STRUCTURAL MODELING OF THE DAMAGE ACCUMULATION: THE LIFETIME ESTIMATION

V. V. LEPOV, E. A. ARKHANGELSKAYA, V. P. LARIONOV
Institute of physical-technical problems of the North SB RAS, Yakutsk 677891, Russia

ABSTRACT

A structural approach to the modeling of damage accumulation and fracture processes has been considered. As known the main advantages of the structural models versus the semi-empirical models are the direct description of the physical processes in material, the possibility of results transition to the bulky structures and the proved instrument to the integrated modeling of damage accumulation and fracture processes.
The microscopic damage distribution data in the low-carbon steel specimens has been obtained by the probe scope analysis of the deformation and fracture surfaces, including "in situ" samples. The stochastic model of the cracks nucleation and propagation in heterogeneous media is modified to taking into account the grain boundaries structure. The model allows one to address the process of crack propagation on the basis of microdefects nucleation mechanism, the small cracks growth and coalescence under the external stress and hydrogen effect. The coupled FE-model of elastoplasticity, diffusivity and damage accumulation to calculate the damage evolution on the scale of the part is applied. The process of the ultimate value of damage accumulation and lifetime exhausting of the pipeline element has been calculated.
The quantitative method of surface damage value estimation on the base of analysis of multifractal specter of scanning scope 3-D images of surfaces of the tensile and fractured specimens has proposed.

INTRODUCTION

The structural models for the stochastic and finite element analysis of crack growth in heterogeneous materials. It is based on multiscale modeling of a material and it incorporates, in a direct way, an information obtained experimentally (by the optical and electronic probes) for the static loaded and hydrogen saturated small-sized low-carbon steel probes.

The basic logic of the approach is as follows (see scheme on Fig. 1): the material properties and loads with the experimental data about the mechanical behavior at different structural levels (first row on scheme) are the initial data for the modeling by the according approach. Particularly, for the mesolevel the stochastic approach used with the special distributions of the microdefects number and sizes as an initial data, that has obtained by the optical and electronic probes. The output of the model is the crack propagation speed, energy dissipation, and damage accumulation speed in specific loading and environment. This data could be useful for the macroscopic FE-modeling on the level of the part. The goal of this modeling is the time of an ultimate state of material achievement and the lifetime of specific structure estimation.

1 EXTRACTION OF RELEVANT MICROSTRUCTURAL INFORMATION

To reveal the mechanisms of damage accumulation and fracture, the fracture surfaces of the sample models and construction elements are being studied by the optical and probe scopes. Damage of materials from different factors such as the static loading and the hydrogen has being estimated quantitatively by the fractal analysis of deformation and fracture surfaces of the probes.

Using the method of tunneling electron microscopy a fracture of the mild low-alloyed steel samples was explored. The samples were saturated preliminarily by the hydrogen in the 400°C temperature and 10 MPa pressure conditions and tested for the delayed fracture sensibility. As the size of investigation area is 2,6×2,6 micrometers, the height of microrelief is achieved 0,2 mkm. The character sizes of the secondary microcracks – depth is 0,2 and width is 0,3 mkm. The indication that the cracks are propagate by the mechanism of nucleation and coalescence of such microdefects as micropores and microcracks is obtained here. The typical size of investigation area is not exceeds 3×3 mkm and the height of microrelief is about 30-100 nm.

