From Rolling to Crash – Some Aspects of Process Chain Simulations

Oleg Benevolenski, Tobias Rist, Winfried Schmitt

Fraunhofer-Institute for Mechanics of Materials, Freiburg, Germany

Summary:

A simplified example from the metal sheet automotive body manufacturing process (Cold rolling – Deep-drawing – Crash) was considered as a basis of the through-process simulation. A simulation framework allowing construction of the process chains by putting together different simulation tools was proposed. Once the process chain is defined the through-process simulation may be performed along the whole process chain. Thus, parameter variations along the process chain are allowed and the effect of the processing parameters on the end product may virtually be determined "at the push of a button".

Keywords:

process chain, through-process simulation, rolling, forming, crash

1 Introduction

For economic and ecologic reasons the automotive industry is more and more faced with requirements to reduce the weight of their products. This can only be achieved by the use of novel materials. While in the past the focus had been put on classical “light weight” materials like aluminum and magnesium, newly developed steels with high strength and ductility come into the center of interest. The mechanical behavior of those materials in different process steps is significantly different from conventional steels. Thus, the necessity to reliably model these materials becomes increasingly important, e.g. in tool making. Additionally, the mechanical properties describing the behavior are strongly dependent on details of the processing route, and these properties undergo an evolution along the different steps of the process chain.

Therefore, an increasing need for adequate simulation tools not only of single process steps like rolling, forming or crash has been identified, but also the through-process simulation of the complete process chain has come to the center of attention. For these reasons, partners from research and industry have joined to strive for the “assessment of (automotive) components on the basis of an integral modeling of the material along the process chain” (supported by the German Federal Ministry of Education and Research under grant-no. 03X0501E). In addition to the application of classical phenomenological material models also microscopic and morphologic aspects will be treated by means of crystal plasticity simulations and representative volume element (RVE) techniques (“integral modeling”). Questions concerning the data transfer between the process steps and the development of an appropriate data structure will also be one of the main issues of the project.

Many aspects of the through-process simulation of the thermo-mechanical production of metal sheet [1,2] as well as forming and crash [3] were addressed in several publications. Less attention was drawn up to now towards integrating both of the above processes into a complete through-process simulation. The main goal of this contribution is to demonstrate advantages of the flexible process chain simulation from rolling to crash without going too deep into details of each process step.

2 Description of the considered process chain

In the study a simplified example along the process chain “Cold rolling – Deep-drawing – Crash” is considered. As a stamping example we choose a so called “hat profile” produced with a draw-bending test (a simple but characteristic deep drawing operation) of a strip made of a cold-rolled ferritic steel. Some of the real steps are omitted in this example. Instead, more attention is paid to some new aspects of the through-process modeling like virtual material testing or transferability of the material models. Intentionally, simplified material behavior and simple geometries are considered. The individual steps are explained in some details below.

2.1 Cold rolling

During cold rolling, like in every other processing step, the mechanical properties of steels undergo substantial evolution. Such phenomena as work-hardening, reduction of formability, development of the anisotropy of elastic and plastic properties are usually observed. Since these changes are mainly attributed to the evolution of microstructure [2] they may be addressed by micromechanically motivated plasticity models.

We use a viscoplastic self-consistent model (VPSC) [4] implicating an aggregate of several hundreds of idealized grains with arbitrary initial orientation of the crystal lattice. Plane strain compression boundary conditions, that are typical for metal sheet rolling, are applied. The thickness reduction amounted to ca. 0.4, which corresponds to approximately -0.9 logarithmic strains.

