International Journal of Plasticity 27 (2011) 82–101

Contents lists available at ScienceDirect

International Journal of Plasticity

journal homepage: www.elsevier.com/locate/ijplas

Experimental evaluation and constitutive modeling of non-proportional deformation for asymmetric steels

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A R T I C L E I N F O

Article history:
Received 6 August 2009
Received in final revised form 31 March 2010
Available online 9 April 2010

Keywords:
Two-stage forming
Non-proportional deformation
Tension–compression asymmetry
Combined isotropic–kinematic hardening

A B S T R A C T

Recently non-proportional deformation has received increased attention from researchers working in the area of experimental and computational modeling of metal deformation. However, most of them are numerical in nature with limited experimental data available, making it further difficult to model non-proportional deformation. In the present work, two-stage uniaxial tests, along with uniaxial cyclic and biaxial tests for different stress ratios, have been performed to evaluate deformation behavior of ultra-low carbon high strength automotive steel. Behaviors like cross-effect and hardening stagnation, which are attributed to the evolution of complex dislocation structures, were observed in this steel. It was also noticed that this steel exhibits tension–compression asymmetry. As for constitutive modeling, a modified asymmetric yield function is proposed to be used with a combined isotropic–kinematic hardening model. Also methods to account for the hardening stagnation during reverse loading and the cross-effect during two-stage deformation are proposed. The resulting constitutive model showed reasonably good agreement with experimental results.

1. Introduction

High strength and advanced high strength steels are finding wide applications in the automotive industry. The main motivation for such increased usage is to reduce vehicle weight with improved safety. However, such steels have their own drawbacks like lower formability and large springback. If such problems are properly predicted in advance, it may be possible for a die designer to take remedial action during the die design stage. However, for predicting such behaviors effectively, it is required to evaluate the deformation behavior under non-proportional deformation conditions and develop constitutive equations suitable for predicting the observed behaviors (Hill, 2000; Kuwabara, 2007).

In-plane uniaxial tension–compression cyclic tests were performed by Kuwabara et al. (1995, 2009), Yoshida et al. (2002), Lee et al. (2005), Boger et al. (2005) and Cao et al. (2009). Yoshida et al. (2002) performed the tests by sandwiching a number of specimens together whereas Lee et al. (2005) and Boger et al. (2005) used solid flat plates as buckling constraints. Kuwabara et al. (1995, 2009) performed tension–compression tests using comb-shaped dies whereas Cao et al. (2009) designed a special wedge type fixture for carrying out tension–compression tests on thin sheets. It has been commonly observed, during uniaxial cyclic tests, there is early reverse yielding (the Bauschinger effect) accompanied by sharp initial

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0749-6419/$ - see front matter
doi:10.1016/j.ijplas.2010.04.002