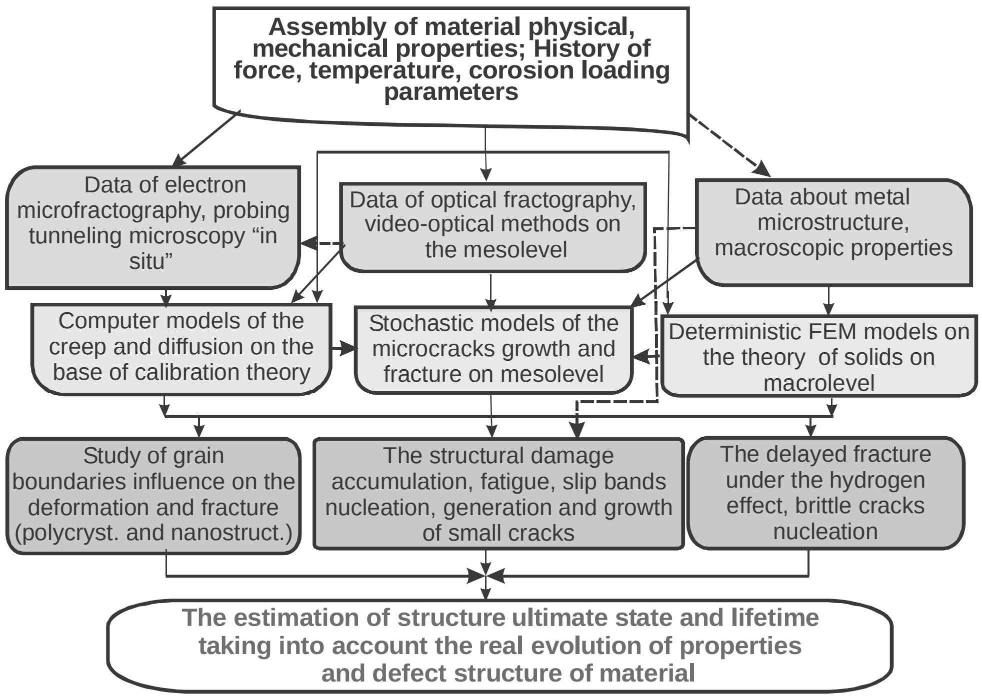

Figure 1: Conceptual scheme of the modeling of the heterogeneous media deformation and fracture processes based on the evolution and hierarchical approaches.

The secondary submicrocracks spreads along the crystallographic planes in grain body of martensite in steel. A two-dimensional image allows to measure the parameters of the submicrocracks – it length is about 2-5 mkm, depth 100-300 nm, and width 200-500 nm. Using a three-dimensional image and the profile the size of the carbide inclusion was determined – it length 2-5 mkm, width – about 300-500 nm, height – about 200 nm. The mechanism of the microcracks nucleation on the microdefects in the form of inclusion is peculiar to the samples, that are subject to hydrogen induced delayed fracture under the static loading, what the shown defects indicate. The distribution of thus defects and imperfections at microlevel and its typical sizes was used in stochastic modeling of germination on microdefects, growth by the viscous-plastic law, and mutual coalescence of small cracks, and the subsequent of the main macroscopic crack.

The study of ultimate states of material is directly connected to the lifetime numerical estimation of constructions manufactured from widely used and new materials. The last investigations in this directions are linked to the study of influence of grain boundaries and interfaces, particularly, impurity segregations on grain boundaries, on the deformation and fracture of polycrystalline and nanostructural materials. By means of electron scanning microscopy the "in situ" investigation of the evolution of surface damage during the deformation of small-sized specimens of the experimental cold-resistant steel was conducted. The fitted 4,5 kN loading device and 20×20×2 mkm tunnelling probe was used. The results of scanning of grain boundary before and after the 5%-deformation is shown on figures 2 and 3. It is seen on the 3D-images and profiles that the surface relief change and the small cracks is appeared, before the extensive macroscopic plastic deformation. The damaging has been numerically estimated by the methods of multifractal analyses of the scanned images (Lepov, [1])

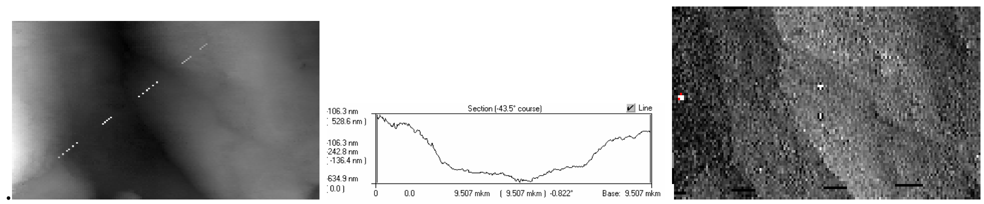

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Fig.2. Initial state of the grain boundaries of the cold-resistance experimental steel (10×7 mkm): a) 2-dimensional scan, b) profile, and c) 3D-image of the scanning surface.

