Modelling of Forming Limit Curves Using the Large-Strain Theory

PhD Thesis

Author: Eng. Liana PĂRĂIANU

Advisor: Prof. Dr. Eng. Dorel BANABIC

Committee for Public Upholding:
- Prof. Dr. Eng. Petru Berce – Dean, Faculty of Machine Building, Technical University of Cluj-Napoca
- Prof. Dr. Eng. Dorel Banabic – Scientific Advisor, Technical University of Cluj-Napoca
- Prof. Dr. Eng. Tudor Inclănzan – Member, “Politehnica” University of Timișoara
- Prof. Dr. Eng. Octavian Bologa – Member, “Lucian Blaga” University of Sibiu
- Prof. Dr. Eng. Gheorghe Achimas – Member, Technical University of Cluj-Napoca

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The current trends in the field of sheet metal forming technology are to use high-performance manufacturing procedures (such as superplastic forming and hydroforming), as well as to adopt the virtual manufacturing techniques. In the case of metal forming, the practical use of virtual manufacturing instruments needs an improvement of the predictive capabilities of finite-element simulation programmes. The accuracy of the numerical results is greatly influenced by the constitutive model, as well as by the performances of the computational models used to evaluate the limit strains. The main activities of the Research Centre on Sheet Metal Forming Technology (CERTETA) are focused on these topics. The objectives of the thesis consist in improving the simulation performances in virtual manufacturing by developing new constitutive equations able to give a better representation of the plastic anisotropy, as well as computational models for the limit strains (with special emphasis on the superplastic forming).

The thesis is divided into 9 chapters. They are devoted to the following tasks: development and validation of a new yield criterion (BBC 2003), implementation of the yield criterion in a limit strain model (solved by using the finite-element model), and finally the experimental validation of the forming limit model.

Chapter 1. INTRODUCTION
This chapter gives a motivation of the research performed by the author, showing the place of this work in the frame of the research activities developed in the world.

Chapter 2. FORMABILITY OF THIN SHEET METALS. STATE-OF-THE-ART
This chapter starts by defining the formability concept and introducing the so-called forming limit curve (FLC). The discussion is mainly focused on showing the state-of-the-art of the mathematical models used to calculate FLD’s.

Chapter 3. MECHANICS OF CONTINUUM BODIES
This chapter contains a brief presentation of some continuum mechanics topics used in the thesis: motion and deformation of a continuous body (kinematical aspects), strain and stress tensors and dynamics of the bodies undergoing large transformations. The chapter also presents the equations governing the inelastic behaviour of sheet metals and shows the way of solving these equations by using the finite-element method.

Chapter 4. YIELD CRITERIA
This chapter contains a bibliographical study concerning the yield criteria developed by other researchers. The formulation, as well as the most relevant characteristics (advantages and disadvantages) of each yield criterion are analysed. A special attention is given to the most recent yield criteria proposed by Cazacu and Barlat, Barlat et al, Bron and Besson, Leacock, etc.
Chapter 5. DESCRIPTION OF THE BANABIC-BÂLAN-COMŞA (BBC) MODELS

This chapter is devoted to the analysis of the yield criteria developed by the members of the CERTETA research centre (Technical University of Cluj-Napoca). The evolution of the BBC yield criteria is discussed, emphasizing the models published in 2000, 2002, 2003 and 2005. The author had a significant contribution to the version published in 2003. The identification procedures specific to each of the above-mentioned yield criteria are also analysed. A validation of the models is also performed using the mechanical data corresponding to a steel and an aluminium alloy. A good agreement between experiment and theory is noticed.

Chapter 6. FLD DETERMINATION USING THE FINITE-ELEMENT METHOD

This chapter provides a description of the numerical strategy implemented in the ABAQUS/Standard finite-element code. Using the facilities offered by this programme, UMAT routines describing the inelastic behaviour of sheet metals are developed. The routines also allow the detection of the strain localisation process. The sensitivity of the computed FLC’s with respect to the variation of the material parameters is also investigated.

Chapter 7. EXPERIMENTAL RESEARCH

This chapter presents the experimental methodology used for the FLC determination in the case of linear and complex strain paths. The research stays in the foreign laboratories (University of Stuttgart and University of Aveiro) have contributed to this experimental work. The data presented in the thesis corresponds to AA3103-0 and AA5182-0 aluminium alloys. This data has been obtained in the case of linear, as well as complex strain paths.

Chapter 8. VALIDATING THE THEORETICAL MODELS

The validation of the FLC theoretical model is performed by comparing the numerical results of the finite-element analysis with experimental data. In the case of the AA5182-0 alloy, the validation also refers to the case of complex strain paths. For the same material, the FLC obtained from finite-element computations is compared to the data provided by a texture model.

Chapter 9. CONCLUSIONS

This chapter summarizes the conclusions emerging from the theoretical and experimental research performed by the author. It also gives a list of the most significant contributions of the thesis:
- Contributions to the development of the BBC 2003 yield criterion by using new identification procedures
- Formulation of a finite-element model of FLC’s based on the Marciniak-Kuczynski theory
- Implementation of the BBC 2003 yield criterion in the finite-element model of the FLC’s
- Numerical solution of the finite-element model of FLC’s using the ABAQUS/Standard programme and its UMAT routine facility
- Experimental validation of the constitutive and computational models
- Defining new research directions in the FLC research domain.
The research performed in the frame of this PhD thesis validates the performances of the BBC 2003 yield criterion developed by the members of the CERTETA centre, as well as the finite-element model of FLC’s. The results obtained by numerical simulation are in good agreement with experimental data. This fact shows that the BBC 2003 yield criterion can be implemented in commercial codes. In fact, an improved version of the yield criterion (BBC 2005) is currently implemented in the AutoForm programme.