Forming simulations based on parameters obtained in microstructural cold rolling simulations in comparison to conventional forming simulations

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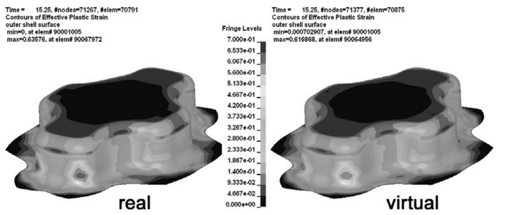
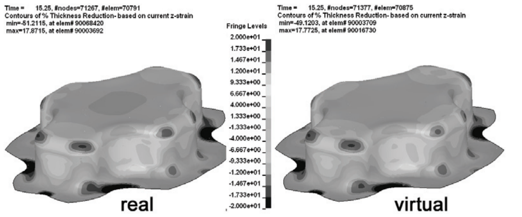
Summary:

This work demonstrates a first approach of using virtually obtained material properties as input for forming simulations. The necessary parameters to apply a Barlat-Lian89 yield surface are computed in the so called "Virtual Lab", which performs FE-simulations on previously cold rolled volume elements to predict the distribution of grains. The resultant stress-strain-curves serve as input parameter for a deep drawing simulation. For reference, an ordinary material data file determined by real uniaxial tension tests is compared to the virtual based material data file. Further, the results of both simulations are exhibited to allow a first evaluation of the deviation from each other. In particular, the Lankford Parameters in 0° and 90° with respect to the rolling direction are predicted by the Virtual Lab quite well. Only the 45° value requires improvement for future analysis of material properties. Likewise, the extrapolation of the hardening curve shows a strong deviation at larger deformation.





The equivalent plastic strain as well as the thickness reduction is less affected by this problem. However, the calculation of the equivalent stress is influenced strongly by the deviating hardening curves at larger strains. This expresses itself in an overestimation of the stress in the simulation as based on the virtually obtained properties.

Keywords:

forming simulation, microstructural cold rolling simulation, parameter transfer, Virtual Lab.

1 Introduction

The reduction of CO2 emissions is one common demand requested of the automotive manufacturers by customers and politicians. Besides technical advances in the drive train a sophisticated light-weight design of the car body helps to achieve this requirement. Additionally, stringent standards in crash-safety and build-quality necessitate a stiff structure of the passenger cabin and the supporting elements. To meet these requirements in equal measure, a composite construction of parts consisting of different materials is indispensable. The goal is to design parts of the car body according to their specific load: Outer parts, with minimum relevance in crash-safety, have to be preferably light, whereas structure parts in the crash-zones should offer a high and well-defined stiffness. To cope with this task, the use of a number of different materials for the metal-parts of one model is necessary. Sheet metal suppliers have identified this market and try to satisfy the needs of the car manufacturers with improvements in properties of formability and strength, so that nowadays a large amount of sheet metal types is available and still increasing.

Another aim of automotive manufacturing is to reduce the development time of successive models. This is basically obtained by computational design. In the recent past, the finite elements method has proved itself to be the most efficient tool relating to sheet metal forming processes. Due to the increasing amount of different sheet metal types in use mentioned above, the acquisition of material-properties as input-data for forming simulations increases analogous. Depending on the material model being used to simulate the formability of the material, several complex and expensive tests (both in time as well as in cost) have to be performed.

At this point, a further field of application of FE-based simulation is able to simplify the parameter acquisition: Simulations of the microstructural behaviour of the material are able to predict several properties of cold rolled sheets in a reliable manner. Virtual tests in the form of pressure-, tensile- or shear-deformation using the results of a previous cold rolling simulation as input can be used to obtain the required input-parameters for forming simulations. The current work delivers an insight into a first approach to using virtually obtained material-parameters as input-data for forming simulations with LS-Dyna.

2 Parameter acquisition as input-data of forming simulations

Forming simulation based on the FEM requires as input specific information about the stress-strain-behaviour of the respective material. Recently, a work routine has been established in the form of a modular conception by separating diverse information in different files: Information about the FE-meshes of forming tools and blank geometry is each stored in single files. Similarly, information about the material behaviour is achieved in one material data file. By doing so, it is possible to prepare templates only with the time dependent information about the staged operations of the whole forming process. The modular conception allows to import all these files and to combine all the information of these particular files in one supervisor file that controls the simulation software. For instance, if the simulation should act as an indicator of the suitability of some different materials for one known forming process, only the material file has to be exchanged. In recent work, this proceeding is applied to compare two different material data files.

