FEA - Simulation of Bending Processes with LS-DYNA

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Abstract

Over the past few years new car body concepts have space frame structures. The consequent application of space frames results in a reduction of weight, fuel consumption, and costs of a body while maintaining a high safety standard. These structures consist mainly of closed profiles and hydroformed components. Prior to the hydroforming process, the profiles are usually pre-bent. The bending of tubes is a crucial step in the hydroforming process chain. For a successful hydroforming the bending demands high precision, reproducibility, and process reliability. These bending operations are frequently performed with parameters which are already on their limit.

For the design of hydroformed components it is unavoidable to ensure all process steps by means of FEA (Finite Element Analysis) - simulation. Especially for a precise prediction of the feasibility of the bending process and the subsequent process steps it is necessary to consider all parameters and tools (e.g. mandrel) in the simulation. This results in very complex simulation models which make great demands on the simulation programs concerning precision, contact and friction.

The contents of this paper deals with the finite element simulation of complex bending processes by using the non-linear simulation program LS-DYNA®. In the first part of the paper the simulation of the Rotary Draw Bending with a mandrel is shown by means of a practical component and the results from simulation are compared and validated with experiments. In the second part the new Free-Bending technique is introduced by an example. Both bending techniques offer new possibilities and application ranges in the field of hydroforming.

Introduction

In recent years the number of hydroformed components in cars has clearly increased. Due to their lightweight and stiff characteristics they are particularly used in crash relevant components of the framework. The advantage of this technology to combine several manufacturing steps by hydroforming results in cost efficient components. However, this production method has high investment costs for the hydroforming press and the costs for the dies can be also very high depending on the complexity of the component. Due to these high costs and the reduction of development time the simulation of hydroforming processes has proven to be very efficient. With the use of Finite Element simulation the general feasibility of the component can be investigated already before the production of the dies and also the number of try-outs can be reduced substantially.

However, for a close-to-reality simulation is it very important to consider all the process steps before the actual hydroforming in simulation. These preceding manufacturing steps are usually the determining factor for the feasibility of the component. The simulation of pre-bent components could be very complex depending on the applied bending technique. Particularly the simulation of Rotary Draw Bending, which is used very frequently, is very complex and a substantial simulation-technical expenditure is necessary to get close-to-reality results. These results (wall thickness distribution, stains, …) serve in the following hydroforming or pre-forming simulation as initial values.

In practice the simulation of the bending processes is often accomplished by one-step solvers to get the results of preformed tubes for the hydroforming simulation. These one-step solvers simulate the bending process from the straight tube to curved geometry in only one-step and compute thereby the strains and the wall thickness of the bent tube. However, several investigations of the results of one-step solvers have shown strong inaccuracies concerning the wall thickness and the strains (Keigler et al, 2003). For components with strong deformation degrees which are in the marginal area of feasibility, an incremental bending simulation is recommended. In the following, the Rotary Draw Bending technique as well as the Free-Bending technique are presented and their simulation models for an incremental simulation with LS-DYNA® are described.

Rotary Draw Bending

The rotary draw bending technique is the most widely used method of bending of pipes and tubes today, particularly for tight radii and for thin wall material. Advantages include maximum control of wall thinning and ovality (Gillanders 1984).

The bending principle

The bending of the tube is done by a swing arm where the tube is clamped just beyond the initial point of the bend. The tube is thereby being drawn around the bend die and a mandrel can be placed inside the tube to assist in forming the bend while controlling ovality and to prevent collapse of the tube during the bending. The pressure die pushes the tube against the wiper - and bend die. Wrinkles are prevented or minimized by the wiper die since the tube is jammed between the mandrel and the wiper die by means of the applied force from the pressure die. A schematic view of the bending dies is represented in Figure 1.

