and applied material science. The last one requires the establishing of physical parameters governing the working capacity of the material in various service conditions. This question was not properly clarified although the huge available data base concerning special features of structural materials allowed such possibility for a rather long time.

The investigation of mechanisms and macroscopic properties of the fracture of aluminium, titanium alloys and steels under static, cyclic and impact loading as well as the analysis of available data from

* Institute of Metallurgy of Academy of Sciences,
Leninskij prospekt 49 ,117911 Moscow
USSR

literature allowed due to determine not only the special features governed by the structure of the material and its properties, ambient environment and the loading mode but also certain general features among which the following ones should be mentioned.

GENERAL REGULARITIES

1. The similarity of stage sequence for cumulation and growth of defects of various sizes (as well as slip steps,pores, microcracks) consists in defects generation increasing their density till to a certain constant value, discontinuous transition to the cumulation process of the next order defects, larger in size and increasing of the number of such defects till to a new critical density value is reached. This process continues till to reaching a constant critical density of microcracks and macrocrack formation. In a a similar way proceeds the cumulation process of cracks in rocks having the tens-hundreds meter sizes.

2. The similarity of stage sequences (in macro- and microscales) of the crack extension process is due to similarity of sequence of stages of defects cumulation in a plastic region at the crack tip.

The fracture starts from the shear crack formation as a result of slip over the maximal shear stress planes. The development of multiple slip at the crack tip leads to the beginning of the second stage of stable crack growth in the direction normal to the applied load. This stage is terminated by the formation of a critical length crack , preceeding to the third stage of unstable fracture.

The similar stages are observed under all loading types being considered, for long and short fatigue cracks growth. The crack development mechanisms at each stage do depend on the material structure, the loading conditions and its type and are determined by certain transition stress intensity factor values.

3. The common kinetics of the plastic deformation zones, estimated by the method of X-ray analysis and governing the sequence of stages as well as other special fracture features of a certain given material under fixed service conditions.

In general case the fracture extension is related to the kinetics of two plastic zones-strongly deformed and weakly deformed ones (1,2). Strongly deformed localized zone is available under arbitrary degree of plastic constraint. With decreasing plastic constraint a weakly deformed zone appears of larger size. It occurs under cyclic loading when the stress intensity factor amplitude increases. It takes place under static and impact loading under increasing test temperature in transition from brittle fracture to brittle-ductile one. A weakly strained zone is observed under the temperatures at which on the fracture surface the fiber component areas appear. The temperature dependence of the zone depths and phisical widening of the diffraction lines in the ductile-brittle transition range has a S-like form and is similar to the temperature dependencies of the zone length of subcritical crack extension, impact toughness and fracture mechanics parameters.

This gives one a possibility not only to understand the nature of ductile-brittle transition but also to use the observed structural variation under fractures for the estimation of brittleness critical temperatures.

4. The self-similarity of the defects cumulation process of various order on the stage of the crack initiation , which is due propably to statistic law of the development of defects and their interaction. The self-similarity of the cumulation of multiple defects means that statistically the geometrical pattern of their distribution remains invariable under deformation process, only the mean distance between defects and their size are varying.

As the proof of statistical conservation of geometric defects pattern can serve scaling of the size distribution curves obtained on various strain stages. The processing of size distribution curves for pores, microcracks, slip step heigths in steels and alloys tested under conditions of creep, fatigue, tension as well as superplasticity conditions and crack size distribution curves in rocks confirmed the scaling assumption for these relations, and consequently the self-similarity of the cumulation process of various order defects.

It is proved that neither crystallographic structure nor the loading type influence markedly the relative intensity of damage process, which is characterized by the slopes of distribution curves in universal coordinates (3). Only the absolute values of the defects density and their sizes do vary as well as their type and mechanisms of their formation and growth and the parameters of process governing the development of a certain defect.

5. The self-similarity of the crack extension process is due to the self-similarity of defects cumulation process. These exists a lot of examples of the self-similarity in micro-and macrovolumes. Among them the following ones should be mentioned: 1) The stage sequence and the front shape of small fatigue cracks similar to stage sequence and front shape of large fatigue cracks; 2) Macrobands on the fracture surface in tension consist from similar small segments having the similar shape; 3) Certain types of dimples on a fracture surface have similarly to macrosamples fracture a cup-cone form; 4) In micro-and macrovolumes the crack extension is an alternating process of rupture and shear.

6. The common S-like character of the deformation and fracture basic regularities related with the variation of the stress state near the defect tip from plane stress to plane strain under the action of various factors.

As the examples of such dependencies can be considered: the fatigue curves, creep curves, stress-life curves, the dependencies of stress on the strain rate, of the fracture toughness on the sample size, crack extention rate under fatigue or creep on the stress intensity factor.

The similarity of these relations is not their only peculiarity: the middle part of S-like strength and fracture curves can be described by power laws in many cases. It is possible that the generality observed of basic regularities of strength and fracture is related to self-similar character of damage cumulation.

7. The equivalence of the various factors influence on the structure of fracture surfaces which increase the plastic constraint. This makes worthwhile to estimate three critical values of the parameters corresponding to the transition to brittle fracture, to fully ductile one and semi-brittle one with equal content of ductile and brittle fracture: Π_I , at which the subcritical extension zone becomes equal to the shear zone on the fracture surface (at $\Pi \leq \Pi_I$ the

fracture mode is brittle one), Π_2 at which the sub-critical zone size is equal to the specimen width (at $\Pi \geqslant \Pi_2$ the fracture is ductile), and Π_c, at which the ductile and brittle fracture areas on the fracture surface are equal.

The estimation of mentioned critical parameters (critical specimen width, critical loading rate, critical structural element size etc.) under arbitrary acting factor allows one to compare the various materials under similarity condition of the stress state. It simplifies the prediction of material properties and reliability control of the structure as well as the choice of regimes of its treatment.

8. The unified parameter which govern essentially the mechanism, the macroscopic fracture properties, possibility of using the fracture mechanics approach, structural sensitivity under various conditions etc. is the ratio of actual stress intensity factor to the stress intensity factor value corresponding to general yielding of the material under applied loading.

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