FEA - Calculation of the Hydroforming Process with LS-DYNA

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Abstract

The automotive industry is constantly searching for product improvements concerning weight reduction and the need for corrosion resistance. Currently aluminium alloys are of special interest because of their low density of 2.76 g/cm³, and good corrosion resistance. The disadvantage of aluminium alloys is poor formability in comparison to steel. Therefore, new forming methods are demanded such as the "tube hydroforming" process, which has been reasonably successful in creating complex parts in aluminium alloys. This process involves the concurrent pressurization and axial compression of a tube, causing the material of the tube to flow into a die cavity, achieving the form of the final component shape. Lightweight and complex forms of aluminium components have been achieved successfully, when the process parameters are calculated and controlled accurately. Due to its various shaping and design possibilities, the hydroforming process has been used for more than 10 years in the automotive industry for the production of complex carrier structure units. The requirements e.g. the shaping possibilities, respectively, the design space of unit geometry, the expansion relationship, as well as the maximum plastic deformation possibility has risen constantly over that time. This requires ever larger efforts to fulfil these requirements under the compliance of fixed time and cost goals. The contents of this work are the task of the FEA-Simulation of the hydroforming process. It consists in a general feasibility study for the forming behaviour of the semi-finished product and/or the tools. Due to the complex connections of the process influence parameters the non-linear finite elements (LS-DYNA) offers the condition to fulfil these requirements, in particular regarding plausibility check, general feasibility as well as adjusting quality and tolerance field promises (formation of wrinkles, springback, form and position tolerances). A quality increase can additionally be derived accompanying the increase of manufacturing security for series production by the evaluation of the manufacturing simulation.

Introduction

In the history of metal forming technology the automotive industry has proven that they have been the driving force in the last century. Thereby the continuous development of manufacturing processes was the basis for continuous improvement of the products. Simultaneously, new procedures were developed which facilitated more complex component geometries and guaranteed an increased efficiency and availability of the parts.
In order to be able to realize the demands, new deformation processes and manufacturing machines were developed which corresponded to the requirements. Over the years the forming procedures which have arisen can be subdivided. One possibility for the classification is the subdivision in procedures of sheet metal forming or in procedures of massive forming. The most frequently used, and also standardized possibility of the subdivision, is defined in the DIN 8582. In this case the procedures are subdivided according to the mainly effective stresses (Figure 1).

