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CHARACTERIZING THE PLASTIC ANISOTROPY AND ITS EFFECT ON SHEET METAL FORMING SIMULATION

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1. INTRODUCTION

Over the last few years, forming simulations have become fully integrated into product, tool and process design. In the ongoing improvement of sheet metal forming simulations through the optimization of the constitutive models, attention should be paid on the right knowledge of the material features and of its strain hardening under several strain path changes and at large strains. It is well known that several aspects of the material modelling can have a great effect on the final result of the simulations: the shape of the yield locus, the hardening model (isotropic, kinematic, mixed), the strain rate sensitivity …

In the present study, we mainly focus on the influence of the work-hardening (*i.e.* the isotropic and the kinematic hardening description) and the plastic anisotropy description (*i.e.* the yield criteria) on the numerical results. The hardening models chosen here are: (1) the physically based Teodosiu-Hu model[1] and called the “microstructural” model: it associates the properties of both an isotropic hardening and a non linear kinematic hardening; (2) the classical isotropic hardening described by Swift law. The initial anisotropy due to the rolling of metal sheets is taken into account with: (a) von Mises criterion, (b) Hill’s 1948 criterion, (c) Cazacu and Barlat criterion[2] and (d) Drucker mixed with a linear transformation criterion[2].

2. DESCRIPTION OF THE MATERIAL BEHAVIOUR

2.1 Description of the yield surface

Several strategies are adopted in the identification of the material parameters for a given criterion going from the classical use of the three Lankford coefficients to a complete set of both Lankford coefficients evolution in the plane of the sheet and the initial yield stresses after several monotonic loadings. Using this strategy, several yield criteria were identified, namely

(a) The classical isotropic von Mises criterion, referred as **von Mises**.

(b) The quadratic Hill 1948 criterion where the material parameters are obtained using the experimental r-value r_0, r_{45}, r_{90} as well as σ_0 which is the initial yield stress along the rolling direction after uniaxial tensile test. This criterion is referred as **Hill48(ref)**.

(c) The quadratic Hill 1948 criterion where the material parameters are obtained using the experimental r-value r_0, $r_{22.5}$, r_{45}, $r_{67.5}$, r_{90} as well as σ_0, $\sigma_{22.5}$, σ_{45}, $\sigma_{67.5}$, σ_{90} where σ_α is the initial yield stresses during a uniaxial tensile test along the α direction with respect to the rolling direction. This criterion is referred as **Hill48**.

(d) The Cazacu and Barlat criterion where the material parameters are obtained using all the set of experimental data as in case of Hill48 $\{r_0$, $r_{22.5}$, r_{45}, $r_{67.5}$, r_{90} as well as σ_0, $\sigma_{22.5}$, σ_{45}, $\sigma_{67.5}$, $\sigma_{90}\}$. This criterion is referred as **CB2001**.

(e) The Drucker's isotropic criterion with a linear transformation of the deviatoric Cauchy stress tensor in order to model an anisotropic material. The identification of the material parameters is obtained using all the set of experimental data as in case of Hill48 $\{r_0$, $r_{22.5}$, r_{45}, $r_{67.5}$, r_{90} as well as σ_0, $\sigma_{22.5}$, σ_{45}, $\sigma_{67.5}$, $\sigma_{90}\}$. This criterion is referred as **D~L**.

2.2 Description of the hardening behaviour

The identification of the work hardening behaviour is carried out using the classical uniaxial tensile test, but also the simple shear test in order to perform the cyclic loading for the identification of the Bauschinger effect. Two-stage non proportional loadings are also carried out using combination of uniaxial tensile test and simple shear for a better description of what we call the "cross-hardening" effect, *i.e.* the occurrence of the work-softening under orthogonal loading. The physically-based model has the advantage to accurately take into account the effect of the strain path change on the evolution of the anisotropic work-hardening behaviour (Figure 1). Moreover, the Bauschinger effect is taken into account. The investigated materials, namely an aluminium alloy AA5182-O doesn't exhibit any Bauschinger or orthogonal effects, which is completely opposite in the case of the second investigated material, the IF mild steel FeP06t. When using the isotropic hardening model, monotonic loading test was used for the identification of the material hardening parameters.

