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A new analytical theory for earing generated from anisotropic plasticity

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ABSTRACT

Commercial canmaking processes include drawing, redrawing and several ironing operations. It is experimentally observed that during the drawing and redrawing processes earing develops, but during the ironing processes earing is reduced. It is essential to understand the earing mechanism during drawing and ironing for an advanced material modeling. A new analytical approach that relates the earing profile to *r*-value and yield stress directionalities is presented in this work. The analytical formula is based on the exact integration of the logarithmic strain. The derivation is for a cylindrical cup under the plane stress condition based on rigid perfect plasticity while force equilibrium is not considered. The earing profile is obtained solely from anisotropic plastic properties in simple tension. The earing mechanism is explained from the present theory with explicit formulae. It has been proved that earing is the combination of the contributions from *r*-value and yield stress directionalities. From a directionality (*y*-axis) vs. angle from the rolling (*x*-axis) plot, the earing profile is generated to be a scaled mirror image of the *r*-value directionality with respect to 90° ($x = 90$) and also a scaled mirror image of the yield stress directionality with respect to the reference yield stress ($y = 1$). Three different materials (Al–5% Mg alloy, AA 2090-T3 and AA 3104 RPDT control coil) are considered for verification purposes. This approach provides a fundamental basis for understanding the earing mechanism. In practice, the present theory is also very useful for the prediction of the earing profile of a drawn and iron cup and its related convolute cut-edge design for an earless cup.

1. Introduction

Generally, *r*-value and stress directionalities are the key input parameters for phenomenological constitutive models. These anisotropies are directly related to earing of a drawn cup. For example, Hill's (1948) yield function (Hill, 1948) accepts either *r*-values or yield stresses along 0°, 45°, 90° as anisotropy parameters, while Yld91 (Barlat et al., 1991a) uses only the yield stress values for the balanced biaxial value as well as along the three major directions (0°, 45°, 90°). The Yld2000 model (Barlat et al., 2003) accommodates both *r*-value and stress directionalities for the three uniaxial and balanced biaxial directions. The Yld2004 model (Barlat et al., 2005) utilizes *r*-value and yield stress data every 15° from the rolling as well as a biaxial datum. Thus, based on the combination of these directionalities, the Yld2004 model is able to predict more than four ears in cup drawing as shown in Yoon et al. (2006). Characteristics for linear transformation yield functions are well summarized at Barlat et al. (2007). It has been proved that a good prediction of these material directionalities controls the overall accuracy of the earing profile. However, the exact mechanism as to how much *r*-value and yield stress directionalities contribute to earing profile respectively has not been established.

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