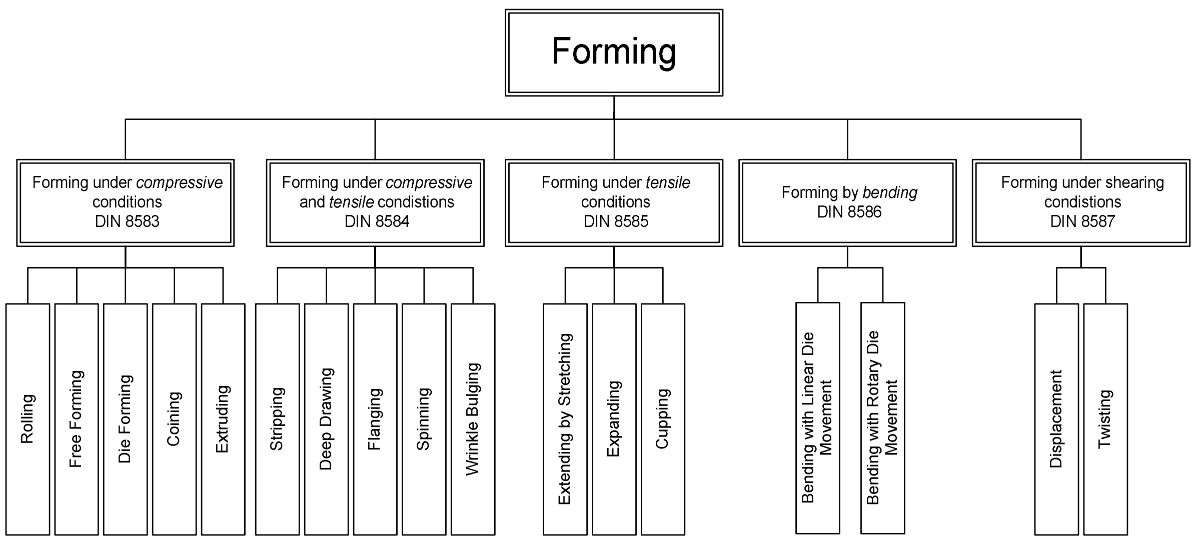

Figure 1: Subdivision of manufacturing processes according to DIN 8582

Due to resources becoming scarcer and increasing environmental pollution, lightweight construction is of specific importance in product design. As a result of these requirements, a new forming process could be established among the classical forming processes - the hydroforming of tubes (Birkert et.al 2002). Because of the increasing complexity of components further forming steps are necessary before the actual hydroforming process is commenced. Normally, these are the tube bending and/or the preforming. The following pages show the forming-steps of a complete manufacturing chain of the hydroforming process.

The Process-Chain of the Hydroforming

Through the increasing complexity of the components further forming-steps have to be ahead to the hydroforming. These are in most cases the tube bending and/or the pre-forming (Figure 2). Subsequently the individual forming steps of a complete manufacturing chain of the hydroforming process are described, beginning with the tube bending.