From the perspective of a forming technician the accuracy of these material data files is essential for correct simulation results, of course within the chosen material model itself. Parameter acquisition is expensive in time and costs whenever a new material has to be tested for forming simulations. Therefore, a simplification of the data acquisition is much appreciated as necessary parameters would be receivable soon and economically priced but equally accurate as the parameters obtained by the standard procedure. At best, this should be accomplished at the sheet metal suppliers, who could provide the according parameters to their clients when offering a new type of sheet metal. Microstructural FE-simulation on volume elements is a promising technique to master this challenge. The distribution of grain of the hot rolled sheets serves as initial situation of a cold rolling simulation. In turn, the resultant distribution can be used for virtual tension, shear or compression test. The stress-strain-response of these simulations shall substitute the curves obtained by real experiments. Further information is available in [1] and [2]

In the standard practice of forming simulation with the objective of checking the producibility of certain parts or designing tools, the source of the parameters is irrelevant as long as the results reflect the reality. Therefore, the “Virtual Lab” could serve as a black box from the perspective of an ordinary user.

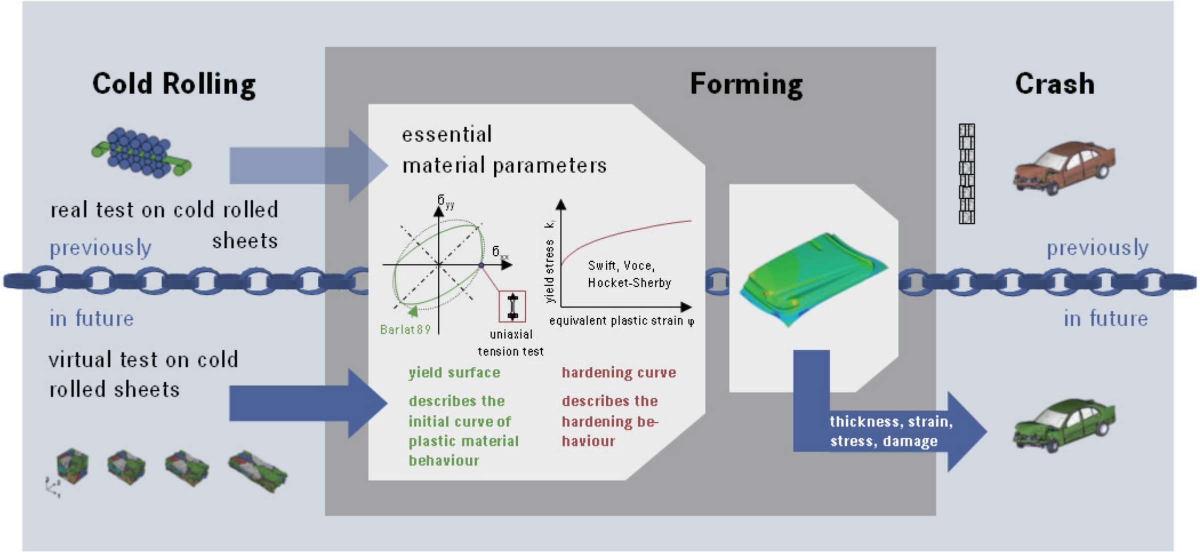


Figure 1: process chain of sheet metal forming

3 Methodology

At present, the Virtual Lab mentioned above is still under development and surely does not provide every possible input-parameter for diverse material models. In a first step the yield surface of Barlat-Lian89 [3] was chosen and combined with a yield curve approximation by the rule of Gosh. The Barlat-Lian89 based MAT_36 LS-Dyna material model [4] requires as input the following parameters usually obtained by experiments:

- Young’s modulus
- Poission’s ratio
- Mass density
- The Lankford anisotropic values in 0°, 45° and 90° with respect to the rolling direction
- Parameters for the description of the chosen hardening rule

Young’s modulus, Poisson’s ratio and mass density usually do not vary within the material group of steels, so that these input parameters are expected as constants for steels. Only the Lankford parameters and the hardening rule exponents have to be fitted to the present material. For this purpose uniaxial tension test in 0°, 45° and 90° with respect to the rolling direction have to be performed. This work intends to give an overview how close the results of the ”Virtual Lab“ match the results of real tension tests, for both material data files an extrapolation of the hardening curve by Gosh is assumed, although perhaps an extrapolation by the rules of Swift [5] or Voce [6] could match better at higher degrees of deformation compared to a real deep drawing process.