3. FEM SIMULATIONS

The cross-die tool (Figure 2) is used as the starting point for a comparison between the virtual products and the real parts. This tool has been initially designed to reproduce most of the industrial strain paths (simple tension, plane strain, shear and biaxial stretching). Therefore, it is suitable tool to investigate the relative weight of the work-hardening and the yield locus description on the accuracy of the numerical predictions. A square metal sheet of 250x250 mm^2 is deeply formed at a given depth and for a given blankholder force. The predictive capabilities of the constitutive laws as well as the relative effect of the contribution of the hardening behaviour and the yield surface description on the thickness prediction are investigated. The computations are performed using in-house finite element code DD3IMP[3] (*Deep Drawing 3D IMPlicit Code*), using 8-node hexahedron solid finite elements with selective reduction integration. Due to the geometrical and the material symmetries, only one fourth of the complete structure is modelled using 62 by 62 in-plane finite elements with 1 layer of elements throughout the thickness.

4. CONCLUSIONS

The analysis carried out in the present work concerns mainly the thickness prediction. The confrontation between the experimental and the numerical results are carefully examined in order to investigate the relative weight of the work-hardening description and the yield locus description on the numerical response.

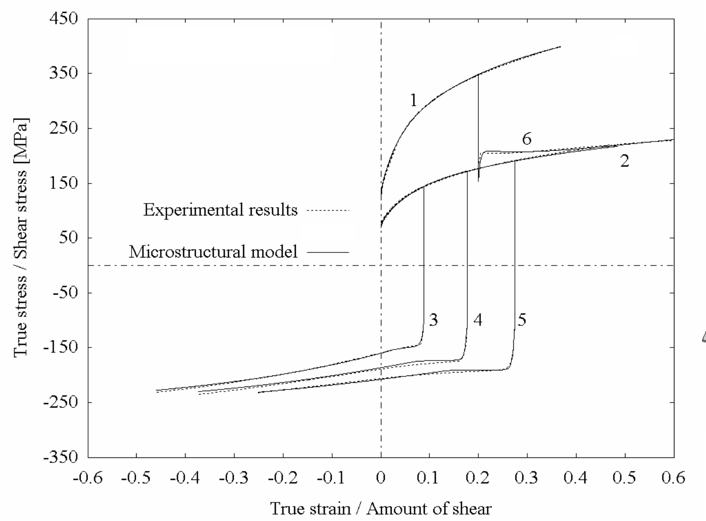

Figure 1. Comparison of mechanical tests with the prediction of the microstructural model for the description of the IF mild steel. (1) Uniaxial tensile test. (2) Monotonic simple shear test. (3), (4), (5) Bauschinger simple shear test after 10%, 20% and 30% amount of shear in the forward direction. (6) Orthogonal test: simple shear in the rolling direction after 20% true tensile strain in the same direction (from Bouvier *et al.*[4]).

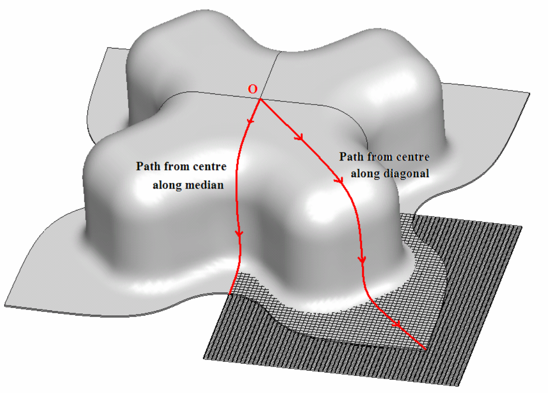

Figure 2. Cross die test[5]

The present study clearly emphasizes the importance of the yield criteria when dealing with the thickness distribution. The sensitivity of the results when comparing the simple isotropic hardening model with a strain path sensitive anisotropic hardening model is almost negligible. The differences between the hardening models become noticeable with the increase of the punch stroke. The results in terms of thickness distribution seem to be more sensitive to the yield criteria than to the behaviour laws (Figure 3 and Figure 4). Moreover, the thickness prediction seems to be sensitive to the strategy used in the identification of the material criteria parameters (*e.g.* the use of the r-values $r(\alpha)$ or/and the initial yield stress $\sigma(\alpha)$, the strain path sort, …).

It is worth noting that the analysis of the forming limit curves of the cross-die test clearly shows the presence of equibiaxial loading. However, in the present work, the experimental value of the r-value r_b as well as the yield stress σ_b after an equibiaxial loading were not available. Numerical study of the criteria parameters identification seems to be sensitive to the equibiaxial values which should be taken into account in the identification process. According to the experimental data, in some parts of the formed part, the decrease of thickness is significant (about 20%). Therefore, an accurate prediction of the thickness evolution clearly contributes to an accurate prediction of the success of the forming process (avoiding necking). While many studies focus on the accurate description of the hardening behaviour, the present preliminary analysis clearly shows the importance of the yield locus description and its identification in the prediction of the thickness distribution with regard to the hardening laws.

