

# Preface

Virtual fabrication is a key ingredient for increasing the competitiveness of the industry, by reducing the time from concept to market and by increasing quality and reliability of the final product. Pushing more and more tasks from the usual design/test/redesign cycles to the computer-based testing of a virtual prototype reduces dramatically the research and development phase. In the metal forming industry an important part of the virtual factory relies on the numerical simulation of sheet metal forming processes by finite element (FE) programs. Among other factors, the success of an FE simulation depends essentially on the accuracy of the constitutive model describing the plastic behaviour of the sheet. Recent advances in the modelling of metals include the modelling of structural inhomogeneities, damage, porosity, twinning/untwining, non-local and second-order effects. Virtually all materials used in the metal forming industry today are anisotropic (material properties are not the same in every direction), showing both as-received (initial) anisotropy and evolving anisotropy related to plastic deformation processes. Plastic anisotropy can be most easily explained by the microstructure of the material.

The book gives a synthetic presentation of the research performed in the field of multiscale modelling in sheet metal forming during more than thirty years by the members of five international teams from Technical University of Cluj-Napoca, Romania; KU Leuven, Belgium; Clausthal University of Technology, Germany; Amirkabir University of Technology, Iran; University of Bucharest, Romania and Institute of Mathematics of the Romanian Academy, Romania.

Chapter 1 is devoted to the presentation of some recent phenomenological yield criteria. As this chapter is only a synthetic overview of the yield criteria, the reader interested in some particular formulation should also read the original papers listed in the reference section. This chapter gives a more detailed presentation of the yield criteria implemented in the commercial programs used for the finite element simulation (emphasizing the formulations proposed by the CERTETA team—BBC2005 and BBC2008 models) or the yield criteria having a major impact on the research progress.

An overview of the crystallographic texture and plastic anisotropy is presented in Chap. 2. After an introduction in the structure of polycrystalline materials and

crystallographic texture the authors present the main equipment and methods for the experimental determination of textures. The relation between texture and properties of materials is also analyzed in a subchapter. An extended subchapter presents different models used for polycrystalline materials with reference in particular to the Taylor model (Full-Constraints).

Chapter 3 is dedicated to multiscale modelling of plastic anisotropy. After an introduction in the topic the authors present the multiscale frameworks in crystal plasticity. The statistical crystal plasticity and the full-field approaches are presented in this section. The main section of this chapter is focused on the hierarchical multiscale approaches. A new hierarchical multiscale framework is presented that allows taking into account the evolution of the plastic anisotropy during sheet forming processes. This approach was followed, in which the fine-scale model provides data needed for identification of the macroscopic one. Generally, the crystal plasticity models have to be evaluated for a huge number of possible stress or strain-rate modes, sometimes exceeding one million realizations. This inspired works that aim at decreasing the computational effort related to virtual experiments. A possible way to capture the influence of microstructural changes on the anisotropic response is to use the crystal plasticity model to calculate some quantities of interest in advance and approximate these in the macroscopic simulation. The evolution of crystallographic texture, which is identified as the main source of the plastic anisotropy, is predicted by the ALAMEL crystal plasticity model. An extension to the phenomenological anisotropic plane-stress yield criterion BBC2008 is proposed, which provides adaptive updates of the local anisotropy in the integration points of the macroscopic finite element model. To this end, the BBC2008 is systematically recalibrated to data provided by the crystal plasticity virtual experiment framework (VEF). An enhanced identification algorithm is proposed. The new algorithm exploits comprehensive material characterization delivered by the VEF. The deep drawing of cylindrical cups is used as a benchmark case to validate the model.

Chapter 4 is focused on the modelling of the void growth in ductile fracture. First is presented a short introduction to Gurson-type models for predicting the fracture of ductile metals. After that an application of some anisotropic extensions of the Gurson–Tvergaard–Needleman model to the prediction of fracture in a sheet deep drawing simulation, including the identification of material parameters from tensile tests performed on sheets is presented. Having concluded that the optimal Gurson-type model for sheets must consider ellipsoidal voids and non-quadratic anisotropic yield criteria, the attention is focused on three such advanced yield criteria—Yld91, Yld2004-18p and BBC2005. A new method based on convex analysis to derive analytical expressions for the dissipation functions of these yield criteria is presented. The expressions thus obtained are not fully explicit and require some supplementary minimizations; however, it is shown that such forms are compatible with the development of Gurson-type models. In a second step Gurson’s model is extended to non-quadratic yield criteria where the “cosh” term is replaced by some other function. In order to calibrate these new models, the Lee and Mear family of spheroidal axisymmetric and incompressible velocity fields are extended