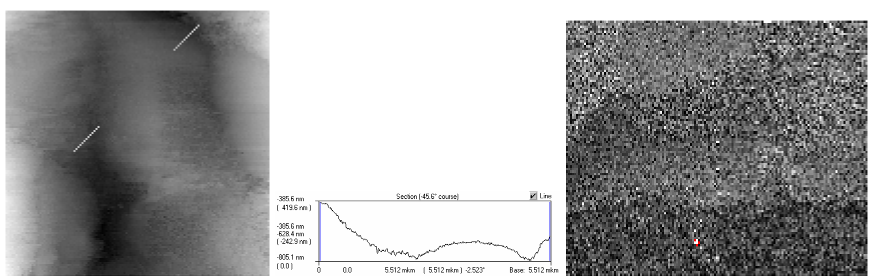

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Fig.3. The grain boundaries of the cold-resistance steel under the 5% deformation (5×5 mkm): a) 2-dimensional scan, b) cross section profile, and b) the 3D-image.

MODELING PROBLEM DEFINITION

The stochastic model of crack propagation in a multiphase, heterogeneous material is based on the mechanism of stress induced opening of the cracks at particles or flaws, its viscoplastic growth and coalescence with a main crack or adjacent pores. The crack growth in multiphase material is simulated by means of developed model based on the well-known stochastic algorithm proposed by Broberg [2].

It is assumed that the coordinates of main crack or initial pore and the mean values of fraction of pores and its size are known from the experimental data, but have a stochastic probability nature. According to scheme on the fig.6, the grain boundary (as a most probable area of the pores' nucleus distribution) is given numerically by CAFÉ model, the fraction of pores is given by the porosity model, and the stress fields are given by the ABAQUS software calculation.

This model has some specific features like the taking into account the effect of hydrogen and the possibility of changing the deformation and growth government equations (for example, for the small cracks growth description).

On figure 4 the result of calculations by the stochastic model of crack propagation in viscous-plastic micro-defect material in cases of randomly homogeneous distributed microdefects and corresponding mesocracks. In all cases the average defect size was 2 mkm, yielding 730 MPa, the tension load characterized by the stress intensity factor in the main crack tip about $K_I = 60$ Мпа м$^{-0.5}$.

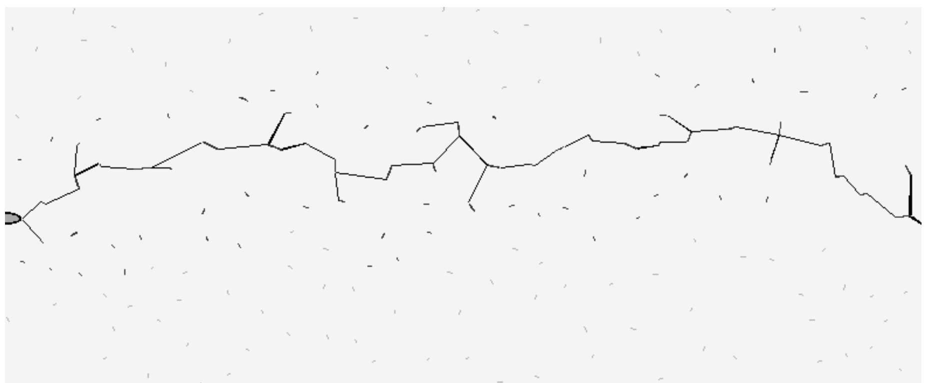

Figure 4. The results of the calculation by the stochastic model of crack propagation in polycrystalline micro-defectable (small cracks) material.

CONCLUSIONS

An evolution structural approach to the modeling of crack growth in heterogeneous polycrystalline materials has been applied. The approach is implied the way of material damage accumulation and fracture modeling.

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