Activities of a material supplier to support the virtual manufacturing process with respect to robust forming simulations

11. LS-Dyna Forum 2012 in Ulm, paper version for the Key-Note Lecture
Lutz Kessler, Jörg Gerlach
Research and Development – Application Technology

ThyssenKrupp Steel Europe

Activities of a material supplier to support the virtual manufacturing process with respect to robust forming simulations

Jörg Gerlach, Lutz Kessler

ThyssenKrupp Steel Europe AG, Duisburg, Germany

1 Introduction

The trend to a digital product and production development is an ever increasing activity of most automotive companies. Crash and forming processes are handled on a daily basis, other activities are also continuously realized. Examples for these simulations are the drying process in the paint shop, digital mock up, durability, stiffness and acoustics. All these fields of activity call for specific material models and their input parameters in order to guarantee a valuable result. It is essential to a material supplier that the simulation results are in accordance with a final real world experience. A beneficial property of a material has, on a long term view, to be included in the modeling to allow a skilled engineering process and to exhaust all capabilities.
The special field of forming simulation is a good example for this process and has become a sustainable portion of part production today. During the last years numerous efforts have been made by universities, software companies, material suppliers and the automotive industry to generate a valuable and trusted process. In so doing the amount of parameters needed to allow a final statement for production has exploded. This is especially true for the amount of material parameters to be fed in a final simulation run for any robustness interpretation. The demand for the simulation results varies with the time of application and the actual goal of the investigation targeted by simulations. The simple die design phase requires a fast and reliable forming simulation process. A support for production processes problems requires a statement for the influence of mostly unknown relevant parameters such as process robustness, material scatter, friction behavior and press dynamics and speeds. As a leading material supplier for automotive steels, ThyssenKrupp Steel Europe AG accompanies this virtual production process. The implementation of existing and new materials into the different phases of process development is supported by own research activities for testing methods, standardizations, numerical methods and for powerful tools to permit a faster material card calibration.

2 A short retrospect

Looking back on the history of sheet metal forming simulation in the automotive industry there was almost no application during the early and late 80’s of the last century. In the 90’s the number of reports dealing with the application of sheet metal forming simulation increased. An early and virtual prediction of part feasibility became an option in the die design phase. However, the number of simulations is still limited for different reasons.

2.1 Aspects of material modeling

When defining sheet metal forming as the transformation of a thin, often steel based, flat metallic sheet into a useful object by means of plastic deformation, it becomes clear that this task cannot be performed without the sheet itself. To simulate this process by means of computational methods, the modeling of material behavior is essential, but remains not the only problem which has to be solved on the way to a reliable simulation result. The fundamental components on the material side are the hardening, the anisotropy and the prediction of failure as given forming limitations.

By analyzing the material models applied in the 1990s it can be noted that the Hill ´48 yield condition in combination with isotropic hardening was mainly used. The advantage of this model was a better material description in multi-axial stress states compared to the v. Mises theory, the ability to capture anisotropic effects and the availability of all necessary material data with just three tensile tests. In literature and code implementation a lot of more advanced material models were already known but not yet applied [1, 2]. The reasons for this were a large number of unsatisfactory boundary conditions for simulations:

- Computer power available
- User skills
- Expectation for the result accuracy
- Material data available
- Effective experiments for data collection
- Resolution of discrete mesh
- Contact and friction modeling

One more obstacle to more accurate material modeling can be seen in a limited advantage of using more sophisticated material models when compared to the money that has to be spent for the data evaluation. An example for this is the general application of the biaxial tensile test to calibrate a more flexible non-quadratic yield locus already available in the FE-program Indeed [2].

In the middle of the 90's different aspects resulted in intensive effort to allow better material modeling. First of all the requirements for the simulation in industry changed [3]. Expectations of the accuracy of the results and the front loading of the simulation prior to the tool design showed a clear need for more advanced modeling options [4, 5]. This process was simultaneously accompanied by other key issues.
On the one hand the material manufacturers and OEMs started to use different material grades like high strength steels or aluminum alloys [6, 7]. As a consequence new testing strategies were developed to calibrate the already existing advanced material models regarding anisotropy and hardening [8].
On the other hand the optimizations in numerical mathematics and the improvement of computer systems led to faster and more robust conditions. All this ended up in the desire for an easy to use, but fast to calibrate material model for all kinds of sheet metal forming processes. In particular it should allow the prediction of strain distribution, wrinkling, spring-back, material draw in, flanging and process robustness by simulation variations at the same time.