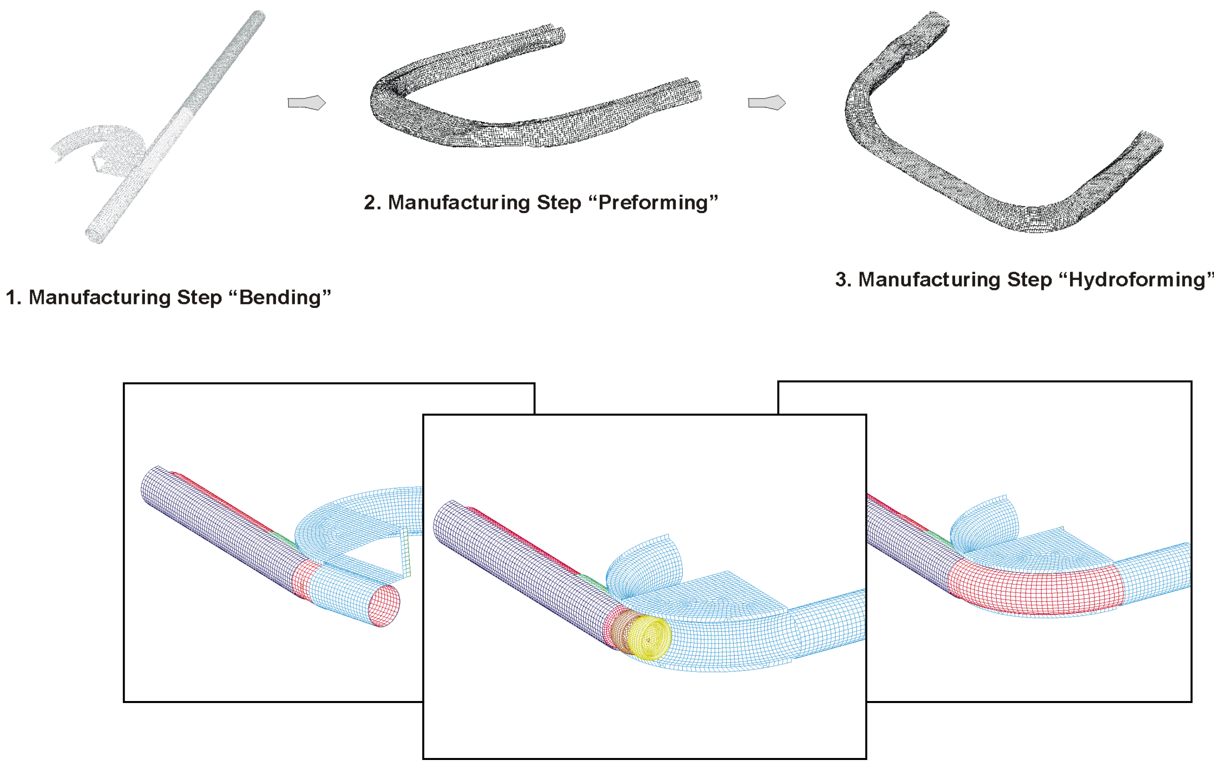

Figure 2: Process-Chain of the hydroforming showing bending, preforming and hydroforming

The Bending

Since 1999, over 3/4 of all hydroformed components in the automotive industry had curved component axis. Two different procedures are state of the art bending processes as pre-forming for the hydroforming process: the conventional rotary draw bending and the die bending. The decision of which procedure will be used depends on economical aspects, mechanical qualities of the material, tube dimension and bending radius.

The increased number of applications of the hydroforming process increased the desire for new, better and more efficient bending-procedures. Thereby different requirements are demanded. The automotive suppliers for exhaust and cooling systems aspire to smaller bend ratios (D/R). The car manufacturers want to realize more flexible bend procedures including different bending radii in a short time frame. Two procedures are very promising concerning these requirements: the rotary draw bending with axial load and the free-form-bending.

The Preforming

The continuously complex component geometries make it more frequently necessary to preform after the bending and before the actual hydroforming process. This process has to be defined considering different economic aspects. Not only do the increasing tool and manufacturing costs have to be considered but also the improvement of the component quality, the increase of the manufacturing safety and the reduction of the tool wear. Whether a preforming process is necessary, in order to guarantee a safe manufacturing of the component, mainly depends on the cross section distribution of the initial component in relation to the final geometry. In general it is distinguished in two main groups which make the preforming necessary:

1. The cross sections of the component geometry allows a secure forming of the initial tube, however, there are fields with high local expansion. In this case the preforming is used to reach a pre-distribution of the tube material. During the preforming a material accumulation is created by purposeful modification of the cross sections at places of local expansion or the shape of the cross sections is adjusted as near as possible to the final contour. Thereby the serial production becomes process safe and the quality of the final product is improved
2. The diameter of the initial tube is larger than the opening of the gravure in the closing-plane. This would lead to a so called „pinch" during the closing of the tools. Thus a flat pressing is necessary. In some cases the flat pressing can be done also in the hydroforming dies. For this purpose stamp units have to be integrated into the hydroforming dies. This possibility has to be examined exactly. The stability of the entire tool is influenced by the integration of a stamp unit and the fatigue resistance can decrease.

To reach the optimal shape of the component after the preforming, different concepts are used. In order to achieve an optimal material accumulation, tools with geometries between the initial and final contour designed. The tools are often near the final component contour but they can also contain slide units which press the material in a defined position. At problems during the closing of the hydroforming dies often very simple preforming tools are designed which flatten the initial tube at some places or over the complete length. A third variant is the combination of flattening and material accumulation. This variant is necessary if a high local expansion exists in areas where the tube diameter is larger than the opening of the gravure.

The Hydroforming

Today, hydroforming processes tend to belong to active fluid medium procedures for the forming of tubes and profiles but also procedures for the forming of welded sheets by means of internal pressure (Fritz et.la 2001). Up to now the main focus of the application lies in the hydroforming of tubes.

First industrial applications of this procedure e.g. for the production of tube bifurcation elements were presented in publications in the 1960s. The use of the hydroforming process increased very quickly as the automotive industry became attentive onto this procedure in the 1980s. They recognized the possible use for the lightweight construction.

