Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 207 (2017) 60–65

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on the Technology of Plasticity, ICTP 2017, 17-22 September 2017, Cambridge, United Kingdom

# Towards prediction of springback in deep drawing using a micromechanical modeling scheme

N. Vajragupta[a]*, H. ul Hassan[a], A. Hartmaier[a]

[a]Interdisciplinary Centre for Advanced Materials Simulation (ICAMS), Ruhr-Universität Bochum, Universitätsstr. 150, D-44801 Bochum, Germany

---

## Abstract

Deep drawing is one of the most commonly used sheet metal forming processes, which can produce metal parts at a high rate. One of the major problems in deep drawing is springback, which is mainly elastic deformation occurring when the tool is removed. The focus of this work is the prediction of springback in deep drawing for DC04 steel using a micromechanical modeling scheme. A novel method is used for the characterization of material that leads to cyclic stress-strain curve. Simulations are performed with the Yoshida Uemori (YU) model for the prediction of springback for a U draw-bend geometry. The maximum deviation between the geometries of experiment and the springback simulation for hat geometry is 2.2 mm. It is shown that this micromechanical modeling scheme allows us to relate the influence of the microstructure to the springback prediction.

Peer-review under responsibility of the scientific committee of the International Conference on the Technology of Plasticity.

*Keywords:* Deep drawing; Springback; Micromechanical modeling; Representative volume element; Yoshida-Uemori model; Virtual microstructures; nonlocal crystal plasticity finite element method

---

## 1. Introduction

Deep drawing is one of the most commonly used sheet metal forming processes. One of the major problems in deep drawing is springback, which is mainly elastic deformation occurring when the tool is removed. As pointed out

---

* Corresponding author. Tel.: +49-234-32-22417; fax: +49-234-321-498.
*E-mail address:* napat.vajragupta@rub.de

1877-7058 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the International Conference on the Technology of Plasticity.
10.1016/j.proeng.2017.10.739

by many researchers, the final shape of the part depends on the amount of elastic energy stored during the process of sheet metal forming [1]. To accurately predict springback in sheet metal forming, it is necessary to develop and to apply appropriate work hardening models including isotropic and kinematic hardening contributions [2]. Yoshida et al. [3] proposed a material model which incorporates the variation in elastic modulus, transient softening, kinematic hardening and the Bauschinger effect based on the cyclic tension- compression test at large strains. This model is based on the two surface modeling scheme i.e. a yield surface moves kinematically within a bounding surface. Kinematic hardening is assumed for the yield surface and mixed isotropic-kinematic hardening for the bounding surface. This combination of isotropic and non-linear kinematic hardening is usually employed for the accurate prediction of the Bauschinger behavior of material under cyclic loading.

To determine the material parameters of such hardening models, cyclic stress-strain curves are required including load reversals at a sufficient plastic strain under both, tension and compression. There are several experimental guidelines that can be used to determine these parameters [4, 5]. Each test has its limitations of either buckling [4] during compression or non-availability of stress-strain data, as for bending tests [5]. Furthermore, there is no immediate possibility to take microstructural influence into account. To overcome these problems, we propose the micromechanical modeling approach. This modeling scheme aims at predicting macroscopic mechanical behavior from simulating microstructure models and homogenizing their results. Thus, macroscopic stress and strain response can be obtained and used to parameterize the kinematic hardening model. In this way, the finite element simulation of microstructures can be considered as a virtual mechanical lab in which data for the parameterization of the YU model is produced.

The objective of this work is to apply micromechanical modeling to predict the springback in deep drawing of DC04 steel sheets. This modeling scheme involves several steps including generation of the microstructure model, or representative volume element (RVE), mimicking the real microstructure of DC04 steel (section 2), implementation of a nonlocal crystal plasticity model along with an appropriate parameterization technique to accurately capture the deformation behavior of a polycrystal (section 3), determination of the Yoshida-Uemori (YU) model parameters from tension-compression simulations of the RVE and, finally, springback simulation in deep drawing (section 4).

## 2. RVE generation using the dynamic microstructure generator

For this work, a quasi-2D RVE is generated using the dynamic microstructure generator (DMG) method [6]. This method couples particle simulations in the simulation package Lammps [7] with radical Voronoi tessellation in the open-source software Voro++ [8] to optimize the size distribution of grains with respect to a given microstructure. In the first step, size of given numbers of (spherical) grains are predefined to mimic a given grain size distribution. The grains are randomly distributed into a rather volume which allows free movement of spheres under a repulsive potential and avoid their overlapping. Radical Voronoi tessellations are performed with the positions of the spherical grains as centers. The volume of the simulations box is continuously reduced, which results is grain size distributions with smaller average grain sizes and, finally, the volume that shows the optimal agreement between simulated and targeted grain size distribution is selected as RVE, with which the further simulations of the mechanical behavior are performed. To obtain a high-quality mesh for a periodic structure, the shape to the RVE generated using the DMG is rugged, which leaves grains intact. Cutting grains to obtain a straight edges for the simulation box, would results in a large number of very distorted finite elements.

To mimic the microstructure of DC04 steel, the target grain size distribution is defined via a log-normal distribution with average grain diameter of 50 μm and a standard deviation of 2 μm [9]. An RVE of 100 grains is generated as illustrated in Fig. 1a. To obtain a quasi-3D RVE necessary for crystal plasticity modeling, the geometry of 2D RVE is extruded for 2 μm into the out-of-plane direction and meshed with 8 nodes linear brick element (C3D8). This RVE consists of 9796 elements. No texture has been observed in the DC04 steel used for the experimental characterization [10], hence, a random orientation distribution is assigned to the grains of the RVE.