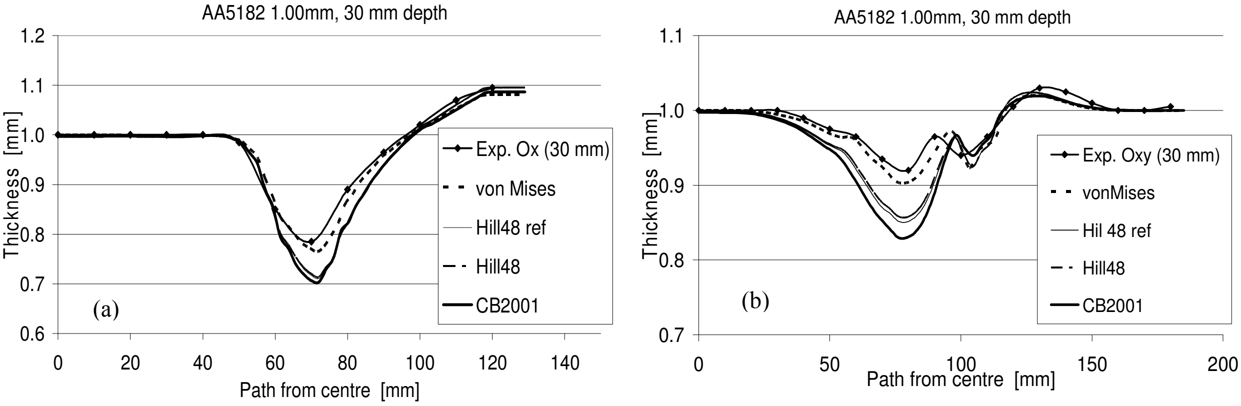

Figure 3. Thickness prediction for the Aluminium alloy AA5182 (1mm initial thickness) after 30 mm punch depth and for 60 kN blankholder force. (a) Thickness distribution along median (0°/RD, Figure 2). (b) Thickness distribution along diagonal (45°/RD see Figure 2). The behaviour is described using Teodosiu-Hu model.

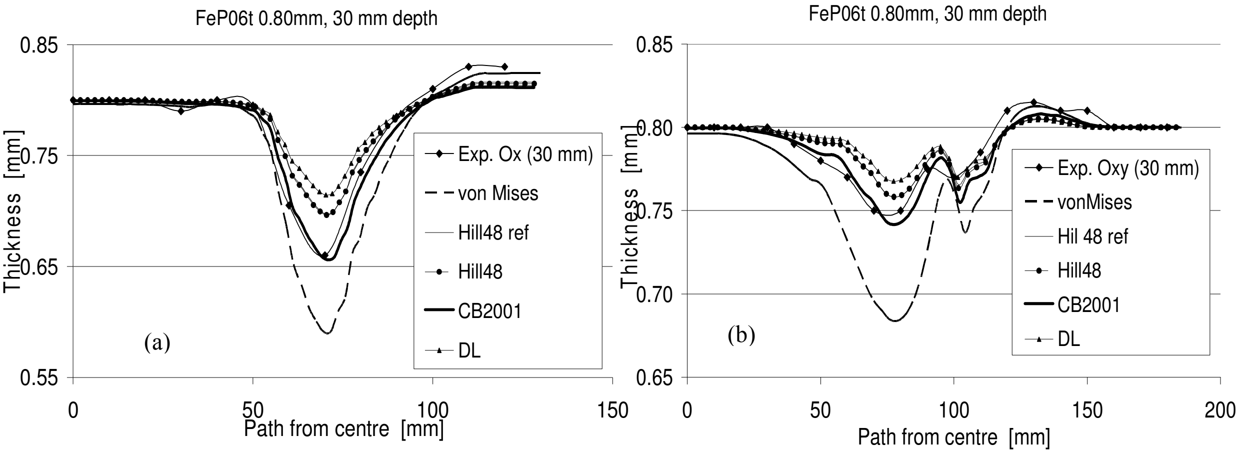

Figure 4. Thickness prediction for an IF mild steel FeP06t (0.8mm initial thickness) after 30 mm punch depth and for 290 kN blankholder force. (a) Thickness distribution along median (0°/RD Figure 2), (b) Thickness distribution along diagonal (45°/RD see Figure 2). The behaviour is described using Teodosiu-Hu model.

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