Strain path dependency in metal plasticity

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Introduction

Most of the industrial metal forming processes are characterized by a complex deformation history, which is composed of successive strain paths that may vary considerably in their orientation (Figure 1).

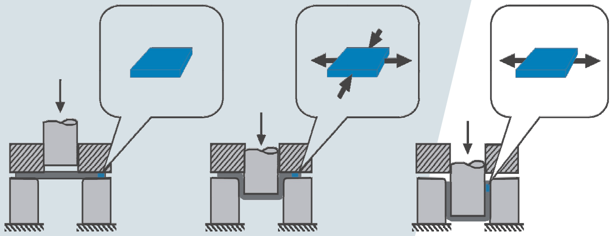
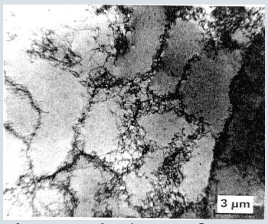


Figure 1 *Strain path change during deep drawing.*

Changes in strain path directions have a significant effect on the mechanical response of metals. Macroscopically the effect of a certain prestrain becomes manifest by an increased reloading yield stress, transient hardening, hardening recovery and failure shift. The effect is strongly anisotropic and depends on the amount of prestrain.
The aim of this project is to arrive at a material model that enables the numerical simulation of the effect of complex strain path histories in sheet metal forming processes, on the basis of evolving dislocation structures.

Cell structure



Strain path change effects physically originate from a complex microstructure evolution. The present work deals with the contribution of the evolution of dislocation cell structures to these effects.
The evolution of a cell structure under deformation is schematized in figure 2.

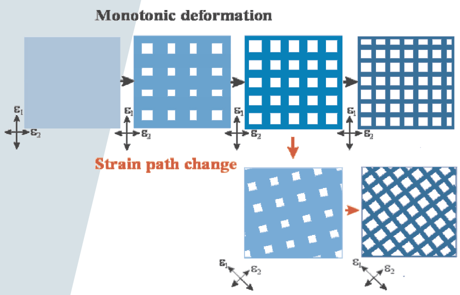


Figure 2 *Scheme of the cell structure evolution.*

Methods

The material with embedded cells is modelled to behave like a composite consisting of a periodic array of two types of elements: the hard cell walls and the soft cell interiors, distinguishable by high and low dislocation densities correspondingly. The evolution of cells (Fig. 2) is taken into account by rate equations for the cell size, the wall thickness and the dislocation density inside the walls.

Results

To validate the model sequences of two uniaxial tensile tests performed in different directions were considered. Figures 3 and 4 show stress-strain diagrams predicted by the model and experimentally obtained for prestrained copper. The curves are shown for different values of the prestrain ε_{pre} and for different angles ξ between the subsequent tensile directions.

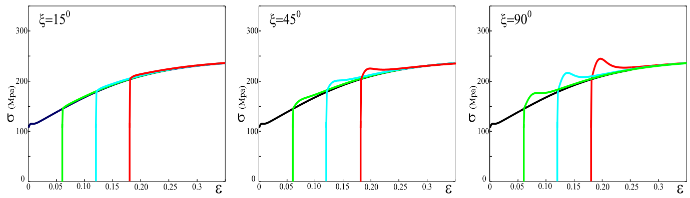


Figure 3 *Theoretical prediction,* $\varepsilon_{pre} = 0$; 0.06; 0.12; 0.18

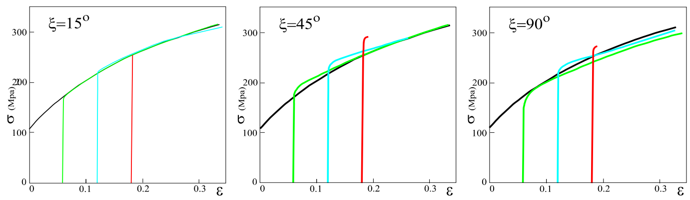


Figure 4 *Experimental results (Mughrabi H.,1986),* $\varepsilon_{pre} = 0$; 0.06; 0.12; 0.18

Conclusions

The model predicts

- ☐ increased reloading yield stress
- ☐ transient hardening
- ☐ influence of the amount of prestrain
- ☐ influence of the amplitude of the strain change

The prediction is accurate for complex deformations with a strain path change up to $45°$.
To improve the model for an adequate prediction of the deformation behavior after strong strain path changes, slip anisotropy should be taken into account.

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