to the general ellipsoidal case. The method used is based on a Piola transform of the spherical Mie decomposition to a new ellipsoidal Mie decomposition. This forms the basis of a spectral method to solve the limit-analysis problem for a spheroidal void in a confocal unit cell. Using this spectral method to find an approximate solution in the case of a hydrostatic macroscopic stress state provides the optimal velocity field describing the expansion of the cavity. The knowledge of this velocity field for a given geometry permits the calibration of the remaining parameters in Gurson-type models. At variance with previous works, the authors have not tried to fit analytical approximations to the calibrated parameters. For a given yield criterion, it has been proposed to use a new fast calibration to tabulate all parameters as functions of void geometry and porosity and to use interpolation in these tables in a finite element simulation. The new tools and techniques presented in this chapter open the way to build Gurson-type models for new anisotropic yield criteria and general ellipsoidal voids.

The advanced models for the prediction of forming limit curves are presented in Chap. 5. After presenting different types of defects in sheet metal forming operations, the discussion focuses on the Forming Limit Curves (FLC). Classical and original theoretical models for the prediction of FLCs are presented in detail. In this context, the authors emphasize their contributions to the mathematical modelling of FLCs, namely: an original implicit formulation of the Hutchinson–Neale model, a modified model based on localized and diffuse necking, an original model based on the non-zero through-thickness shear stress effect on the FLC, a model without initial inhomogeneity and a model using the Gurson–Tvergaard–Needleman (GTN) theory. A subchapter is dedicated to the comparison of the FLC’s predicted by different theoretical models. The commercial programs (emphasizing the FORM-CERT program developed at the CERTETA centre) and the semi-empirical models for FLC prediction are presented in the last sections of the chapter.

Chapter 6 is devoted to anisotropic damage in elasto-plastic materials with structural defects. The material is damaged when the microstructural changes, like microcracks and microvoids, take place in the material (at the microstructural level) and no macrocracks can be observed. The failure is characterized by dominant macro cracks, which are generated as an ultimate stage during the damage (microstructural) process of the material. The author assumed that the plastic flow and the development of the microvoid and microcracks are distinct irreversible mechanisms produced during the deformation process. In contrast to the plastic behaviour, the damage affects the material elastic properties. The chapter deals with finite elasto-plastic models, which involve the defect density tensor, as a measure of the defects existing in the damaged microstructure. The author extended to finite deformation the relationships between the continuum theory of lattice defects and non-Euclidean geometry in the linear approximation, which have been presented (from geometrical aspects only) within the small strain constitutive framework. The evolution equations for the plastic distortion and the defect density tensor are compatible with the free energy imbalance on the isothermal processes, which describes the dissipative nature for the irreversible behaviour.

Chapter 7 deals with modelling the Portevin–Le Chatelier (PLC) effect. An elastic-viscoplastic model of McCormick type incorporating dynamic strain ageing and negative strain-rate sensitivity is considered. A methodology for the identification of the unstable PLC range of strain rates and mechanical parameters is considered by using a bifurcation analysis of spatial homogeneous processes. A critical condition on material parameters for the PLC effect is established. The loss of homogeneity and the strain localization phenomena are investigated numerically for both constant strain-rate and stress-rate experiments. The sensitivity of the model to the mode of testing is investigated. The influence of the testing machine is not taken into account by adding a machine equation, but by considering mixed stress- and strain-controlled boundary conditions. A discussion and comparison with existing models in the literature is also provided.

The book is of interest to both the research and industrial communities. It is useful for the students, doctoral fellows, researchers and engineers who are mainly interested in the material modelling and numerical simulation of sheet metal forming processes.

Cluj-Napoca, Romania  
May 2016

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Multiscale Modelling in Sheet Metal Forming

Banabic, D. (Ed.)

2016, XIII, 405 p. 137 illus., Hardcover

ISBN: 978-3-319-44068-2