Modeling the Press Hardening Process

Mats Oldenburg

Luleå University of Technology, Sweden

1 Introduction

Simultaneous forming and quenching is a current manufacturing process for low weight and ultra-high strength components. The process is often referred to as *hot stamping* or *press hardening* and is mainly used for producing safety related components for the automotive industry, such as side impact beams, bumper beams and different types of structural components. The use of press hardened components has increased exponentially in the automotive industry during the last two decades. The driving forces behind this development are concern for the environment and passenger safety. The use of ultra-high strength components enables design of low weight vehicle structures with maintained or increased passenger safety. Currently and in a foreseeable future, the press hardening is the dominating technology on the market for low weight design of automotive structures.

The hot stamping process uses boron steel blanks which are first austenitized at a temperature of approximately 900 °C. The blank is then formed and quenched in cold tools to obtain martensitic ultra-high strength material. The forming operation at elevated temperatures allows complex geometries to be obtained due to the high formability of the hot material.

A material model for simulation of the thermo-mechanical press hardening process, MAT_UHS_STEEL (MAT_244), has been implemented in LS-Dyna [1]. The model is based on research and developments within the Solid Mechanics research group at Luleå University of Technology.

2 Model development

The development of simulation methods for the analysis of the press hardening process has been carried out in several research projects including studies of several phenomena related to the process and several development steps since the middle of the 1990'ies including:

- The development of a new finite element <u>shell formulation for thermo-mechanical analysis</u> of sheet metal forming. The use of quadratic interpolation functions for temperatures in the thickness direction makes it possible to model one- or two-sided cooling in the press hardening process. The linear interpolation in the plane of the shell maintains compatibility between thermal expansion and other mechanical fields. The formulation was implemented in the public dyna3d code together with an explicit thermal solver [2].

- Investigation of the <u>material properties of a boron alloyed</u> steel used in press hardening manufacturing process. The study gives input for material modelling of the thermo-mechanical process of forming and hardening of boron steel. One important part of the study shows the influence of straining in high temperatures on the microstructure and on the transformation plasticity. This study is used as a base for modelling of the microstructure evolution and transformation plasticity [3].

- The use of <u>inverse modelling and innovative experiments for material characterisation</u>. In this work, it is shown that it is possible to evaluate experimental data for conditions that can not be established physically. Iso-thermal data for deformation of the austenite phase of boron steel has been evaluated by continuous cooling and deformation experiments combined with inverse modelling. The procedure is due to that there are only 10 seconds available until the austenite transforms to other phases [4].

- The development of a complete thermo-mechanical constitutive model for simulation of press hardening and similar processes. The model accounts for and establishes time dependent and time-independent phase transformations, mechanical and thermal properties as well as transformation plasticity during the complete cooling and deformation process from 900 °C to room temperature [5],[6].

3 Ongoing research

There are several completed and ongoing research projects at the Solid Mechanics research group at LTU that concern refinement of the simulation methods or make use of the model capabilities. Examples of such research tracks are:

- Studies of processes for manufacturing of components with spatially varying microstructure, i.e. components with tailored material properties, such as soft zones [7],[8]
- Experimental studies and model developments for pressure and temperature dependent heat transfer coefficient in the contact between the blank and tool,[9].
- Development of ductile failure models for multi-phase materials such as press hardened components with spatially varying micro-structure, [10],[11].

4 Acknowledgments

Former PhD-students and coworkers carrying out most of the research work concerning the development of simulation methods for analyses of the press hardening process are gratefully acknowledged. These persons are found in the reference list below. The fruitful cooperation with several companies such as Gestamp Hardtech (former SSAB Hardtech), Volvo Car Corporation and Ford Motor Company is also gratefully acknowledged.

5 References

[1] Olsson,T.:An LS-DYNA material model for simulations of hot stamping processes of ultra high strength steels, in: Hot sheet metal forming of high-performance steel, CHS2: 2nd int. conf., June 15-17, 2009, Luleå, Sweden, Verlag Wissenschaftliche Scripten, 2009. 229-237

[2] Bergman, G., Oldenburg, M.: A finite element model for thermo-mechanical analysis of sheet-metal forming, Int. J. Numer. Meth. Eng. 59, 2004, 1167–1186

[3] Somani, M.C., Karjalainen L.P., Oldenburg, M. and Eriksson, M.: Effects of plastic deformation and stresses on dilatation during martensitic transformation in a B-bearing steel, J. Mater. Sci. Technol., vol. 17, No 2, 2001, 203-206

[4] Åkerström, P., Wikman, B. and Oldenburg, M.:, Material parameter estimation for boron steel from simultaneous cooling and compression experiments, Modelling Simul. Mater. Sci. Eng. 13, 2005, 1291-1308

[5] Åkerström, P., Oldenburg, M.: Austenite decomposition during press hardening of Boron steel - computer simulation and test, Journal of Materials Processing technology 174, 2006, 399-406

[6] Åkerström, P., Bergman, G., Oldenburg, M.: Numerical implementation of a constitutive model for simulation of hot stamping. Modelling Simul. Mater. Sci. Eng. **15,** 2007, 105–119

[7] Oldenburg M, Lindkvist G.: Tool thermal conditions for tailored material properties, HTM: Journal of Heat Treatment and Materials: Zeitschrift für Werkstoffe, Wärmebehandlungv Fertigung, 66(6), 2011, 329-334.

[8] Oldenburg M.: Warm forming of steels for tailored microstructure, in: Hetnarski R, Ed., Encyclopedia of Thermal Stresses, Springer, 2014, 6469-6479.

[9] Salomonsson P., Oldenburg M., Åkerström P., Bergman G.,: Experimental and numerical evaluation of the heat transfer coefficient in press hardening , Steel Research International, 80(11), 2009, 841-845.

[10] Östlund R, Oldenburg M, Häggblad H-Å, Berglund D.: Evaluation of localization and failure of boron alloyed steels with different microstructure compositions", Journal of Materials Processing Technology, 214(3), 2014, 592–598

[11] Östlund R, Oldenburg M, Häggblad H-Å, Berglund D.: Numerical failure analysis of steel sheets using a localization enhanced element and a stress based fracture criterion", International Journal of Solids and Structures. 56, 2015, 1-10.