The principle of the process for the hydroforming of tubes follows from Figure 3. A tube is loaded into a die which inside geometry corresponds to the exterior geometry of the part to be manufactured. The normally longitudinal divided tools are closed by means of the ram

movement of a hydraulic press. The tube end faces are loaded by two in tube longitudinal direction moveable stamps. Each of the forces effecting the tube end faces have to be sufficient to seal the tube interior. Therefore forces are necessary which at least correspond to the force calculated by tube cross section surface and internal pressure. The axial loads can be increased over this value if the forming-task requires it. Compressive stresses are produced inside the tube whereby the formability can be increased.
In the further progression of the process the internal pressure is increased until surface contact is made between the expanding tube wall and the inside surface of the dies. After the complete surface contact has occurred the internal pressure is lowered to the environment pressure, the axial stamps are relieved and the hydraulic press opens for the unloading of the completed component (Birkert et al 2002).

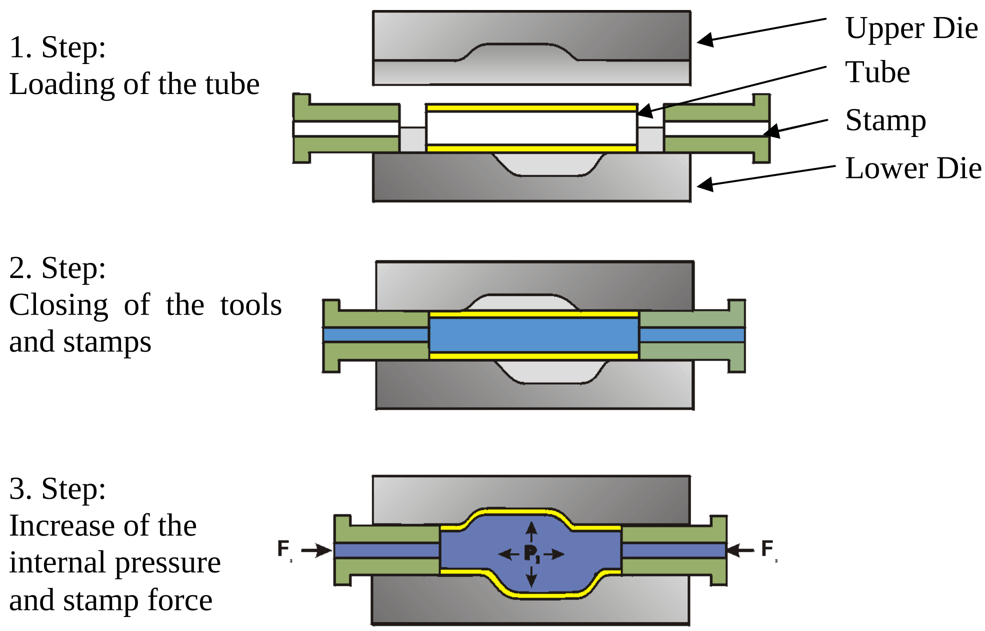

Figure 3: Operation sequence of the hydroforming process of a tube

The increasing number of applications of the hydroforming process shows the potential of this production method. The most important arguments are the flexibility in the cross section design, the integration of secondary form elements and the high stiffness of the final part in comparison with sheet metal constructions. Particularly in lightweight construction the hydroforming process is used. In this case aluminium is very important (Wieser et al 2002). During the effort to use the maximally possible expansion of the aluminium (approx. 20 %) the boundaries of the formability are very often reached. It is difficult for the product designer to rate the feasibility of the component particularly at components which need additional forming processes like bending or pre-forming. Therefore a theoretical pre-inspection is necessary which examines the component regarding the feasibility and properties as wall-thickness distribution and strain hardening. In the last years the FEA - (Finite Element Analysis) Forming - Simulation has proved that it is a very useful tool for this purpose (Haas 2001). In addition prototyping prior to the serial production could be abolished by means of the FEA-Forming-Simulation. Through that prototyping costs could be saved and product design times could be reduced.

