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Work hardening behavior of prestrained steel in tensile and torsion tests

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The work hardening behavior of metals subjected to strain path changes is different from that in monotonic deformation. Such changes can also lead to transients in flow stress and in the strain hardening rate. The origin of these phenomena is the instability of the dislocation structure produced during the initial straining. Subsequent deformation under a different path involves a restructuring of the dislocations [1].

The effect of a change in the strain path on the behavior of prestrained aluminum alloys was studied by Wilson *et al*. [2]. Decreased or enhanced work hardening rates were observed at the beginning of the second stage of deformation. These effects were associated either with the reorientation of internal stresses or to the dissolution of the original dislocation structure and the formation of a new one.

Vieira and Fernandes [3] studied the influence of a double change in the strain path on the flow curve of copper sheets. The overall behavior depended more on the orientation relationship between the previous and the subsequent stage and less on the sequence of deformation. A high initial flow stress was usually followed by a low work hardening rate. The dislocation structure tended to correspond to the last mode of deformation.

A transient flow behavior can also be caused by a change in the strain rate. The association of changes in the strain path and in the strain rate was investigated by Bate [4]. The effect of a strain rate change on the work hardening of aluminum samples was cancelled when a large change in the deformation mode was imposed. The elimination of the rate sensitivity was associated with the disruption of the cell walls due to a change in the strain path.

The effects of a change in the strain path were evaluated in tension and torsion tests in this paper. The experiments were conducted in two and three stages and the results were compared with the flow curves from monotonic experiments.

The material was a low carbon steel (0.245%C; 0.407%Mn; 0.155%Si; 0.0076%S). The torsion and tension specimens, 3.10 mm in radius (R) and 44.70 mm in length (L), were annealed in vacuum at 1000 °C for 20 min and furnace cooled to room temperature.

The tests were performed at room temperature in a MTS servo hydraulic testing machine. The initial strain rate used in all experiments was $6.34 \times 10^{-2}\ s^{-1}$ [4, 5]. The samples were stored at ~ -5 °C between two stages of deformation.

Load (Q) and elongation (ΔL) were measured in tensile tests and torque (T) and angle of twist (θ) were measured in torsion tests. These data were converted into effective stress (σ) and strain (ε) using the following equations [6, 7]:

Tension (uniform strain range):

$$\sigma = \left[\frac{Q}{\pi R^2}\right]\left[1 + \frac{\Delta L}{L}\right] \tag{1}$$

$$\varepsilon = \ln\left[1 + \frac{\Delta L}{L}\right] \tag{2}$$

Torsion:

$$\sigma = \left[\frac{3.3\sqrt{3}T}{2\pi R}\right] \tag{3}$$

$$\varepsilon = \left[\frac{\theta R}{\sqrt{3}L}\right] \tag{4}$$

Work hardening rate was measured at different strain levels, based on the derivation of smoothed flow curves.

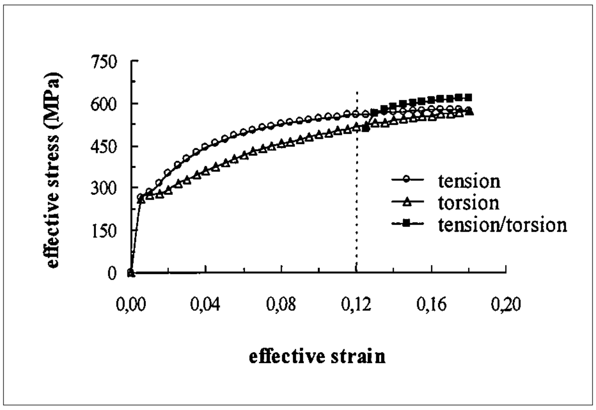

Figure 1 Curves strain-stress of steel: comparison of tensile, torsion and torsion after tensile prestrain.

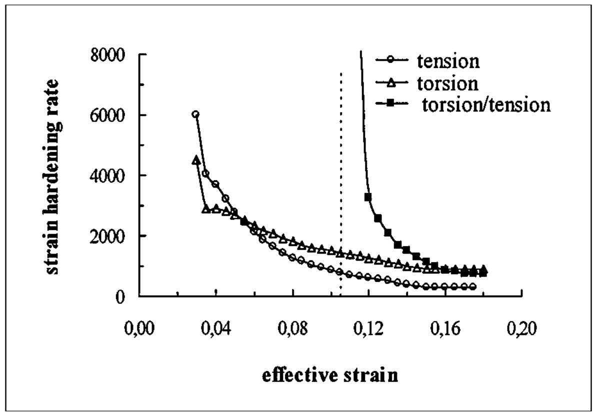

Figure 4 Effect of a torsion prestrain in tensile test on the relationship between the strain hardening rate and the effective strain.

