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Effects of texture on shear band formation in plane strain tension/compression and bending

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Abstract

In this study, effects of typical texture components observed in rolled aluminum alloy sheets on shear band formation in plane strain tension/compression and bending are systematically studied. The material response is described by a generalized Taylor-type polycrystal model, in which each grain is characterized in terms of an elastic–viscoplastic continuum slip constitutive relation. First, a simple model analysis in which the shear band is assumed to occur in a weaker thin slice of material is performed. From this simple model analysis, two important quantities regarding shear band formation are obtained: i.e. the critical strain at the onset of shear banding and the corresponding orientation of shear band. Second, the shear band development in plane strain tension/compression is analyzed by the finite element method. Predictability of the finite element analysis is compared to that of the simple model analysis. Third, shear band developments in plane strain pure bending of a sheet specimen with the typical textures are studied. Regions near the surfaces in a bent sheet specimen are approximately subjected to plane strain tension or compression. From this viewpoint, the bendability of a sheet specimen may be evaluated, using the knowledge regarding shear band formation in plane strain tension/compression. To confirm this and to encompass overall deformation of a bent sheet specimen, including shear bands, finite element analyses of plane strain pure bending are carried out, and the predicted shear band formation in bent specimens is compared to that in the tension/compression problem. Finally, the present results are compared to previous related studies, and the efficiency of the present method for materials design in future is discussed.

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1. Introduction

When formability of a metal sheet subjected to in-plane stretching is discussed, an onset of sheet necking in the form of a locally reduced thickness is used as a *forming limit* criterion, and a simplified theoretical treatment of this phenomenon is usually made under plane stress assumption. The onset of sheet necking is said to occur when a global elastic unloading starts outside the neck region. But, the occurrence of sheet necking does not necessarily mean final fracture. In some metal sheets, the material inside the neck deforms plastically far beyond the onset of necking, and shear band formation across the thickness and with some inclination to the surface of the sheet leads to real fracture. For other materials, the shear band appears right after or almost together with the neck formation, and no clear neck is detected at the observation of the broken specimen. Thus, in order to know accurately when the material is actually broken, studies of shear band formation are critically important. The high amount of research regarding the shear band is an indication of the importance and the difficulty in understanding the phenomenon. To study the shear band development in a material sheet, a plane stress assumption is no longer sufficient, and a three-dimensional analysis has to be carried out.

During bending of a sheet specimen, a 'diffuse neck' type deformation cannot develop due to constraints on straining. Usually, stable bending of a sheet specimen is interrupted by the shear band formation at a certain stage of bending. That is, the bendability of sheet metal is directly governed by the shear band formation. Currently, aluminum alloy sheets with higher bendability are strongly desired in the automotive industry for the so-called 'hemming' type of forming. The higher bendability is also requested from industries of computer and electronics.

One of the principal factors that affects the formability of polycrystalline metal sheets is considered to be the crystallographic texture. The shear band development in a textured polycrystal subjected to plane strain tension/biaxial tension has been studied (Tvergaard and Needleman, 1993). A few studies on bendability of textured sheet specimens, which is governed by the shear band formation, have been carried out (Becker, 1992; Dao and Li, 2001). In these shear band studies, however, the effect of texture has not been investigated systematically: i.e. results for an artificial rolling texture produced by a plane strain compression were simply compared to a result for a random texture (Tvergaard and Needleman, 1993; Dao and Li, 2001), and only one calculation with a real texture of an aluminum alloy sheet was carried out by Becker (1992). Very recently, systematic studies of the effect of textures on sheet necking under plane stress conditions have been initiated (Wu et al., 2004; Kuroda and Ikawa, 2004; Kuroda, 2005).

Numerical studies for shear band have been comprehensively carried out. For hardening materials under isothermal states, effects of vertex-type of response on shear banding have been investigated (e.g. Hutchinson and Tvergaard, 1981; Triantafyllidis et al., 1982; Kuroda and Tvergaard, 2001a), while effects of thermal softening on shear banding have been widely studied also (e.g. Batra and Liu, 1989; Zhu and Batra, 1993; Batra and Zhu, 1995; Schoenfeld and Wright, 2003; Batra and Wei, 2006). Very recently, shear band