In this examination two different material input files are used. The first material data file serves as reference and bases on the standard procedure of acquiring material parameters: Several uniaxial tension tests on a dual phase steel in 0°, 45° and 90° with respect to the rolling direction establish a basis for an averaged yield curve and Lankford values. The second material data file exclusively uses the information about the stress-strain-behaviour of a dual phase microstructure estimated by the Virtual Lab. Both material data files differ from each other only in the Lankford parameters and the hardening rule parameters as shown in *Figure 2*

	real test	Virtual Lab
Lankford parameters		
r0°	0.8699	0.8237
r45°	0.6654	0.8120
r90°	0.8015	0.7998
Hardening rule parameters		
$kf = a \cdot (b + \phi)^n - c$		
a	4.94	1.5239277
b	0.00449	0.000022
c	3.70	-0.052916
n	0.0353	0.260021

Figure 2: Input-Parameters

The Lankford parameter for 90° was estimated very close to the real value. Likewise, the value for 0 degrees is within a 5% deviation to the real value. Only the 45° parameter exhibits a deviation of 22%. Despite the obvious differences in the hardening parameters, the hardening curves are in the same order of magnitude for plastic strains smaller than 20% as seen in *Figure 3.*

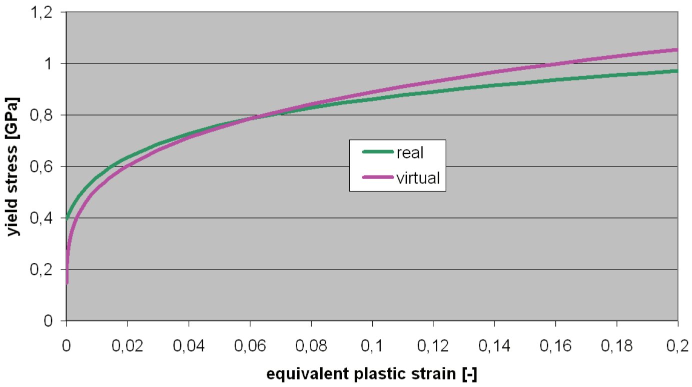


Figure 3: hardening curves of real and virtual material

4 Deep drawing simulation

The material files were included in succession in a LS-Dyna template of a deep drawing process of a so called ‘cross die’ tool (see *Figure 4*). The process parameters “draw depth“ and “binder force“ are chosen, so that a real deep drawing experiment with the considerate dual phase steel would produce good parts.