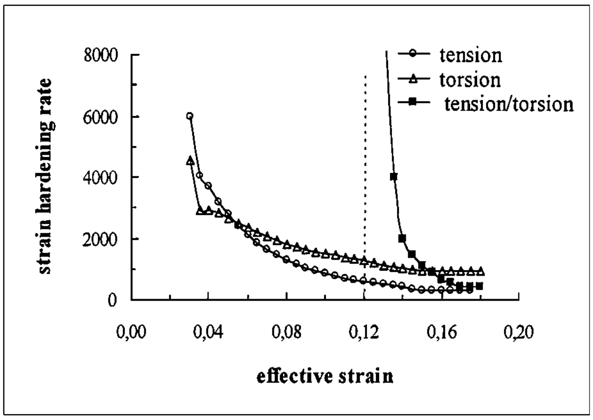

Figure 2 Effect of a tensile prestrain in torsion test on the relationship between the strain hardening rate and the effective strain.

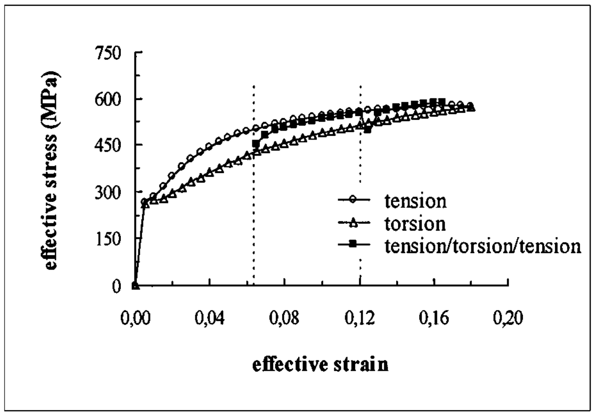

Figure 5 Curves strain-stress of steel: comparison of tensile, torsion and tensile after torsion prestrain.

The first sequence of strain paths is shown in Fig. 1, which also displays the monotonic tension and torsion stress-strain behavior. The specimen was prestrained ~0.12 in tension and then subjected to torsion. The change in the deformation mode from tension to torsion led to an initial flow stress similar to that observed in the fully monotonic torsion curve. The work hardening, however, was much higher (as confirmed in Fig. 2), leading to torsion flow stresses substantially above those from monotonic processing.

The initial flow stress after the path change from torsion to tension (Fig. 3) was much lower than for monotonic straining in tension. This is very different from the results in the tension to torsion experiments. On the other hand, the work hardening rate in the second deformation mode was higher than under fully monotonic straining in tension (see Fig. 4).

The third sequence of strain paths was a three stage experiment (Fig. 5). The specimen was prestrained ~0.065 in tension, twisted ~0.055 and then subjected again to tension. The tension-torsion behavior in the first stage led to results similar to those in Fig. 1, despite the difference in the strain level at the strain path change (0.12 in Fig. 1 and ~0.065 in Fig. 5). For the

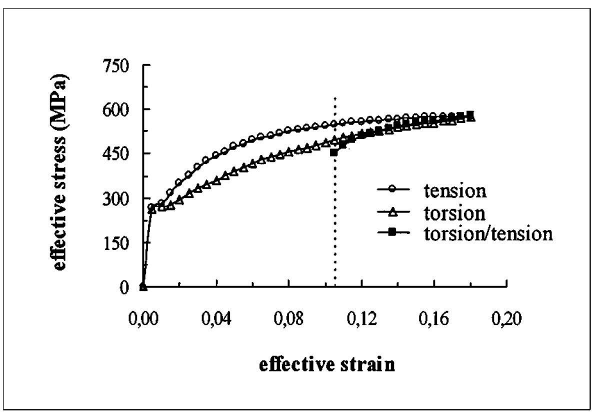

Figure 3 Curves strain-stress of steel: comparison of tensile, torsion and tensile after torsion prestrain.

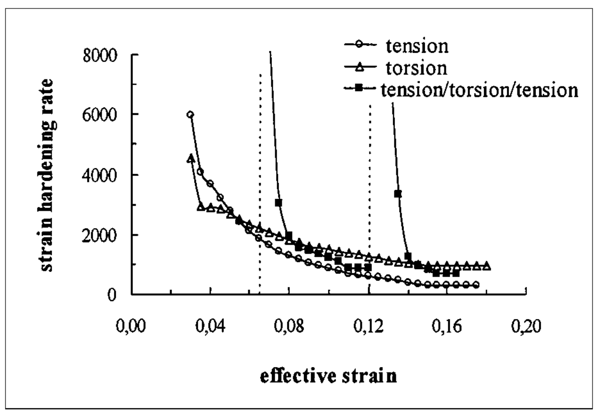

Figure 6 Effect of a tensile prestrain in torsion and tensile test on the relationship between the strain hardening rate and the effective strain.

second stage (torsion back to tension) the experiments were performed at about the same strain level as in Fig. 3 (∼0.105 in Figs. 3 and 5). The results are again similar, but the fall in work hardening rate in the third stage was faster than in the two stage experiment.

The present results indicate that the strain path history has a clear influence on the effective stress-strain curves of 0.24%C steel under torsion and tension.

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