# DEFORMATION DAMAGE DIAGNOSTICS BY ACOUSTIC EMISSION METHOD

Kozinkina A.I., Vorovich Research Institute of Mechanics and Applied Mathematics SFU, Rostov on Don, RU
Berezin A.V., Mechanical Engineering Research Institute of Russian Academy of Sciences, Moscow, RU

The inclusion of damage accumulation is necessary to a state diagnostics of materials and constructions under stress. The damage, arising under action of mechanical stresses it is physically interpreted as a process of initiation and growth of micro voids and micro cracks owing to break of interatomic bonds. In addition, the physical approach to destruction as to kinetic process includes the idea of its many-step behavior. For most of materials, a selection of three stages, namely initial, basic and final ones, is thought to be worthwhile [1]. The initial stage is due to appearance of local stresses and accumulation of defects at microlevel as submicroscopic voids in size of order 1 nanometers. The basic stage consists in formation of incipient voids and its coalescence up to the critical sizes, commensurable with the sizes of structural heterogeneity of materials. The submicrovoids in size of order $10^2$ nanometers characterize the typical incipient voids in solid bodies, whereas micro- and macrodefects in size of order $1\ldots10^2$ microns and more are commensurable with the sizes of structural heterogeneity of materials. At the given stage, thus, it is formed a local critical loosening which leads to occurrence of the neck or the main crack. The final stage consists in sharp localization of plastic deformation, growth of macrodefect, avalanche destruction. Depending on external conditions and qualities of a material such as plasticity, heterogeneity, initial damage, the contribution of the specified stages to total time as far as the failure is different. The parameters correlating with transition points possess the versatility properties and invariance properties therefore, they are best informative at prediction of physicomechanical features of materials. In this connection for ascertaining quality of a constructional material and its serviceability, the interstage points determination and quantitative damage estimation are of greatest practical interest.

The acoustic emission method may be considered as a direct method of measurement of defects in the sense that to each collective act of damaging material structure there corresponds a primary elastic impulse. The process of its radiation represents an act of acoustic emission. Hence, the measurement of intensity of АЭ acts flux and its total number allows investigating a kinetic of damage accumulation. Experience, which has been accumulated, is indicative of direct interrelation between the integrated characteristic of АЭ and processes of deformation and destruction. Correlation dependences are approximated by power function in most cases.

It has been established, that for constructional metallic materials the relationship between total quantity of АЭ acts ($N_{an}$) and residual strain ($\varepsilon_r$) is close to parabolic and in coordinates: $N_{an} = f(\varepsilon_r^{1/2})$ it is approximated by a polygonal line with two characteristic bend points separating the stages of damage accumulation. A comparison between mechanical destruction diagram [2] and AE diagram has shown that the first point corresponds to a point of material destruction (D) and the second point (V) corresponds to a moment of neck formation. Furthermore, the singularities are exposed on corresponding dependences at loading high-strength tool materials with very low AE activity. Fig. 1 presents the AE diagram for steel 45, where $\delta_d$ corresponds to a magnitude of destruction component of residual strain; $\delta_p$ corresponds to a magnitude of a plastic component of residual strain.

Alternatively, at consideration of body plastic deformation in view of formation and growth of voids it is possible to show, that its concentration ($c$), defined as ratio between volume of voids and volume of a material, is determined by a destruction component of residual strain. Then, from geometry of АЭ diagrams follows:

$$c = \left(\varepsilon_r^{1/2} - \delta_D\right)^2 \left(1 - \frac{\gamma_2}{\gamma_1}\right)^2 , \tag{1}$$

where $\delta_D$ are coordinate of a destruction point; $\gamma_1$ – slope tangent of the line corresponding to plastic stage of deformation; $\gamma_2$ – slope tangent of the line corresponding to destruction stage of deformation.

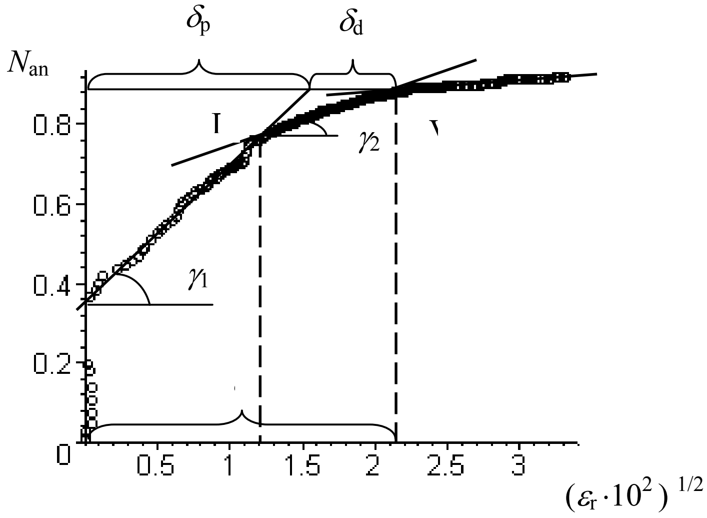


Fig 1.: AE diagram of damage accumulation for steel 45.