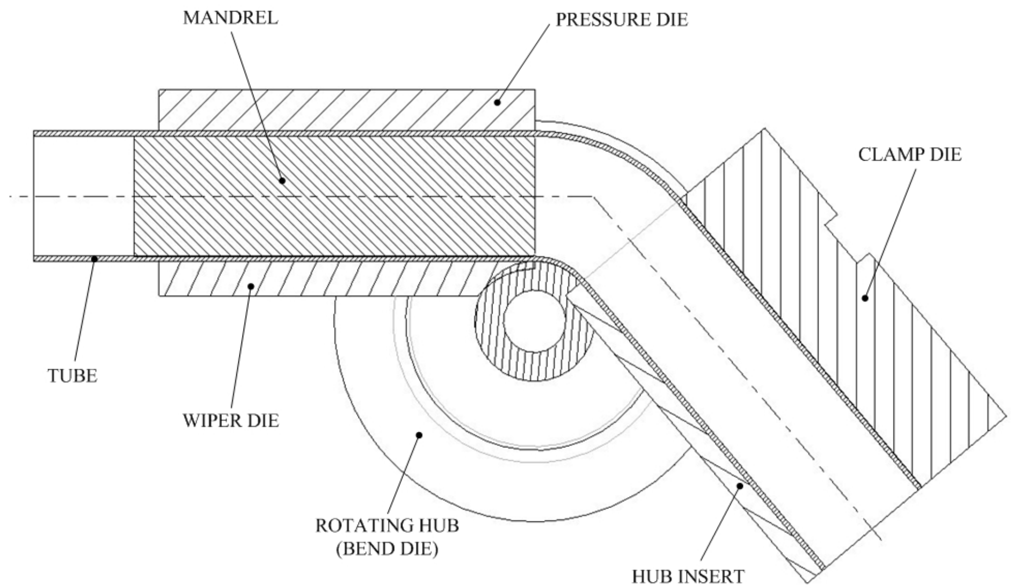

Figure 1: Rotary Draw Bending - a schematic view of the bending dies

The simulation model in LS-DYNA®

For an incremental simulation of Rotary Draw Bending all dies have to be considered to get close-to-reality results. Especially the mandrel which is available in several different types (plug, ball-mandrels, …) plays an essential role. For a simulation in LS-DYNA® all dies are meshed with shell elements and are defined as rigid bodies. The tube is discretised either with shell elements or with solid elements. However, for thin wall tubes a shell mesh is recommended, since otherwise the number of elements is very high and the calculation time of the bending process increases extremely. For the material definition there are several possibilities which depends on the material of the tube. For steel tubes with less anisotropy a material definition of v. Mises or Tresca can be used (e.g. Mat 24) and for aluminium tubes with strong anisotropy a material definition of Barlat or Hill (e.g. Mat 36) should be used. The contacts are defined with a CONTACT_SURFACE_TO_SURFACE contact definition. If a ball mandrel is used also the contacts between the several balls and the mandrel should be defined. The clamping of the tube can be done in two separate ways. The simple one is to fix the first node row of the tube at the clamp die and the hub insert with a CONSTRAINED_EXTRA_NODES_SET definition. In this case the diameter of the clamp die and the hub insert is the same as the outer diameter of the tube. The other way is to define a separate clamping simulation where the clamp die, which has a 0.1 - 0.2 mm smaller diameter than the tube, moves toward the hub insert and clamps the inlaying tube. This way is in fact closer to reality but it needs some more time and is not needed in most cases. For tubes with several bends, each bend has to be calculated in a separate simulation. Figure 2 shows the simulation steps of a tube with 5 bends.

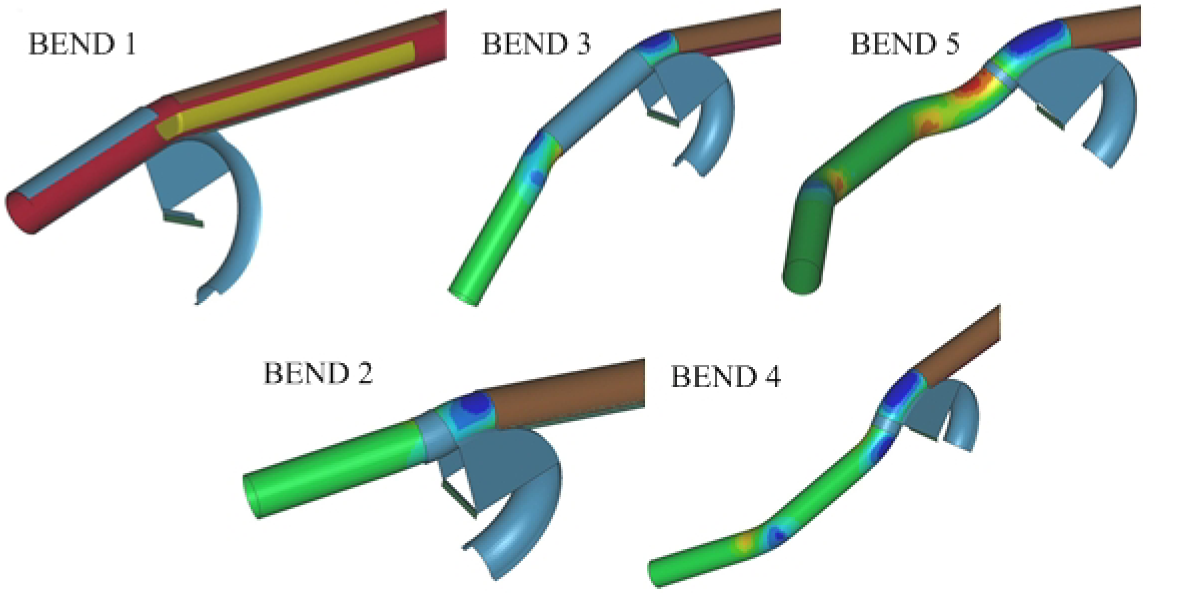

Figure 2: Continuous simulation of a tube with five bends

The simulation of small bends which need a ball mandrel are defined with the detailed mandrel with all the balls and links. The links are thereby simplified as beams which were connected at one ball with a spherical joint and at the other ball it is fixed. Figure 3 shows a ball mandrel and the appropriate simulation model.

