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International Journal of Plasticity 22 (2006) 342–373

INTERNATIONAL JOURNAL OF Plasticity

www.elsevier.com/locate/ijplas

Forming of aluminum alloys at elevated temperatures – Part 2: Numerical modeling and experimental verification

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Received 30 January 2005
Available online 31 May 2005

Abstract

The temperature-dependent Barlat YLD96 anisotropic yield function developed previously [Forming of aluminum alloys at elevated temperatures – Part 1: Material characterization. Int. J. Plasticity, 2005a] was applied to the forming simulation of AA3003-H111 aluminum alloy sheets. The cutting-plane algorithm for the integration of a general class of elasto-plastic constitutive models was used to implement this yield function into the commercial FEM code LS-Dyna as a user material subroutine (UMAT). The temperature-dependent material model was used to simulate the coupled thermo-mechanical finite element analysis of the stamping of an aluminum sheet using a hemispherical punch under the pure stretch boundary condition. In order to evaluate the accuracy of the UMAT's ability to predict both forming behavior and failure locations, simulation results were compared with experimental data performed at several elevated temperatures. Forming limit diagrams (FLDs) were developed for the AA3003-H111 at several elevated temperatures using the M-K model in order to predict the location of the failure in the numerical simulations. The favorable comparison found between the numerical and experimental data shows that a promising future exists for the development of more accurate temperature-dependent yield functions to apply to thermo-hydroforming process.

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0749-6419/$ - see front matter
doi:10.1016/j.ijplas.2005.03.006

Keywords: Thermo-mechanical; Temperature; Material anisotropy; UMAT, Cutting-plane algorithm; Yield function, FLD

1. Introduction

Numerical analysis is critically important to understanding the complex deformation mechanics that occur during sheet forming processes. Finite element analysis (FEA) and simulations are used in automotive design and formability processes to predict deformation behavior accurately during stamping operations (Chung et al., 1992, 1996). Although available commercial FEA codes offer a library of material models applicable to a variety of applications, they often do not offer highly specialized material models developed for a specific material and process. Also, very few available material models are capable of handling complex forming simulations that incorporate the temperature-dependence of materials. The process becomes increasingly complicated when materials exhibit anisotropic behavior. Currently available commercial codes do not offer material models that are appropriate for simulating the thermo-mechanical forming processes of anisotropic materials such as aluminum sheet alloys. The importance of using an appropriate material model for aluminum during hydroforming processes using Barlat's YLD96 model have been emphasized previously (Zampaloni et al., 2003; Abedrabbo et al., 2005b).

Use of anisotropic material models in FEA requires thorough material characterization under multiple loading conditions. Since the material anisotropy and hardening behavior, i.e., material response to loading conditions, change with elevated temperatures, the anisotropy coefficients and the hardening behavior must be determined as a function of temperature to perform accurate thermo-mechanical numerical analysis for these materials.

Prior research available for simulation of warm forming processes focuses only on the effect of elevated temperature on the evolution of the flow (hardening) stress. These include Li and Ghosh (2003), Ayres (1979), Ayres and Wenner (1979), Painter and Pearce (1980), Takata et al. (2000), Naka et al. (2001) and Boogaard et al. (2001). The evolution of the yield surface of aluminum alloys as a function of temperature and the effect on the anisotropy coefficients were not fully explored. In most cases, either Hill's 1948 model (Hill, 1948) or the von Mises isotropic yield functions was used. Boogaard et al. (2001) characterized the behavior of AA5754-O for which two types of functions representing the flow stress were used: the modified power law model and the Bergström model. The yield surface used in this case was assumed to remain constant with respect to changing temperatures. Only the coefficients of the power law model were curve-fit exponentially as a function of temperature. The predictions of the material model, however, underestimated the values of the punch load in both models (power law and Bergström models). Čanađija and Brnić (2004) presented an associative coupled thermoplasticity model for *J2* plasticity model to represent internal heat generated due to plastic deformation. In it, temperature-dependent material parameters developed were used.