The $\varepsilon_r$ - dependences of the defect concentration obtained according to (1) and experimental results are presented on fig. 2 for various steels.

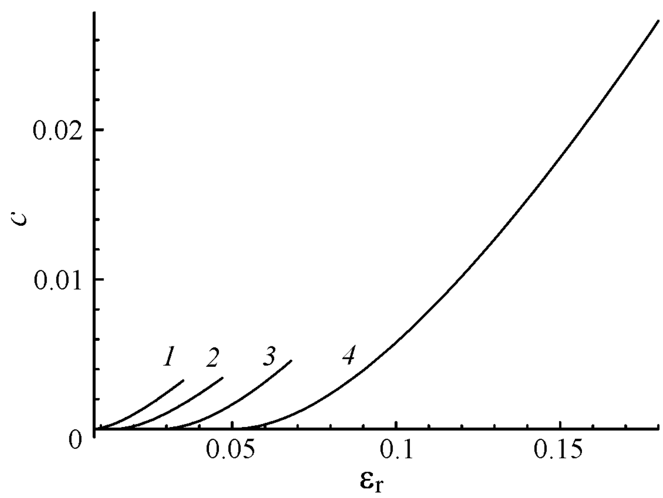


Fig.2.: $\varepsilon_r$ - dependences of c: 1 – st. 10GN2MFA; 2 – st. 45; 3 – Al; 4 – Cu

In table 1 are listed the numerical values of *c*, calculated by the AE procedure considered above and using the microstructural data obtained with the help of electronic microscopy and low-angle x-ray diffraction [1].

Table 1. Values of defect concentration

| Steel | Annealing within 2h, $T$, $^{o}$C | $c_0$ | $c$, calculated by the AE procedure | | |
|---|---|---|---|---|---|
| | | | $0{,}01\Delta\delta_d$ | $0{,}5\Delta\delta_d$ | In point V |
| Steel У9 | 700 | $5{,}2\cdot10^{-7}$ | $1{,}7\cdot10^{-7}$ | $4{,}2\cdot10^{-4}$ | $1{,}7\cdot10^{-3}$ |
| Steel 10ГН2МФА | 700 | $5{,}2\cdot10^{-7}$ | $2{,}7\cdot10^{-7}$ | $6{,}7\cdot10^{-4}$ | $2{,}7\cdot10^{-3}$ |
| Steel 45 | 700 | $5{,}2\cdot10^{-7}$ | $3{,}5\cdot10^{-7}$ | $8{,}8\cdot10^{-4}$ | $3{,}5\cdot10^{-3}$ |
| Al | 400 | $1{,}4\cdot10^{-4}$ | $3{,}5\cdot10^{-7}$ | $8{,}7\cdot10^{-4}$ | $3{,}5\cdot10^{-3}$ |
| Cu | 250 | $4{,}1\cdot10^{-3}$ | $5{,}1\cdot10^{-6}$ | $1{,}3\cdot10^{-2}$ | $5{,}1\cdot10^{-2}$ |

As may be seen from the Table, the accuracy of defect concentration determination by AE data is compared with accuracy of x-ray diffraction and electronic microscopy methods. The obtained values *c* also are in agreement with various estimations of critical defects concentration in a point V, received by other researchers [1]. So, in conformity with the destruction statistical theory the initiation of macrocrack occurs at a local concentration of voids $c \approx 10^{-2}$ - $10^{-3}$. It accords well with the experimental data observable at creep, in the course of lateral rolling, at another metallic materials test and with idea of concentrating criterion of destruction.

It should be noted that relation (1) implies a monotone increasing *c* from zero value, whereas in real material at point D are formed so much defects. In this manner the values of *c* given in Table I may be considered as lower bound of *c* estimation.

## References


1. Cheremskoi P.G., Slezov V.V., Betehtin V.I. Voids in solid body (in Russian). – Moscow: Energoatomizdat, 1990, 376 p.
2. Rybakova L.M. Mechanical relationships of metal destruction with bulk and surface plastic deformation (in Russian). – Problemy Mashinostroeniya I Nadezhnosti Mashin - 1993, No. 8, pp. 32–37.