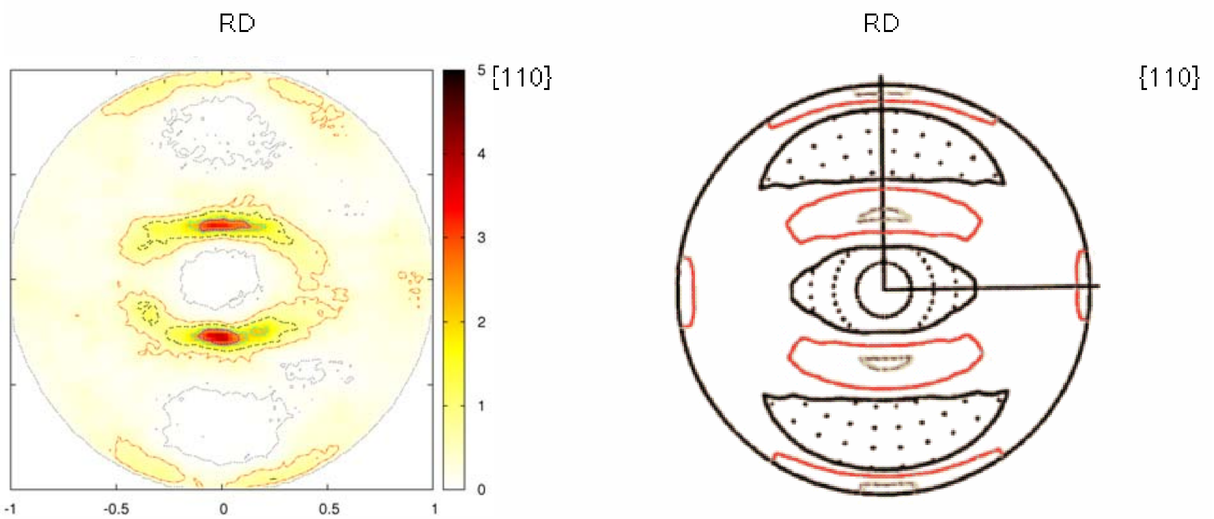


Fig. 2: Typical pole figures of the textures after rolling of the ferritic steel, calculated (left) and experimental (VPSC6 Manual, C.N.Tomé, R.A.Lebensohn, right)

The typical output of the model is the distribution of the crystallographic orientation (that may be assessed with pole figures, see. Fig. 2) and the current hardening state on individual crystallographic slip systems.

2.2 Virtual testing and parameter transfer

Just as material properties at a given stage of the process chain can be obtained by mechanical tests with specimens, these properties may alternatively be acquired by means of virtual experiments. For this purpose the output of rolling simulation characterized by severe grain distortions and typical distribution of crystal orientations and degree of hardening is used as input for the following virtual experiments. Here, the VPSC module is used again to load a material volume with predefined initial state along desired loading paths (corresponding to a tensile test with given specimen orientation). The tensile stress-strain curve after cold rolling calculated in this way is shown in Fig 3.

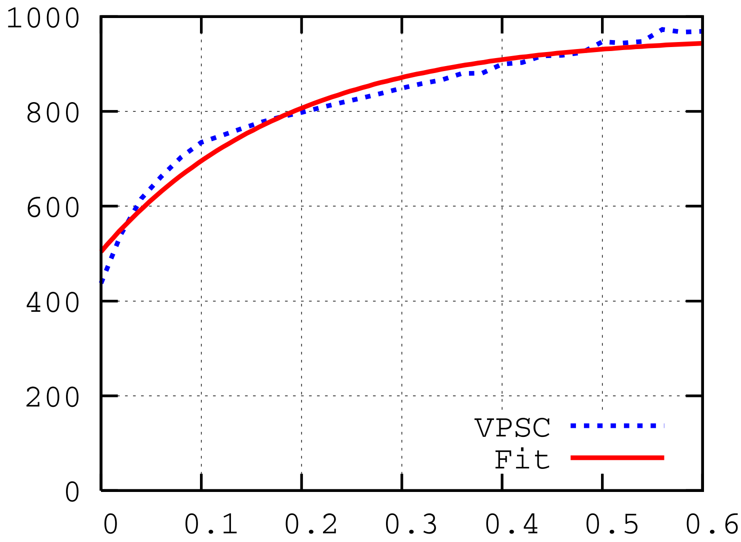


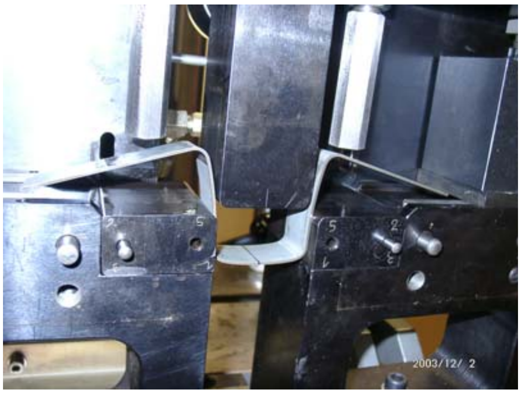
Fig. 3: Simulated tensile behavior of the ferritic steel and fitting of the material parameters according to Chaboche's model [5].