2.2 Aspects of failure prediction

The classical method of predicting a possible failure in sheet metal forming is found in the concept of forming limit curves (FLC) or a limitation of material thinning. In particular the FLC is widely applied, even when knowing that it is only valid for nearly linear strain paths [9]. The testing procedure to evaluate a forming limit curve is relatively expensive. Different specimens have to be formed and the strain to be measured. Finally an individual interpretation of the forming limit curve has to be done. All these steps offer a wide range of interpretation and are not very strictly regulated. To allow the design of a complete forming process including re-striking or flanging operations, additional criteria are required. Here concepts of forming limit stress curves are applied in order to avoid the FLC restrictions [10]. Driven by the trend to high and ultrahigh strength steel grade applications, not only membrane based failures but also other types occur in the press shop. Examples for upcoming models are Lemaitre, Gurson, GHISSMO and CrachFEM, The last two mentioned already combine different effects in one model to allow a faster interpretation by the user. An overview is given by [11]. Some formulations can already be used today in commercially available program codes such as LS-Dyna. Nevertheless much effort is needed in the development of robust general experiments, material parameter identification methods for modeling and the interpretation of the additional numerical results. Two key factors slow down the process of having one unique computational method. On one hand the different process steps of forming, joining and crash merge to form a combined engineering process. A model good for one process is not necessarily able to cover the coupled process steps as well. Questions of result transformation and mapping regulations play an important role. On the other hand the amount of different materials used today hinders the fast evaluation process for a final model selection.

3 Demands on material models today

By solving quite a number of the computational problems in the commercially available codes in recent years the material has once again become one of the key figures of concentrated research activities. The main point for this is an ambition to model the most exact plastic behavior for one piece of sheet, while mostly ignoring the fact that sheets from several coils used for stamping a specific part naturally possess slightly different properties.

For characterizing the anisotropic yield behavior of sheets a lot of different yield loci models are available today. A good overview of the existing models and the parameters required is given in [12]. In contrast to the original yield locus of Hill ´48 the promoted yield loci today are not clearly identified with the uniaxial tensile test alone. Additional tests in different stress states have to be made. Here we would like to emphasize that the strategy for calibration of yield loci in sheet metal forming may in general be based on three different methods:

- Cruciform tensile tests for multi stress point predictions in the first quadrant or
- Combining independent experiments to identify the hardening under different stress combinations or
- Using texture measurement and Taylor theory to derive a yield locus

It has to be emphasized here, that most of the testing methods mentioned above are not defined by any standard, except for the classic tensile test. As a material supplier, ThyssenKrupp Steel Europe AG is interested in establishing a stable process to identify the material parameters needed for model calibration. As an example together with other companies we initiated the installation of working groups inside the German Deep Drawing Research Group (GDDRG) to define a standard for the experimental determination of forming limit curves or hydraulic bulge tests [13, 14]. Through the engagement of the automotive, the aluminum, and the steel industry and university institutes, widely accepted standards have been defined over recent years and valuable basic research has been completed to understand the influencing parameters when using these tests for material data generation. This experimental basis with identical interpretation methods available today offers some advantages:

- A data base can be developed to store data as the conditions for measuring are well accepted
- Model parameter findings can be discussed based on a common understanding
- Material data from different laboratories become comparable, this includes the chance of sharing the costs for measurements

For a wide range of steel grades ThyssenKrupp Steel Europe now offers fundamental simulation data, a good advantage for especially smaller companies which do not have their own laboratories or testing facilities.

4 Assistance from a material supplier

ThyssenKrupp Steel Europe aims to support the individual in exact simulation for forming, joining and crash processes and follow the trends and requirements of the upcoming robustness simulations by designing material specific, but quick to apply simulation methods.

