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Evolving hardening behaviors of high strength steel sheets under altered loading paths

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Abstract

In this work, the subsequent yield loci of the given DP steel sheets were experimentally determined by conducting biaxial tensile tests with pre-strained cruciform specimens. The results revealed that distortional hardening behavior, which has been previously discovered and calibrated under proportional loading conditions only, still exist in the complex loading conditions. Moreover, the expanding and translating of the yield loci was non-neglectable, which means the isotropic and kinematic hardening should be considered. Therefore, the combined isotropic-kinematic-distortional hardening model was proposed to calibrate the evolving hardening behaviors of the given sheet metals. Afterwards, the proposed model, together with other hardening models, were programmed as user subroutines UMAT and VUMAT in ABAQUS respectively. The V-bending tests and FE simulations were then conducted to evaluate the springback predicting precision with proposed model.

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Keywords: High strength steel; Evolving hardening behavior; Pre-strained biaxial tensile test; FEM; Springback prediction

1. Introduction

In the contemporary automobile industry, traditional materials are being replaced by steel with higher strength and light metals with lower stiffness aiming to pursue weight reduction and collision-safe performance.

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Nevertheless, high strength and low stiffness are the two major factors which significantly contributing to the increase of springback in the sheet metal forming [1]. One common method is to consider springback compensation in the tool designing stage, which heavily relies on the accurate prediction of springback. Finite Element Method (FEM) is a practical numerical method in predicting the springback of the press forming, yet its precision strongly depends on the adopted constitutive model, especially the hardening model component.

From phenomenological perspective, four kinds of elementary hardening types could be distinguished: isotropic, kinematic, rotational and distortional hardening [2]. For isotropic and kinematic hardening models, the shape of the subsequent yield surface is considered to remain the same. However, several experimental evidences have indicated that the shape of the experimental yield surfaces for some sheet metals (e.g. steel, brass and aluminum alloys [3]) would be changed during the plastic deformation, mainly because of the materials' texture evolution in the micro-scale. For the purpose of calibrating this yield surface distorting behavior, some distortional hardening models were proposed. For instance, Plunkett et al. [4] introduced variable anisotropic parameters to the CPB06ex3 yield criterion aiming to describe the strong evolving anisotropy of the high-purity zirconium during the plastic dissipation. The anisotropic parameters in this model were considered as the piecewise liner function expressed in terms of equivalent plastic strain. Similar approaches were also proposed by Ghaffari Tari et al. [5], etc.

In the previous work [6], the distortional hardening behavior of the DP steel sheets was discovered and calibrated with proposed distortional hardening model. Nevertheless, as discussed in Ref. [6], the proposed model was developed and verified in the proportional loading condition only. The validity of the proposed model under complex loading paths is still needed to be verified. In this work, the subsequent yield loci of the DP steel sheets were experimentally obtained by conducting biaxial tensile tests with pre-strained cruciform specimens. The results revealed that the distortional hardening behavior still exist in the complex loading conditions. Moreover, the expanding and translating of the yield loci was non-neglectable, which means the isotropic and kinematic hardening should be considered. Therefore, the combined isotropic-kinematic-distortional hardening model was proposed. Afterwards, The V-bending tests and simulations were conducted to evaluate the springback predicting precision with proposed model.

2. Materials and experiments

2.1. Materials and testing apparatus

A series of high strength DP steel sheets with different tensile strength, produced by BaoSteel Group, were investigated in this work due to their widely applications in automobile industry, of which the mechanical properties are listed in Ref. [6].

The equipment comprised a biaxial loading machine, hydraulic control panel and PLC unit, as shown in Fig. 1(a). The geometry of specimen utilized in the biaxial tensile tests was presented in Fig. 1(b). This kind of specimen with slitted arms could provide much lower shear stress component in the concerned central area. In order to evaluate the experimental yield loci of the orthotropic materials in principal stress space, the arms of the specimen should be parallel to the RD (rolling direction) and TD (transverse direction) of the cold-rolled sheets.

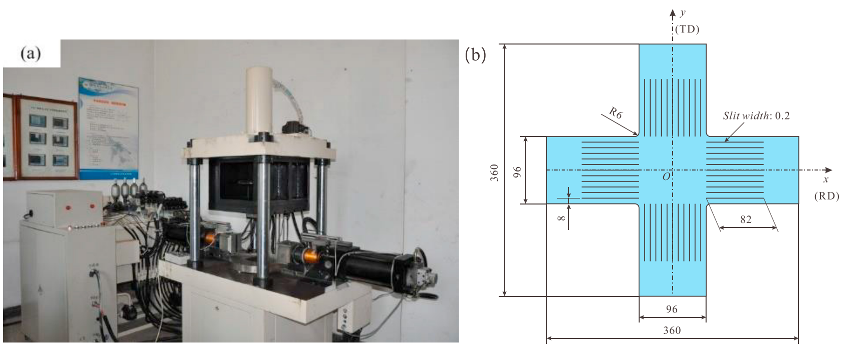

Fig. 1. (a) The Biaxial tensile testing apparatus; (b) Geometry of the cruciform specimen (dimensions in mm)