Warm forming of aluminum sheet: Physically based constitutive models

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Introduction

Correct description of the material behaviour is an extra challenge in simulation of the thermo-mechanical aluminium sheet forming process in automotive industry. To accurately model the deep drawing or stretching of aluminum sheet at elevated temperatures, the material model must account for varying strain, strain rate, temperature, and changing microstructure. Therefore, it is preferable to use physically based models that can take hold of the essential phenomena controlling the deformation based on the underlying physics of the deformation coupled to microstructure evolution. Also the model should still be tractable for large scale finite element simulations.

Figure 1 : Car body inner and outer panels.

Physically based models

The aim of the project is to implement the physically based model Alflow [1] for work hardening of aluminum alloys in the finite element code DiekA, which include the free variation of temperature and strain rate and the effect of dynamic strain ageing due to solutes on microstructural evolution and work hardening.

Alflow model

The model approach relies on multi parameter description for the microstructure evolution. At small strains the stored dislocations are arranged in a cell structure characterized by the cell size δ and the dislocation density within the cells ρ_i. At large strains the dynamic recovery of dislocation becomes important and the cell walls collapse into sub-boundaries of well defined misorientations, φ. Extensive presentations of the model are given in [1]. The microstructure evolution is covered by the following three differential equations:

$$\frac{d\rho_i}{d\gamma} = \frac{d\rho_i^+}{d\gamma} + \frac{d\rho_i^-}{d\gamma}, \quad \frac{d\delta}{d\gamma} = \frac{d\delta^-}{d\gamma} + \frac{d\delta^+}{d\gamma}, \quad \frac{d\varphi}{d\gamma} = \frac{d\varphi^+}{d\gamma} + \frac{d\varphi^-}{d\gamma}$$

Results

The Alflow model has been able to predict reliable tensile stress-strain data for 5754-O alloy, and also been able to represent the negative strain rate sensitivity due to Mg solutes at temperatures below 125°C. Cylindrical cup deep drawing simulations were performed at various temperatures and the punch force-displacement results compared with experiments [2] have been presented in Figure 2.

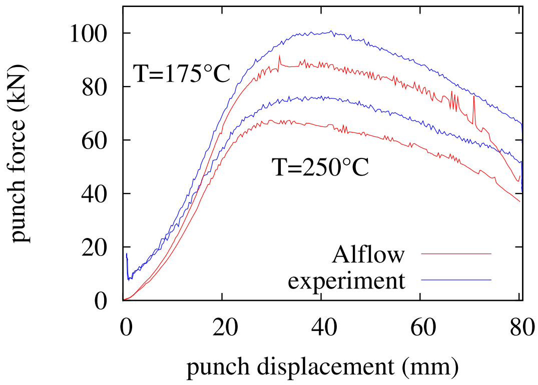

Figure 2 : Punch force-displacement curves.

References

1. E. Nes. Modelling of work hardening and stress saturationin FCC metals. *Prog. Mater. Sci. Forum*, 41, 129–193, (1998).

2. A. H. vd. Boogaard and J. Huétink. Simulation of aluminium sheet forming at elevated temperatures. *Comput. Methods Appl. Mech. Engrg.*, 195, 6691–6709 (2006).