FEA-Simulation of the hydroforming process chain

Important for the evaluation of the influencing factors during the FEA-Simulation is an exact, three-dimensional modelling of the tools and the tube. The tools are modelled detail-truly and meshed during the pre-processing with 4-nodes shell elements. The tube becomes finely discretised (according to the geometrical dimensions) and is meshed with Fully-Integrated shell elements. All calculations were carried out with the explicit Finite Element system LS-DYNA. The tools are defined as Rigid Bodies. They are undeformable and can, according to their function, get assigned a movement- and/or a degree of freedom definition. These are described as velocity or force controlled load curves. For the tool and also for the component the material data (density, modulus of elasticity, radical strain coefficient, yield stress, and so forth) has to be defined. For the description of the flowing-behaviour of the semifinished product LS-DYNA offers different material law formulations. For steel materials the v. Mises approach is suitable beside the formulation after Hill which considers also the strain hardening and the anisotropy in thickness direction. For the description of the material behaviour of aluminium alloys the approach according to Barlat is suitable for a flowing law formulation which considers, not only anisotropy but also the kinematic hardening (Bersted). A further technological parameter for the resulting deformations and/or the deformation degree of a forming process is the description of the friction behaviour between semifinished product and tool. In general in the materials-forming technology the Coulomb's friction law is used which is defined by the static and dynamic friction coefficient restricted by the maximum friction shear stress τ_R. In Figure 4 the FEA-Simulation of a hydroforming process chain is exemplarily represented.

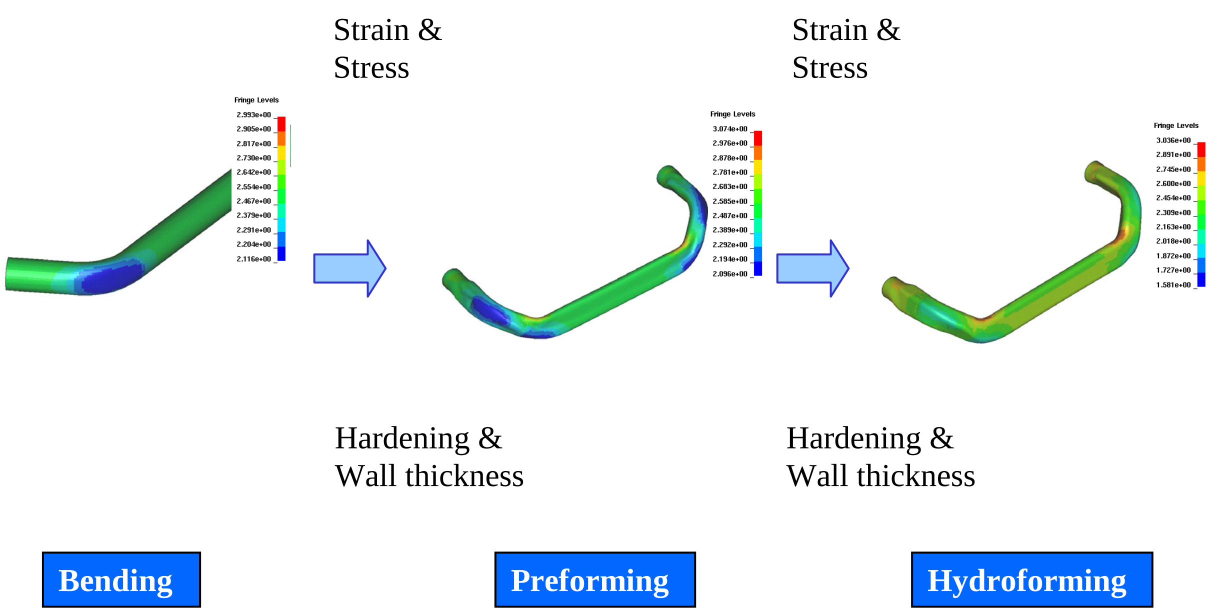

Figure 4: FEA-Simulation of a hydroforming process chain including bending, preforming and hydroforming

Important for an as precise as possible FEA-Simulation is the transfer of the results starting from the straight tube up to the last forming step (Gantner et al 2003). The results of a preform operation provide the starting point of the following forming process. By that the forecast accuracy could be further increased. LS-DYNA facilitates such a transfer of the results. In Figure 5 is the result of the FEA- Simulation of a structure component and the comparison with the formed component shown. With the use of the closed process chain (bending, pre-forming and hydroforming) a maximum difference of less than 0,1mm could be reached.

