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MATERIAL CHARACTERIZATION FOR SIMULATION OF SHEET METAL FORMING

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Summary: *Advanced material models from the Chaboche family are well suited to cover spring-back effects and strain rate sensitivity in sheet metal forming simulations. Experimental techniques (such as tension-compression tests and other tests), parameter identification, and applications to real parts will be presented together with first steps towards "virtual materials testing" by means of texture simulations. Materials investigated range from different mild and high strength steels to magnesium sheet tested at elevated temperatures.*

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1 INTRODUCTION

The ambition to reduce development time and costs in the metal forming industry has led to a wide application of finite element (FE) codes. Commercial FE-programs for sheet forming simulation give good results in terms of formability, strain distribution, wrinkling etc. Springback, however, remains a phenomenon often reported as being difficult to simulate. There are certain aspects which make springback especially critical for sheet metal forming. So, even small angular springback in deep-drawn structures may cause large spatial deformations and distortions of the whole part. This behaviour is especially dramatic in case of open contours having small bending stiffness in one direction. The application of new materials, including high strength steel, aluminium and magnesium alloys, for light weight structures in the automotive industry is often impeded by the insufficient predictability of the springback effect.

The prediction of springback during sheet forming requires the exact calculation of the stress distribution in the sheet. Most sheet metal elements undergo a complicated cyclic deformation history during the forming process. Therefore, the Bauschinger effect must be considered in the modelling of the deformation behaviour of the material. Models with combined isotropic and kinematic hardening[1] are well suited to model this behaviour.

Stimulated by the need for light-weight construction in the automotive industry sheet magnesium alloys have attracted growing attention in the recent years. Poor formability of magnesium due to only a few active slip systems in its hexagonal close-packed lattice at ambient conditions necessitates the processing at temperatures above 150°C, where the thermal activation of additional slip systems is achieved. The use of sheet magnesium alloys for deep drawn components like motor hoods requires numerical simulations of the drawing process not only to control the elastic spring back but also to ensure that the forming limits of this material are not exceeded. Therefore, the deformation and damage properties of a MgAZ31 sheet were investigated. A Chaboche model with several kinematic hardening components and a recovery term was found to be the most appropriate.

2 MODELS

Chaboche-type models[1] define a yield function (Eq. 1)

$$f = \sqrt{\frac{3}{2}(S_{ij} - \alpha_{ij})(S_{ij} - \alpha_{ij})} - R - \sigma_0 \quad (1)$$

where σ_0 is a material Parameter, S_{ij} is the deviatoric stress tensor..The Visco-plastic flow follows a normality rule

$$\dot{\varepsilon}_{ij}^{vp} = \dot{p}\sqrt{\frac{3}{2}}n_{ij}, \quad (2)$$

where

$$n_{ij} = \frac{S_{ij} - \alpha_{ij}}{\left|S_{ij} - \alpha_{ij}\right|}. \quad (3)$$

The equivalent plastic strain develops as

$$\dot{p} = \left\langle \frac{\sqrt{\frac{3}{2}(S_{ij} - \alpha_{ij})(S_{ij} - \alpha_{ij})} - R - \sigma_0}{K} \right\rangle^n, \quad (4)$$

where n and K are the strain rate exponent and the viscosity coefficient. The isotropic part of the hardening is characterized by R, which develops according to Eq. 5.

$$\dot{R} = b(Q + R)\dot{p} \quad (5)$$

The kinematic part of the hardening is given by the back-stress components α_{ij} which can be described as a sum of several back-stress components:

$$\alpha_{ij} = \sum_{m=1}^{M} \alpha_{ij}^{(m)} \quad (6)$$

each of them has an evolution equation

$$\dot{\alpha}_{ij}^{(m)} = c^{(m)}\left(r^{(m)}\sqrt{\frac{2}{3}}n_{ij} - \alpha_{ij}^{(m)}\right)\dot{p}\,. \tag{7}$$

c, r, b, Q are material parameters.

This model and its extensions covering variable Young´s moduli for better springback prediction have been implemented at IWM as User subroutines in ABAQUS. As a rule, the determination of the material parameters requires tension compression tests.

