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Anisotropic responses, constitutive modeling and the effects of strain-rate and temperature on the formability of an aluminum alloy

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ABSTRACT

Finite deformation anisotropic responses of AA5182-O, over a wide range of strain-rates (10^{-4} to $10^{0}\,s^{-1}$) and temperatures (293–473 K) are presented. The plastic anisotropy parameters were experimentally determined from tensile experiments using specimens from sheet material. Using the experimental results under plane stress conditions, the anisotropy coefficients for Barlat's yield function (YLD96) were calculated at different strain-rates and temperatures. The correlations obtained from YLD96 are in good agreement with the observed experimental results. The strain-rate sensitivity of AA5182-O alloy changed from negative at 293 K to positive at 473 K. Khan–Huang–Liang (KHL) constitutive model is shown to correlate the observed strain-rate and temperature dependent responses reasonably well. The material parameters were obtained from the experimental responses along the rolling direction (RD) of the sheet. Marciniak and Kuckzinsky (M–K) theory was used to obtain the theoretical strain and stress-based forming limit curves (FLCs) at different strain-rates and temperatures. The experimental result from the published literature is compared with the FLCs from the current study.

1. Introduction

The increasing demand for fuel efficient vehicles without compromising on their strength and safety of passengers resulted in the use of aluminum alloys in structural and certain non-structural components that were earlier manufactured using steel. Aluminum alloys have high strength to weight ratio; however, they exhibit poor formability at room temperature in comparison to usual steels in automotive industry. Hence, enhancing the formability of aluminum alloys is currently an area of considerable interest in the industry. The amount of formability of sheet metal is usually referred to as the forming limit. It is defined as the state, during the forming operation at which a localized thinning of the sheet initiates, eventually leading to its failure (Stoughton, 2000). Several studies have been performed to understand the formability of aluminum alloys (Wilson, 1988; Cole and Sherman, 1995; Barlat et al., 1997; Lang et al., 2007; Lademo et al., 2008). Li and Ghosh (2003) observed that the formability of aluminum alloy sheets could be greatly improved by warm forming. However, this process increases the manufacturing cost. Finite element analyses and simulations are being used to characterize the material properties during the forming processes. These simulations require an accurate anisotropic yield function and a constitutive equation that can predict the material response with reasonable accuracy.

The formability of sheet metal is commonly evaluated from strain analysis using a forming limit diagram (FLD). Keeler and Backhofen (1964) and Goodwin (1968) introduced the concept of FLD. The technique consists of etching a circular grid on the surface of the sheet metal, which is then stretched to failure, using a hemispherical or a circular punch with a flat

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