Since the end of the 1990s an internal database for the storage of material data has been developed at ThyssenKrupp Steel Europe. The main objective was the standardization of simulation tasks for the material data process based on application. In order to do so, the following steps were developed and implemented:

- Measurement of representative material data according to SEP 1240
- Collection of data and validation with cross-comparison to the general production process
- Database provision, documentation and an authorization concept. The authorization concept guarantees that only material data proven for external usage can be exported to customers
- The dissemination of data is done by an Excel export function
- To support the FEM-application. Since 2000 a special user interface has been available to create material cards for different simulation programs

For new material development the data is produced for early trials in the steel plant in order to have a first chance of FEM-application. During the steel development process these properties might change on the way to the series production. When reaching series status, all of the defined test results in SEP

1240 are available, additional data (e.g. fracture) can be asked for individually and is not included in a standard material data set.

The upcoming material models for forming simulations need much more material parameters than defined in the SEP 1240. Here the hydraulic bulge test, the simple shear test and a plain strain tension test are often mentioned and are examples of non classic testing methods. This data is relatively expensive when compared to a classical tensile test, especially when carrying out such tests for different badges of a steel grade in order to derive a systematic basis. As a result of research projects some main points have been identified:

- The hydraulic bulge test supports the identification of the individual extrapolation of the hardening curve.
- The traditional extrapolation functions according to Swift and Hollomon are not valid for all the steel grades existing today
- Even when using the above mentioned additional test, there is no guarantee for the identification of the best material model by converting these results in a material card
- A clear need for simple validation experiments has been identified in order to check the final material setup for forming simulations
- To carry over the individually determined material parameter to the robustness simulation is hindered by the complexity of the models

For the future application of reliable material parameters in robustness simulations it is essential to roughly derive most of the hard to measure material parameters. A practical way is to correlate the difficult to measure parameters or to determine parameters with the data most available for tensile testing.
With the introduction of the ThyssenKrupp Steel Extrapolation Method (TEM) in 2006 [15] a first correlation was done for the extrapolation of hardening. Based on existing bulge tests for all kinds of cold rolled materials a correlation was made to the mechanical data from the tensile testing. This permits a forecast for hardening behavior at large strains for steel grades from tensile strength of 270 MPa up to 800 MPa. In addition to the hardening behavior the data also permitted an identification of an optimal ratio of the biaxial stress to the uniaxial stress point which is important for the yield locus choice and calibration. This method has been fully implemented in the FEM program AutoForm since version R1 and forms the basis of all available material cards generated at ThyssenKrupp Steel Europe for forming simulation purposes.

The concept of correlating material data from tensile tests to measured material behavior has also been proven and checked for the prediction of forming limit curves. As a basis for this work an amount of over 150 FLCs from the above mentioned data base was used to identify the necessary parameters and functions. Finally a unique function has been identified which allows the forecast of a forming limit curve through only the mechanical properties tensile strength, total elongation and sheet thickness. This method is published in [16] and is flexible enough to follow new standardization methods like ISO 12004. Before the publication took place this method had for years successfully been applied for all customer support tasks for forming analysis in press shops all over the world.

The above two mentioned examples are fully based on data coming from tensile testing. In order to check the quality of the quick to apply correlation functions (yield locus, hardening behavior and failure criteria) there is a need for special experiments with complex material forming conditions. In a common project with the BMW Group different experiments, relatively free from the influence of friction, have been developed to obtain a quality impression of the derived material card applied for forming simulation [17, 18]. The specialty of these experiments is an application capability for all possible orientations to rolling direction. At the end these experiments also allow the identification of material group characteristics by evaluating the best and worst material forming potential.

All the above mentioned correlation tools are a prerequisite for realistic robustness simulation when trying to identify the impact of material properties. With this knowledge it is possible to create material cards which are realistic in calculating the expected scattering of material parameters which cannot be measured in advance of a production run [19].