Another important factors in forming processes, especially for aluminium and magnesium alloys, is the plastic anisotropy after rolling. For taking into account the Bauschinger effect and the anisotropy simultaneously, the model with isotropic-kinematic hardening has been extended by different phenomenological quadratic and higher order yield surfaces. These models correspond to expansion and shifting of the initial yield locus but can not describe changes of its shape (bulging and/or rotation). Polynomial yield functions with hardening tensors up to sixth order are needed to model such behaviour – distortional hardening[2]. Many extensive experiments are necessary to determine the required parameters. Therefore this approach is extremely time-consuming and cost intensive.

The calculation of the yield surface from the crystallographic texture data is an alternative way to obtain the plastic anisotropy. The texture itself can be derived by simulating the preceding rolling process including a suitable texture model. A visco-plastic self-consistant model (VPSC-model)[3] has been implemented in the FE-code ABAQUS/Explicit for this purpose[4].

3 TENSION-COMPRESSION TEST

An essential requirement for the application of the advanced plasticity models is the experimental determination of cyclic stress-strain curves for sheet materials. For this, IWM-SimBAU has developed a test set-up with a very stiff loading frame, and a special specimen design (see Figure 1).

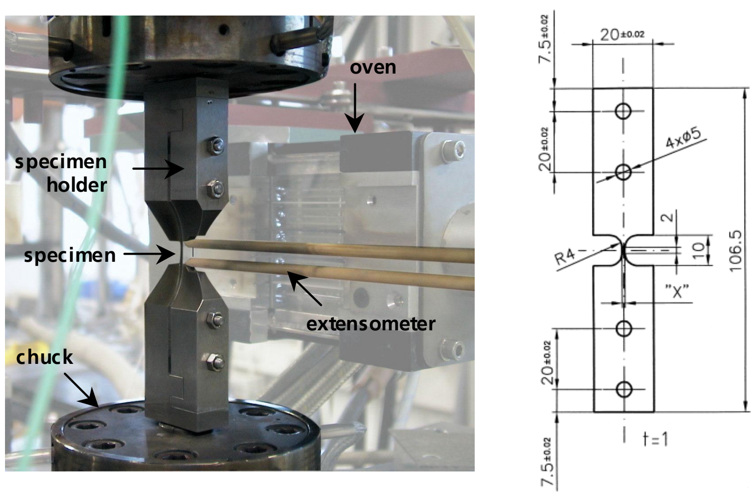

Figure 1: Test rig for tension-compression tests and specimen design

Using the experimental method described above several types of mild and high strength steels as well a magnesium alloy where investigated and drawing operations were simulated. Figure 2 shows the springback evaluation of a cross girder. Measured and calculated springback are in excellent agreement (9.1° and 9.2°).

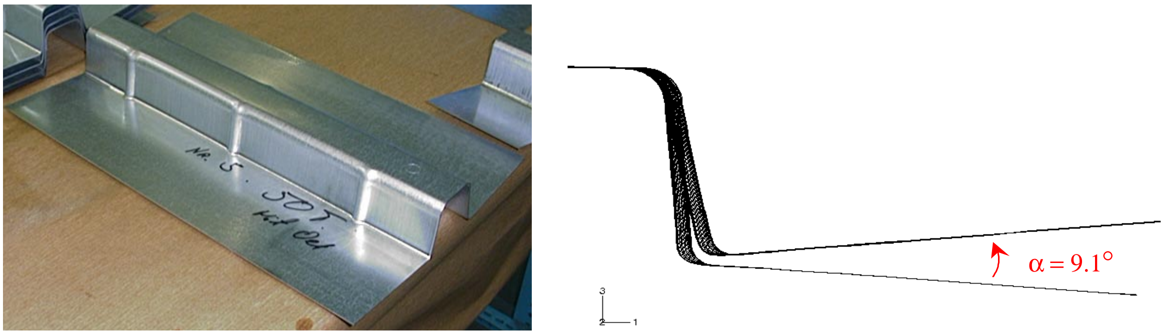

Figure 2: Cross girder. Photograph (left) and calculated value of spring-back (right). (Courtesy ThyssenKrupp Stahl AG)

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