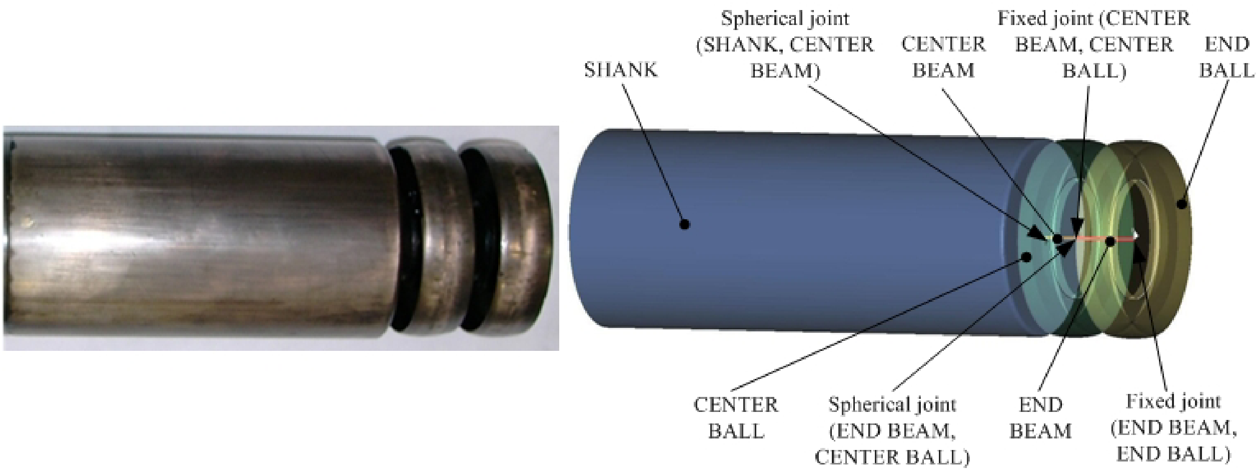

Figure 3: Ball mandrel with the appropriate simulation model

Rotary Draw Bending with Axial Pushing Force

Bends with an extreme bend factor (ratio of the bending radius to the outer tube diameter) can be realised with axial pushing force. New bending machines have therefore the possibility to push the tube during the bending towards the bend die which leads to smaller strains and smaller wall thickness reduction in the outer bend of the tube. These characteristics are very important in the field of the automobile exhaust gas pipe due to the fact that such bending radii became necessary in consequence of increasingly smaller installation space. A further advantage is the decrease of the wall thickness reduction in the outer bend. This aspect is also interesting for an application of the new Rotary Draw Bending technology in the field of hydroformed components with extreme geometries.

Simulation of Rotary Draw Bending with axial pushing force

For the simulation of this bending technique the force is applied to the last two node rows at the end of the tube. The force is thereby defined by a force curve which increases very fast at the beginning of the bending process and decreases then slowly. Figure 4 represents a tube which was bent with axial pushing force.

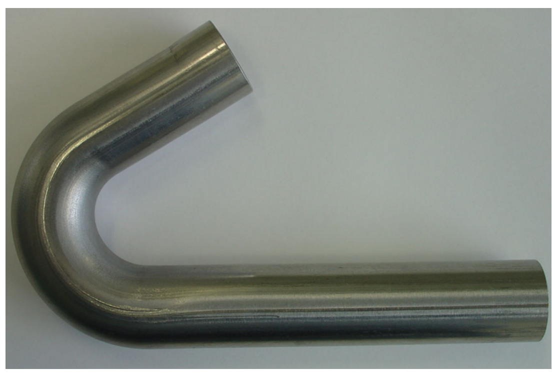

Figure 4: Steel tube which was bent with axial pushing force: 32 mm diameter, 1.2 mm wall thickness, 148° bending angle, 35 mm bending radius

The tube shown in Figure 4 was simulated with solid and shell elements. The solid meshed tube has 4 brick elements through the thickness with an edge length of 0.8 x 1.2 x 0.3 mm and the elements are fully integrated. The shell meshed tube is discretised with fully integrated 4 node elements with an edge length of 1.5 x 1.5 mm and with 5 integration points through the wall thickness.

The Figure 5 represents the results of the solid and the shell simulation in comparison with the ultrasonically measured tube. A comparison of the results shows a good congruence in the middle section of the bend. At its beginning and at its end the results of the solid and the shell simulation show minor differences to the measured results.

