Materials and Design 32 (2011) 1554–1558

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Short Communication

On the kinetics of localized plasticity domains emergent at the pre-failure stage of deformation process

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ARTICLE INFO

Article history:
Received 5 April 2010
Accepted 25 September 2010
Available online 1 October 2010

ABSTRACT

The behavior of localized plasticity domains occurring at the final stage of plastic flow process has been investigated. A series of runs was conducted on materials differing in crystal lattice type, which enabled establishment of the regular features exhibited by the flow process upon a transition to macroscopic necking and viscous failure. It is found that the most distinctive regularity is the occurrence of flow domains, which are moving in a concerted manner towards the pole of a bundle of domain trajectories plotted in the time–space co-ordinates. The deformation patterns are found to be related to the kinetics of nucleation and motion of localized plasticity fronts. The probable origin of the observed effects is considered.

1. Introduction

The theoretical findings by Aifantis [1–4], Estrin and co-workers [5], Evers and co-workers [6], Tanaka [7], Zaiser and Aifantis [8], Zbib and de la Rubia [9], which are validated experimentally by Zuev and Danilov [10], Zuev [11,12], Zuev and co-workers [13,14], testify that the plastic deformation tends to localize on the macro-scale level over the entire flow process. Various localized plasticity patterns would emerge in the deforming specimens, with the pattern type being determined by the work hardening law acting at the given flow stage.

Available experimental and theoretical evidence for plastic flow macro-localization suggests that localized plasticity inhomogeneities have a macro-scale of about 10^{-2} m. Thus a deforming medium would spontaneously separate into alternating deformed and undeformed domains (zones) as shown in Fig. 1. It is of importance that the emergence of stationary or mobile domains moving at rates in the range $10^{-5} < V < 10^{-4}$ m/s is determined by the work hardening law acting at the corresponding plastic flow stage.

It is well-known that the working stress σ and the plastic strain ε are related by the Ludwik equation (see, e.g. Honeycombe [15]) as

$$\sigma = \sigma_0 + \theta\varepsilon^n. \quad (1)$$

Here $\sigma_0 = const$; $\theta(\varepsilon) = d\sigma/d\varepsilon$ is the work hardening coefficient and $0 \leqslant n \leqslant 1$ is the hardening exponent. In the course of plastic flow the exponent n would gradually decrease, which enables one to distinguish a number of stages on the flow curve with the n value varying in a discrete way, as it was shown by Zuev et al. [13].

2. Experimental procedure and results

On the base of available experimental evidence [11,12], the quantitative characteristics of localized plastic flow process were determined for a wide range of commercially pure metals and alloys having FCC, BCC and HCP crystal lattice (see Table 1). It is found that the mechanical characteristics of materials and the shape of plastic flow curves obtained for the test specimens vary significantly, depending on chemical composition, grain size of polycrystalline materials and extension axis orientation of single crystals. In what follows the distinctive features common to all the investigated materials are discussed.

The investigations were carried on for flat specimens having gauge $50 \times 5 \times 1$ mm; these were tested in tension at a constant rate of about 6.5×10^{-5} s^{-1} in an Instron-1185 test machine at 300 K. The observations of localized plasticity domains illustrated in Fig. 1 were performed by the method of speckle photography [16]. The method is described in detail elsewhere [10]. Fig. 2a–d demonstrates typical examples of patterns observed for investigated materials. Analysis of the X–t diagrams presented in Fig. 2 permits estimation of domain's motion rates as $V = dX/dt$; the value n is defined with the help of Eq. (1). On the base of these data the following work hardening stages have been singled out on the flow curves obtained for investigated metals and alloys:

- linear work hardening stage for $n = 1$ ($V = const$);
- parabolic work hardening stage (Taylor's stage) for $n \approx ½$ ($V = 0$);
- pre-failure stage for n values in the range $0 < n < ½$ ($V \neq 0$).

The current study is mostly aimed at analyzing the evolution of localized plasticity domains at the pre-failure stage of deformation

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doi:10.1016/j.matdes.2010.09.031