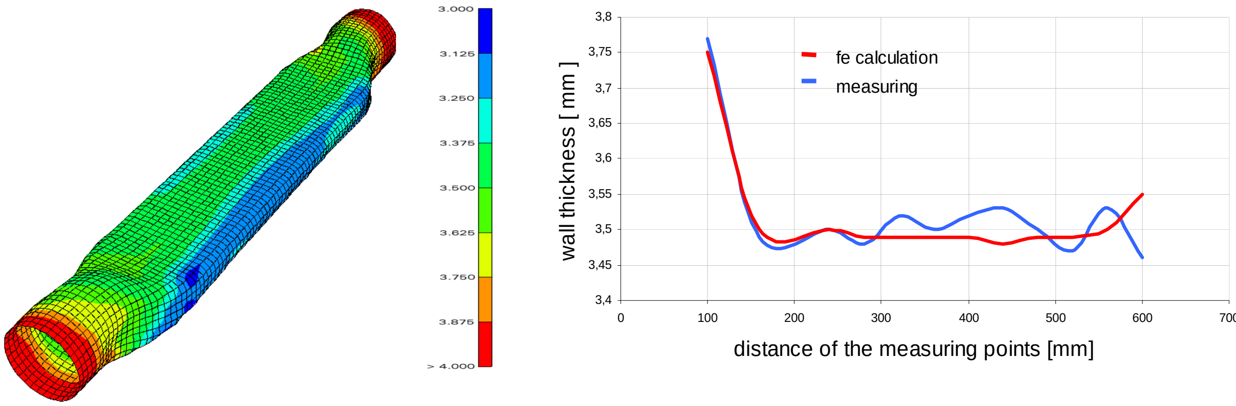

Figure 5: Comparison of a formed component with the FEA-Simulation

Upon completion of the Forming-Simulation the entire potential of the FEA is not utilised. Up to now the simulation focused only on the forming process. With the results a further optimization of strength and/or weight is possible. The state of the art in the strength analysis of, for example, structure components is an ideal state of the component, i.e. it has constant wall-thickness and uniform stiffness. This assumption is not correct. Strain hardening in the material and thickening and/or thinning out in the wall-thickness arise through the deformations during the forming process. The strain hardening increases the strength of the component through which in the arrangement to the ideal component very great differences arise. These result as a consequence of a consideration of the real (simulated) wall-thickness, a weight reduction of the component can be reached. In particular in the case of great numbers of pieces a very large potential for cost reduction arises. The extended process of the hydroforming process chain is represented in Figure 6.

