ENERGY STORAGE RATE IN NON-HOMOGENEOUS DEFORMATION

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When a material deforms plastically, a part of mechanical energy w_p expended in the plastic deformation is converted into heat q_d while the remainder e_s is stored in the material. Thus

$$e_s = w_p - q_d . \quad (1)$$

The stored energy is an essential feature of the cold-worked state and represents the change in internal energy of the material. The measure of energy conversion at each instant of the deformation process is the rate of energy storage $\frac{de_s}{dw_p}$.

Deformation processes modify the temperature field of the strained specimen. At the first stage of plastic deformation the temperature distribution on the specimen surface is uniform what is usually used as an indicator of homogeneous deformation, on the macroscopic scale [1]. With the increase in strain the temperature distribution on the specimen surface becomes non-uniform what corresponds to non-homogeneous deformation. It is well known that before the fracture the strain hardening rate $\frac{d\sigma}{d\varepsilon}$ (σ is the yield stress and $\varepsilon = \ln(l/l_0)$ where l is the instantaneous length of gauge part of the specimen, and l_0 the initial length) rapidly decreases with strain because of damage mechanisms appearance [2]. The energy storage rate seems to be influenced by these mechanisms as well. As far as the authors are aware, there is no systematic work done to confront the strain hardening with the energy storage rate in the non-homogeneous deformation range. A mention to this problem is included in paper by Chrysochoos [3]. Some attempts have been made in present work to investigate a change in $\frac{de_s}{dw_p}$ with a change in $\frac{d\sigma}{d\varepsilon}$ during uniaxial tensile deformation of austenitic steels and to confront one with another.

Two groups of specimens made from austenitic steels 316L and 304L were strained by using the MTS-810 testing machine at the constant deformation rate $\dot{\varepsilon} = 4.3 \cdot 10^{-3}\ s^{-1}$. The steels were initially annealed at 1100 °C and water quenched. The dimensions of gauge part of specimens were 25 mm x 10 mm x 1.5 mm. In the course of deformation process, the tensile force, elongation and temperature distribution on the sample surface as functions of time were measured and recorded. The temperature distribution on the specimen surface was determined by IR camera. On the basis of the mechanical and thermo-mechanical characteristics, the strain hardening rate and the stored energy as the function of the plastic work were obtained.

For the homogeneous deformation range the experimental method of stored energy determination, proposed in previous works by Oliferuk et al. [1, 4] was employed. The energy w_p was found from the load versus elongation curve. The heat q_d was determined by simulating the process of specimen heating during deformation using a controlled electrical power supply in such a way that the temperature increase with time during the simulation was identical with that measured during tensile testing. The energy storage rate $\frac{de_s}{dw_p}$ was obtained by differentiating e_s as a function of w_p. The method makes possible to measure *in situ* the energy balance only under condition of homogeneous deformation**.**

The estimation of the energy storage rate $\frac{\Delta e_s}{\Delta w_p}$ during non-homogeneous deformation is based on comparison of the average temperature increment of deformed sample related to the given increment of the expanded energy (for example equal to 1 J) during a homogeneous deformation and during non-homogeneous one [5]. It has been shown in paper [5] that such approach allows us to estimate the highest value of the energy storage rate. The real rate of energy storage can not exceed this maximal value.

The results for both groups of specimens are shown in Fig. 1. It is seen that before the fracture the energy storage rate $\frac{\Delta e_s}{\Delta w_p}$ rapidly decreases with strain and then becomes negative for both groups of the tested specimens. This means that a part of energy stored during previous deformation begins to release. The energy storage rate $\frac{\Delta e_s}{\Delta w_p} = 0$ at

$\varepsilon = 0.36$ for the 316L steel and at $\varepsilon = 0.46$ for the 304L steel. It is easy to notice that the $\frac{\Delta e_s}{\Delta w_p} = 0$ nearly corresponds to the point on the stress-strain curve at which the Considère stability criterion $\frac{d\sigma}{d\varepsilon} = \sigma$ is satisfied at $\varepsilon = 0.35$ for the 316L steel and at $\varepsilon = 0.43$ for the 304L steel. Taking into account that the real rate of energy storage can not exceed the estimated maximal value the discrepancy between the point corresponding to Considère criterion and the point $\frac{\Delta e_s}{\Delta w_p} = 0$ can be even smaller. This result provides the physical confirmation of Considère criterion. The release of stored energy may be connected with evolution of damage mechanisms.

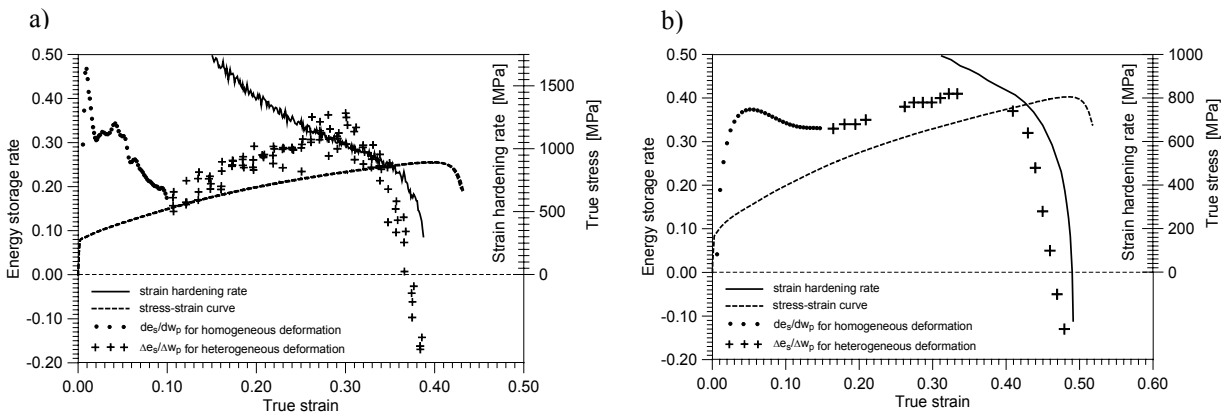

Fig. 1. The stress-strain curve, the energy storage rate and the strain hardening rate as a function of true strain for: a) the 316L austenitic steel (4 specimens), b) the 304L austenitic steel (1 specimen).

The amount of the energy storage rate $\frac{\Delta e_s}{\Delta w_p} = 0$ could be used as an indicator to describe the progressive predominance of damage leading to the fracture of a material.

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