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Study of limit strains for FCC and BCC sheet metal using polycrystal plasticity

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ABSTRACT

In this research, we analyze forming-limit strains of FCC and BCC materials using a viscoplastic self-consistent polycrystal model (VPSC) in conjunction with the Marciniak–Kuczynski (MK) approach. In particular, our work is focused on the theoretical analysis and comparison between FCC and BCC crystal structures made by Inal et al. [Inal, K., Neale, K.W., Aboutajeddine, A., 2005. Forming limit comparison for FCC and BCC sheets, International Journal of Plasticity, 21, 1255–1266]. These authors performed their simulations based on a generalized Taylor-type polycrystal model (MK-FC), finding a remarkably low forming-limit curve for the FCC material and an extremely high forming-limit curve for the BCC material, in the biaxial stretching range. We verified that our predictions are similar to Inal's results for both FCC and BCC materials when the MK-FC model is used. However, MK-VPSC calculations do not give such extreme values, and we believe that this theory predicts much more reliable results for both FCC and BCC crystallographic assumptions. We also found that localized necking depends on texture evolution in the vicinity of equi-biaxial stretching, through the sharpness of the predicted yield surface. Finally, it is shown that the MK-VPSC's predictions are in good agreement with experimental data for AA5182-O and a DQ-type steel-sheet metal.

1. Introduction

Formability of sheet metals can be characterized by the forming limit diagram (FLD) introduced by Keeler and Backofen, 1964. This concept has proved useful for representing conditions at the onset of sheet necking and now is a standard tool for characterizing the material forming behavior. The FLD represents, in one map, all combinations of critical-limit surface strains corresponding to failure. Within the FLD, a line called the forming-limit curve (FLC) marks the onset of local necking and divides strain space into safe and failure zones. The object of sheet-metal process design is to ensure that strains in the sheet do not approach this limit curve. Though the concept of the FLD is simple, a material's ability to deform plastically depends on a large number of coupled effects, making its experimental determination non trivial and a very time consuming procedure. As a result, considerable effort has recently been made to develop theoretical predictive models, based on the continuum theory of plasticity and different instability criteria. Among these, models enjoying particular success are those where the strain instability appears in the deformation process due to an imperfection already present in the material. In particular, Marciniak and Kuczynski (1967), developed probably the most influential approach for initiating localized necking. According to this model, an infinite sheet contains a local imperfection region, which is a band having an initial thickness less than that of the sheet. These authors showed that the presence of such an imperfection can lead to unstable deformation in the thinner region and subsequent localized necking and failure.

As Wu et al. (2005) pointed out, within the M–K framework, the influence of various constitutive features on FLDs has been explored using phenomenological plasticity models and crystal plasticity. Authors have tested the implementation of different yield criteria in the M–K model. In particular, Cao et al. (2000) predicted localized thinning of sheet metal alloys combining the M–K analysis with a general anisotropic yield criterion. Banabic and Dannenmann (2001) used the yield criterion proposed by Hill, 1993 for calculations of the limit strains in connection with Swift's instability condition for diffuse necking. Using the M–K theory, Butuc et al. (2002) investigated the performance of two non quadratic yield functions applicable to orthotropic sheet metals, Yld96 and BBC2000, for making forming-limit predictions. Later, Butuc et al. (2003) conducted necking simulations based on a M–K defect using the Yld96 yield function and a combined model of texture and strain-path induced anisotropy. They found that, for a BH steel sheet when the strain path is complex, the microstructural hardening model with a texture-based yield locus is superior to the phenomenological approaches. However, they did not take texture evolution into account. Ávila and Vieira (2003) proposed an algorithm for the prediction of the right side of the FLD using the methodology proposed by Marciniak and Kuczynski, with five different yield criteria. They concluded that the type of yield criteria used in

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