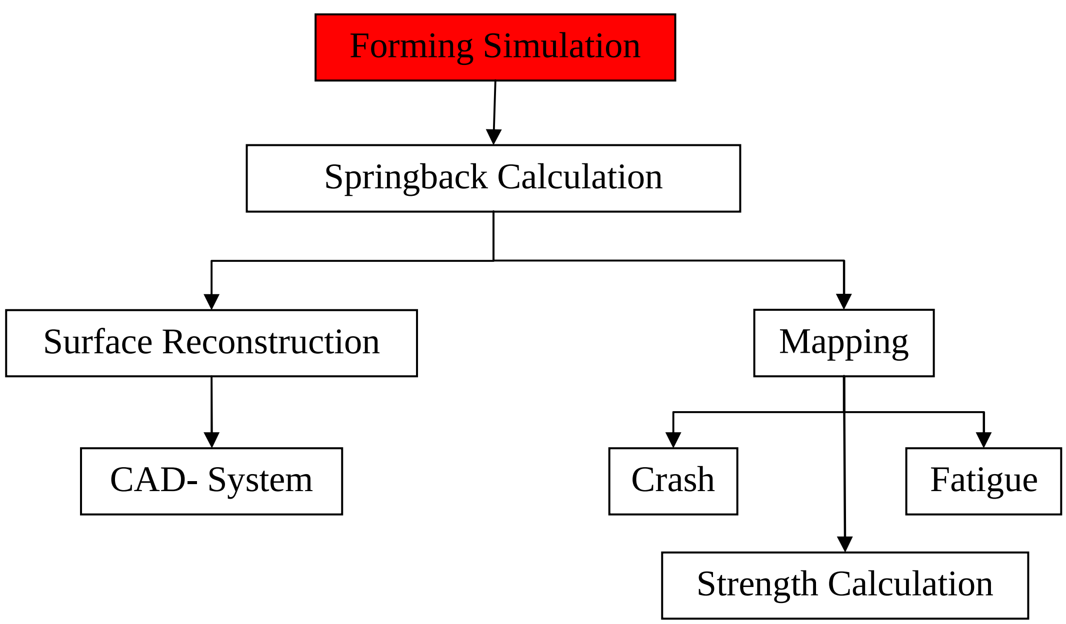

Figure 6: Extended process chain for the FEA-Simulation

From Figure 6 it appears also that the transfer of the results of the Forming-Simulation on a Crash- or Fatigue- Model can also increase the accuracy of these analyses because it is calculated not with the “ideal” geometry but with the real (Forming-Simulation results).

Summary

The enormous potential of the FEA-Simulation was shown in different fields in recent years. A reference for that is the continuously increasing number of installed systems and carried out applications. Explicit Solver offer very good possibilities for the metal forming and prove a very high accuracy. With the possibilities of LS-DYNA, results of a calculation can be used in subsequent processes. With the implemented mapping tool also a convenient possibility to adjust the mesh to the respective following problem (Crash, Strength, Fatigue) was created. Development requirement exists in the field of the springback calculation. The results show the tendencies of the springback (for example the direction) very good however the amount of the indicated springback is still afflicted with failures. Nevertheless, the number of applications of the FEA will keep on going also on the field of the cold metal forming and is thereby supported by the very fast development of the computer hardware.

References

Birkert, Sünkel (2002): “Hydroforming – Forming with Active Medium in the Automotive Industry“ (Original German Title “Hydroforming – Umformen mit Wirkmedien im Automobilbau”, 2002, Landsberg/Lech, Germany, Verlag Moderne Industrie, ISBN 3-478-93271-8

Fritz, Schulze (2001): “Product Engineering” (Original German Title “Fertigungstechnik”);2001, Berlin Heidelberg, Germany, Springer Verlag, ISBN 3-540-41238-7

Wieser, Keller, Brünger (2002): “Non Heat-Treatable Aluminum Materials for Automotive Application “, In Papers of the Interantional Conference “New Developments in Sheet Metal Forming“, Juni 4-5, Fellbach/Stuttgart, Germany, MAT-INFO Werkstoff-Informationsgesellschaft mbH, pp. 365-383, ISBN 3-8355-305-0

Haas, Bauer, Hall, Mihsein (2001): “State of the Art in the use of (LS-DYNA) forming simulation in hydroforming and preceding processes”, Third European LS-DYNA Conference 2001, June 18-19, Paris, France

Gantner, Harrison, De Silva, Bauer (2003): “More Realistic Virtual Prototyping by means of Process Chain Optimisation”, Proceedings of the 4th European LS-DYNA Users Conference, May 22-23, 2003, Ulm, Germany, pp. E-III-01 – E-III-13, ISBN 3-00-011175-1