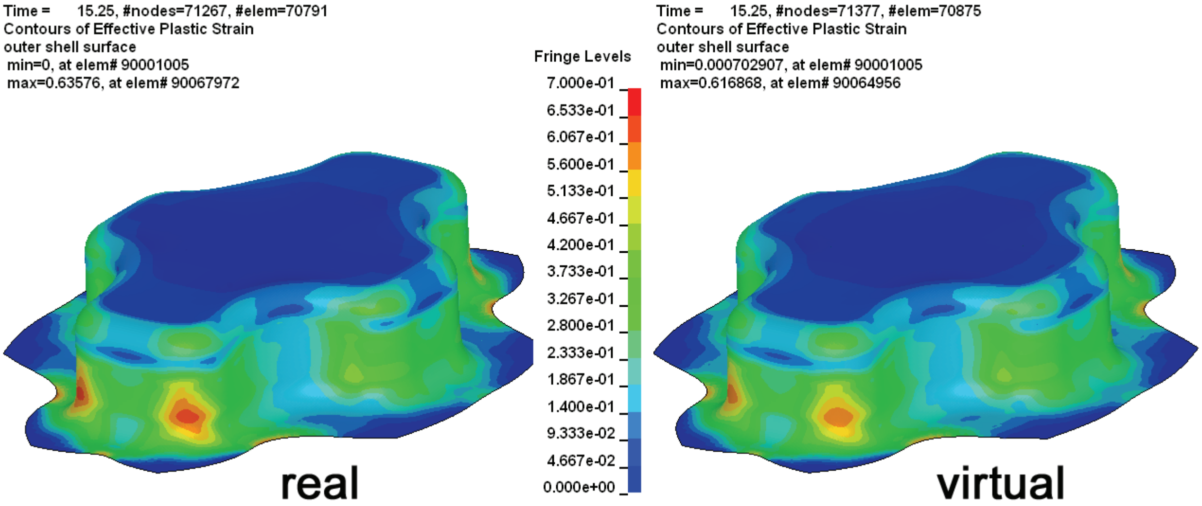


Figure 4: effective plastic strain

By evaluating the effective plastic strain one can see in *Figure 4* that the allocation looks relating. Only in a few areas the fringe levels do not coincide. The maximum level of 61.5% for the Virtual Lab based simulation is predicted accurate enough in comparison to the 63.6% of the reference simulation. Regarding the fact that reference simulation itself still exhibits a discrepancy to the real measured strain allocation, which is not examined in this work, the result of the virtual-based simulation can be seen as an alternative.

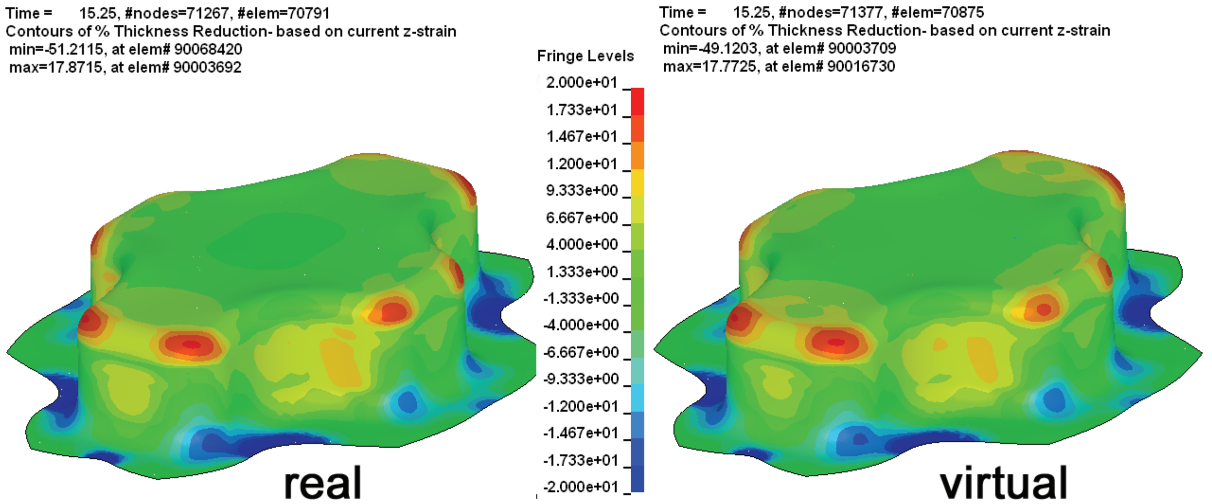


Figure 5: thickness reduction

The relative thickness reduction (*Figure 5*) is of similar accuracy than seen at the strain prediction. Minimum and maximum values are nearly identical and the allocation of the thickness reduction looks despite some small exceptions in the yellow and orange middle range fringes (and thus non-critical areas) very similar.

