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PII: S0020-7403(14)00281-1
DOI: http://dx.doi.org/10.1016/j.ijmecsci.2014.08.016
Reference: MS2799

To appear in: *International Journal of Mechanical Sciences*

Received date: 26 March 2014
Revised date: 18 July 2014
Accepted date: 19 August 2014

Cite this article as: Feifei Zhang, Jieshi Chen, Jun Chen, Xinhai Zhu, Forming limit model evaluation for anisotropic sheet metals under through-thickness normal stress, *International Journal of Mechanical Sciences*, http://dx.doi.org/10.1016/j.ijmecsci.2014.08.016

Forming limit model evaluation for anisotropic sheet metals under through-thickness normal stress

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ABSTRACT

M-K method has been used with Barlat's 1989 anisotropic yield surface to predicate forming limit to study the effect of the normal stress and material anisotropy. The 3D stress state is converted to plane-stress state according to the hypothesis that hydrostatic stress has no effect on plastic deformation. The predicted forming limits correlate well with experimental data for AA5XXX under plane-stress condition and AA6011 aluminum alloy under three-dimension stress condition. Analyses show that normal stress increases the forming limit described both in strain space and in stress space. Moreover, the sensitivity of forming limit curve to normal stress is associated with the material's hardening effect.

Keywords: Forming limit; Normal stress; M-K model; Barlat's 1989 yield function

1. Introduction

The classical theoretical models of necking in thin metallic sheets assume a state of plane-stress loading. However, during some sheet metal forming processes, such as hydroforming, the sheet is also subjected to a significant normal stress along thickness direction which influences the forming limit. Accordingly, it is necessary to take into account the normal stress in FLD prediction and many researches have been conducted in this field

Ragab and Baudelet [1] performed two stretching methods to determine the forming limit curves, and they found the one that was bulged by lateral hydrostatic pressure produced higher limit stains than the one stretched by tensile forces lying in the plane of the sheet. Their study proved that the out-of-plane normal stress could improve the forming limit of sheet metals. Fuchs et al. [2] carried out some tube bulge experiments, and they observed that the forming limit of the sheet increased when high hydraulic pressure was imposed on both sides of the sheet metal. Wang et al. [3] also studied the double sided high pressure (DSHP) process, and it was found that the formability was increased because the presence of the external pressure increased the magnitude of normal stress. Experimental results showed that the expansion ratio of 5A02 aluminum alloy tube was about 10.6% when there was no external pressure, however, the expansion ratio of the tube was up to 13.5% when the external pressure was 100MPa.

Besides the experimental studies mentioned above, many researchers have been devoted to theoretical research of the effect of normal stress on forming limit. Wu et al. [4] proved that the hydrostatic pressure increases the uniform tensile strain or the necking strain by carrying out a detailed analysis of uniaxial tension under superimposed hydrostatic pressure. Moreover, the hydrostatic pressure increases the sheet metal limit strains for any strain path when the hydrostatic pressure is relatively low. However, when very high hydrostatic pressure is superimposed, necking may not be considered as the relevant failure mechanism. In order to take into account the influence of the normal stress on forming limit, Smith et al. [5] studied six formability models for suitability in finite element modeling of DSHP process. The analysis showed that the forming limit models which captured the effect of normal stress were mostly suitable for formability assessment of DSHP process.

In recent years, several new forming limit models that account for the influence of the normal stress

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