5 Conclusion

To support the virtual production process ThyssenKrupp Steel Europe has made considerable effort over the last years. For all kinds of basis simulation tasks the data base can offer original material data according to SEP 1240 and the agreement of VDA and VDEh. This alone is in some fields of simulation activity insufficient. In particular for advanced forming simulation such as spring-back or sophisticated material models, additional input values become necessary. To minimize the experimental cost and to ensure a valuable application of these models a combined approach using measurement, correlation and the validation process has been developed. Thus some hard to measure input parameters needed for e.g. robustness simulations can be derived from tensile test results in an easy and practical way.

6 Literature

[1] Haug E., di Pasquale E., Pickett A.K., Ulrich, D.: *Industrial sheet metal forming simulation using explicit finite element methods*. VDI Berichte 894, VDI Verlag, 259-291, 1991.

[2] Hillmann M. at al.: *A highly vectorized FE_program for sheet metal forming simulation for the automotive industry*. VDI Berichte 894, VDI Verlag, 549-567, 1991.

[3] Mathke J., Wegener W.: *Simulation als Bestandteil rationeller Blechumformung*. In: VDI Berichte 1142, 191-222, 1994

[4] Stoughton T.B.: *Computer Simulation Of Sheet Metal Forming*. In: IBEC ´93, Advanced Technologies & Processes, 101-108, 1993

[5] Leverton T., Scoones, A.: *On The Use Of Computer Based Simulation To Reduce Die Manufacturing Lead Times*. In: IBEC ´93, Body Assembly & Manufacturing, 99-105, 1993

[6] Hartmann G., Müschenborn W.: *Höherfeste Feinbleche und neue Blechkomponenten für den Automobilleichtbau*. In: Neue Entwicklungen in der Blechumformung, DGM, 1-29, 1996

[7] Murtha S.J., Story J.M., Jarvis G.W. Zonker H.R.: Anisotropy effects in the forming of aluminum sheet. SAE Paper 950702, 1995.

[8] Vegter H., An Y., Pijlman H.H., Huétnik, J.: *Advanced mechanical testing on aluminum alloys and low carbon steels for sheet forming*. Numisheet ´99, 3-8, 1999.

[9] Müschenborn W., Sonne H.M.: *Influence of the strain path on the forming limits of sheet metal*. Archiv Eisenhüttenwesen 46, 597-602, 1975.

[10] Stoughton T.B.: *A general forming limit criterion for sheet metal forming*. Int. J. Mech. Sci., 1-27, 2000.

[11] Wierzbicki T., Bao Y., Lee Y.W., Bai Y.: *Calibration and evaluations of seven fracture models*. Int. J. Mech. Sci. 47, 719-743, 2005.

[12] Banabic,D., Bunge H.-J., Pöhland K., Tekkaya A.E.: *Formability of Metallic Materials: Plastic Anisotropy, Formability Testing, Forming Limits*. Springer Verlag, Berlin; Auflage: 1, 2000.

[13] Keller S., Hotz W., Friebe H.: *Yield curve Determination using the bulge test combined with optical measurement*. IDDRG Conference Proceedings, Golden, 2009, p. 319-330

[14] ISO 12004-2, *Metallic materials - Sheet and strip - Determination of forming-limit curves - Part 2*: *Determination*

[15] Gerlach J., Kessler L.: *A consistent approach for simplifying the material modelling in forming simulations aming at cold rold steel grades*, steel grips (4) 2006, 255-260, 2006

[16] Gerlach J., Kessler L., Köhler, A.: *The forming limit curve as a measure of formability – Is an increase of testing necessary for robustness simulations?* IDDRG 2009

[17] Gerlach J., Kessler L., Linnepe M.: *Material aspects in forming simulation – how far should we go?* Zürich, FTF-Conference Proceedings, 2009

[18] Heinle I., Kessler L., Beier T., Grass H., Meinhardt J., Lipp A., Bäck T.: *Challenges in validation of material modelling for forming simulations*. In: Proc. AutoMetForm, November 24-26, Freiberg, 2010, Germany, p. 83-99.

[19] Gerlach J.: *Sensitivity and robustness analysis for quantification of the influence of material scattering*. Zürich, FTF-Conference Proceedings, 2007