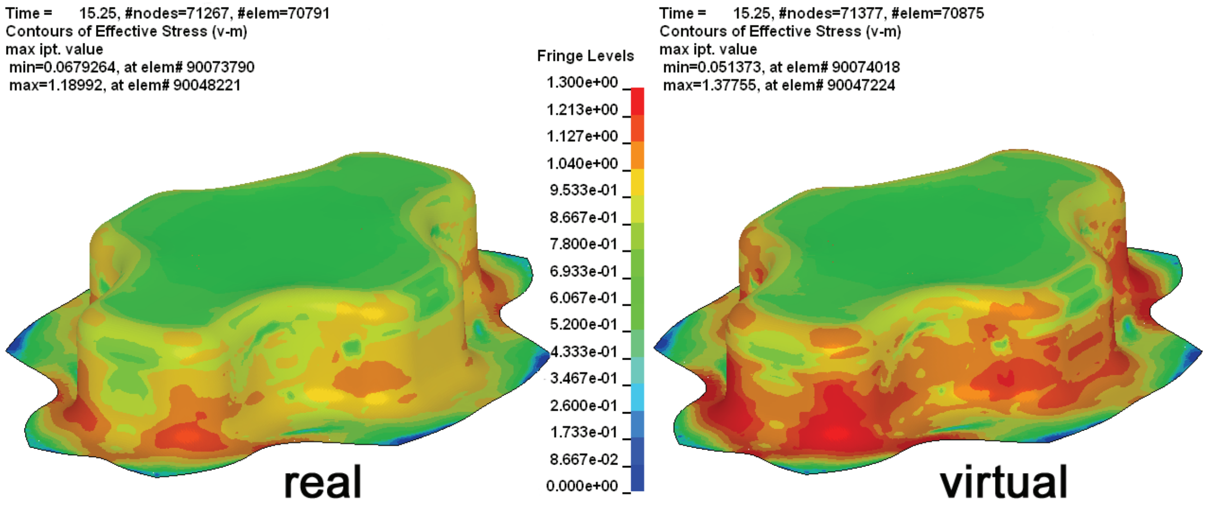


Figure 6: effective stress (von mises stress)

Figure 6 shows that the contours of the effective stresses diverge remarkably from each other. The maximum value estimated by the Virtual Lab based material data is about 15% higher than that one estimated by the real material data. Assuming that the simulation based on the real material data is closer to the actual stresses in reality, the simulation based on virtual data would overestimate the stresses. A standard user in product developing, who works with this virtually obtained material data, would therefore not exploit the material's potential concerning forming ability. However, comparing the areas of high stresses in *Figure 6* with the areas of equivalent plastic strain in Figure 4 one can see, that the differences in stresses between real and virtual data rise from strains larger than 20%. Keeping this fact in mind while regarding the hardening curve in *Figure 3* it becomes obvious that the curve extrapolation is the main reason for the differences in stresses. The strains in the trouble spots are far beyond the illustrated 20% in *Figure 3.* One comprehensive explanation for this discrepancy is the fact that the basic curves of the real material data are obtained in reality by uniaxial tension tests with plastic strains up to 15%, while the stress-strain-curves taken as basis for the virtual material data only reaches about 10% (owing to limited available computing time). Therefore the extrapolation of the virtual hardening curve lacks supporting points at higher strains.

5 Discussion and Outlook

As shown in the above, the accuracy of FE-simulations based on material data files that are obtained by microstructural simulations is remarkably good. Due to the fact that this approach is the first ever, one could suspect that the potential of this proceeding is not fully exhausted. Successive work should base on virtual tension tests that reach at least to the end of the uniform elongation area for a better extrapolation of the hardening curves. Furthermore, a bulge test should be carried out to choose a matching hardening rule (Swift, Gosh, Hocket-Sherby) based on the knowledge of supporting points at larger strains. Only by doing so, it can be guaranteed that the stress response of both simulations (Reality based and Virtual Lab based) to larger strains reflects the behaviour of the actual material hardening in reality. At the time of preparing this work the results of a bulge test were not available, so the Gosh hardening rule was chosen only by experience with other dual phase steels. The noticed deviation of the Lankford parameter in 45° to the measured value in 45° with respect to the rolling direction is also a fact that will critically be observed.

It should be mentioned that a forming simulation can only be as accurate as the applied material model. If some forming processes within the microstructure are not considered in the basic approach of the material model, the most meticulous parameter acquisition does not yield an exploitable result. In this work, the yield surface of Barlat-Lian89 [3] was used that considers isotropic hardening only. In the future, it would be worthwhile to enhance the Virtual Lab towards more output-parameters for fitting further material models. For instance, a biaxial tension test, a simple shear test or tension-compression-test could easily be implemented. In a further step the effects of distortional hardening taking strain path changes into account could be implemented as well. Advanced material models that consider the cross hardening effect of strain path changes as described in the work of Teodosiu [7] or Wang et al [8,9] also complement the basic idea of the Virtual Lab.

6 Literature

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