Modelling and Simulation of the Portevin-Le Chatelier Effect

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Abstract. During deformations of an Al-Mg alloy (AA5754) dynamic strain aging occurs in a certain range of temperatures and strain-rates. A manifestation of this phenomenon, usually referred to as the Portevin-Le Chatelier (PLC) effect, consists of the occurrence of strain localisation bands accompanied by discontinuous yielding. The PLC effect is due to dynamic dislocation-solute interactions and results in negative strain-rate sensitivity of the flow stress. The PLC effect is detrimental to the surface quality of sheet metals and also affects the ductility of the material. Since the appearance of the PLC effect strongly depends on the tri-axiality of the stress state, three-dimensional finite element simulations are necessary in order to optimise metal forming operations. We present a geometrically non-linear material model which reproduces the main features of the PLC effect. The material parameters are identified by experimental data from tensile tests. Special emphasis is put on the prediction of the critical strain for the onset of the PLC effect and the statistical characteristics of the stress drop distribution.

1 Physical and Mechanical Characteristics of the PLC Effect

The material instability called PLC effect is a special type of dynamic strain aging, which is observed during deformation processes of, e.g., Al, Fe, Cu, and Ni base alloys. This effect describes the discontinuous yielding in strain localisation or shear bands (Fig. 1 left). While the deformation process initially begins in a stable manner, instantaneously shear bands appear in dependence of the deformation rate and temperature. For special alloys the critical strain for the onset of the PLC effect is minimal for special strain rates, while for smaller or greater strain rates the PLC effect occurs later in process, which is called inverse and normal behaviour, respectively (Fig. 1 right). Strain localisations produce a typical serrated material response in the stress strain curves of tensile tests. In stress driven tests steps are observed in the stress-strain curve. However, for strain rate driven tests the serrations have different statistical characteristics in dependence of the applied strain rate, and so one typically distinguishes three different types (Fig. 1 middle)

A: high strain rate - stochastic development of bands over the hole specimen
B: medium strain rate - hopping bands
C: low strain rate - the PLC-band goes continuously through the specimen

As a consequence, the material quality is reduced, which is manifested in a loss of ductility and a reduction of the surface quality of the deformed part. In Figure 1 (left)
we see that the waviness and roughness of the deformed specimen is increased, so expensive post processing is needed to ensure product quality. In the case of the inverse and normal behaviour of the critical strain, however, the production process can be optimised by avoiding these critical strain rates, where the onset of PLC effect is earliest in process.

2 Experimental Findings

To deal with the PLC effect, tensile tests have been performed. Polycrystalline flat specimens (gage length 21mm, width 5.1mm, thickness 1.55mm) have been