Depending on the plasticity model employed during the drawing simulation the appropriate sets of the virtual tests should be performed. Such a set may include flow curves in different in-plane directions, defining the shape of the yield surface and its development under certain loading cases, etc.

Assuming that an isotropic elastic-plastic material model with exponential hardening described according to Chaboche [5] is employed for the drawing simulation, the model parameters are obtained by automatic fitting of the “virtual” flow curve from Fig. 3.

3 Deep drawing and crash

Using material models with the parameters determined as above the drawing simulation was performed. A steel strip was stamped to form a “hat profile” and was then relaxed elastically by removing the tools (“springback”).



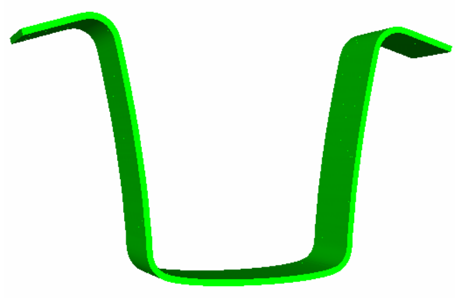


Fig. 4: Simulated strip deep drawn to form a “hat profile”.

Taking over the results of the drawing analysis (namely stresses, strains, geometry etc.) a crash analysis on the “hat profile” was performed subsequently. The part was constrained at both free ends, supported by a rigid wall from above and then impacted by a flat impactor from below (see Fig. 5).

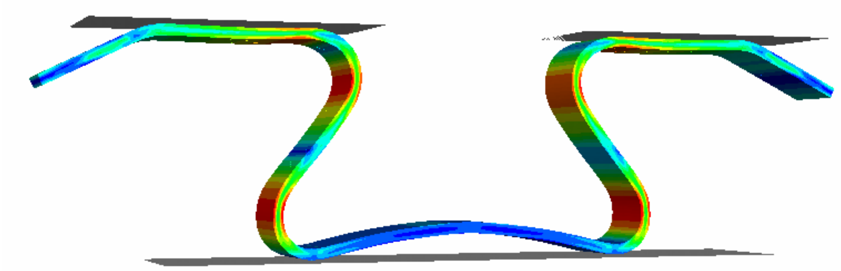


Fig. 5: “Hat profile” after impact.

4 Concept of the process manager

A tool (“process manager”) for flexible construction of the process chains by combining heterogeneous simulation tools was developed. In a simplified form, the functionalities of the tool are:

- Definition of process chains by compiling individual steps;
- Creation and deleting of individual steps;
- Controlling the data transfer between individual steps (simulation modules).

The manager is independent of particular simulation codes, it was implemented in form of a python script

5 Conclusions

A simplified example from the metal sheet automotive body manufacturing process was considered as a basis of the through-process simulation. The developed simulation framework allows construction of the process chains by putting together different simulation tools.

Once the process chain is defined the through process simulation may be performed along the whole process chain. Thus, parameter variations along the process chain are allowed and the influence of processing parameters on the end product may potentially be determined “at the push of a button”.

6 Outlook

Further relevant processing steps (like thermal treatment) will be included in the modeling. The through-process validation should complete results of the simulations at certain selected steps.

7 Acknowledgements

This work was supported by the German Federal Ministry of Education and Research under grant-no. 03X0501E. The authors also like to thank Mr. Florian Diesch for the development of the process manager during his diploma thesis.

8 Literature

[1] Engler, O., Löchte, L., Hirsch, J.: "Through-process simulation of texture and properties during the thermomechanical processing of aluminium sheets", Acta Materialia, 55, 2007, 5449–5463

[2] Gottstein, G.: "Integral Materials Modeling" in "Integral Materials Modeling: Towards Physics-Based Through Process Modeling" Edited by Gottstein, G., 2007, 5–15

[3] Zöller, A., Frank, T., Haufe, A.: "Berücksichtigung von Blechumformergebnissen in der Crashberechnung", Proceedings: LS-DYNA Anwenderforum, Bamberg, 2004, B–I-5–16

[4] Lebensohn, R.A., Tome, C.N.: "A self-consistent anisotropic approach for the simulation of plastic deformation and texture development of polycrystals: Application to zirconium alloys", Acta Metallurgica et Materialia, 41, 9, 1993, 2611-2624

[5] Lemaitre, J.P., Chaboche, J.L.: "Mechanics of Solid Materials ", Cambridge University Press, 1990, 581