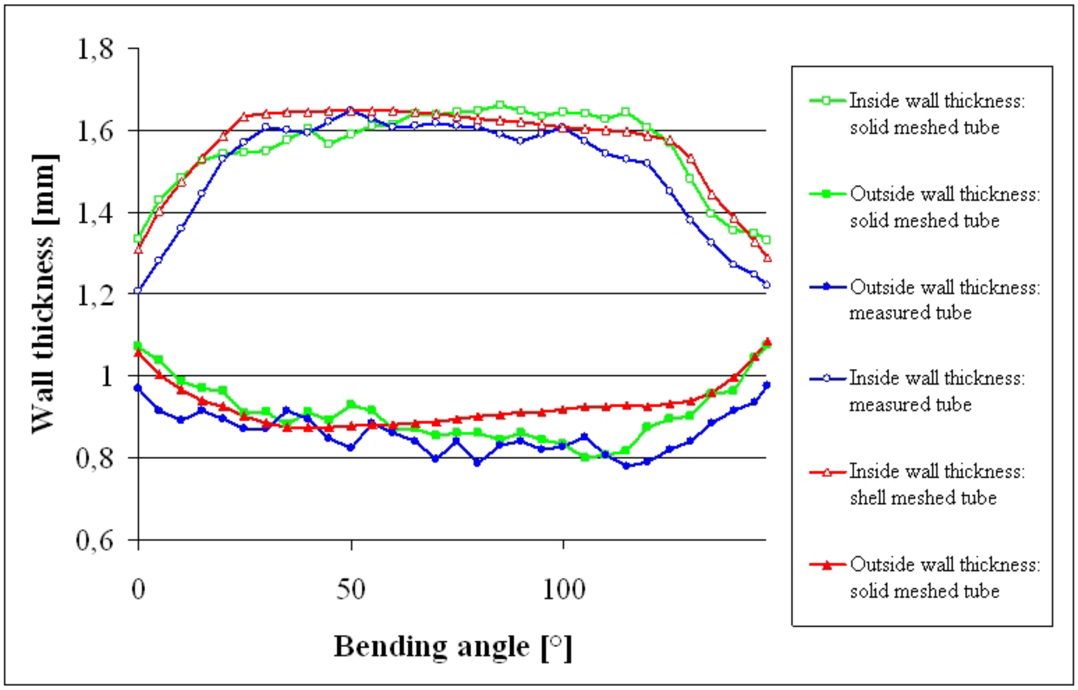

Figure 5: Results of the solid and shell simulations in comparison with the measured tube

Free-Bending

Free-Bending is a new bending technology with a wide range of applications. This bending technique allows the bending of almost any required geometry. The special concept permits it to realise almost arbitrary bending angles with freely definable bending radii without tool changes and without re-clamping. Thereby, the bends can flow in a transition-less way together and can be in several planes (Murata et al, 2003). It is also possible to create bends over 180° together with spiral forms. Besides the geometrical capability, a very good cycle time is given regarding the application in series production by the very fast bending speed up to 350 mm/s (Neu, 2003).

The bending principle

The Free-Bending machine has three main tools: a guide, the bend die and the ring. The bend die is spherically seated in the ring and is also spherically seated on the guide. For bending, the tube is pushed through the guide and the bend die by an axial drive and the ring is driven in the plain which is orthogonal to the tube axis. A schematic representation of the dies is shown in Figure 6.

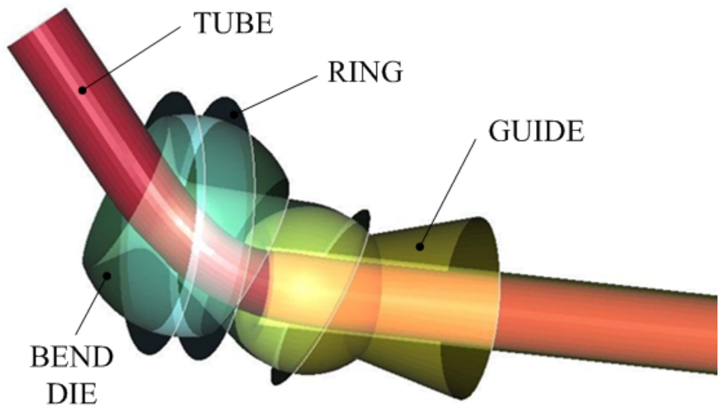

Figure 6: A Schematic representation of the dies of a Free Bending Machine

The simulation of Free-Bending

For an investigation of Free-Bending with a close-to-reality simulation model a tube geometry with different bending radii and different bending angles was bent and simulated with LS-DYNA®. The steel tube with 6 bends has a diameter of 25 mm and a wall thickness of 2mm (see Figure 7). To demonstrate the advantages of this new technology the bends 4 and 5 were bent as transition-less splines.

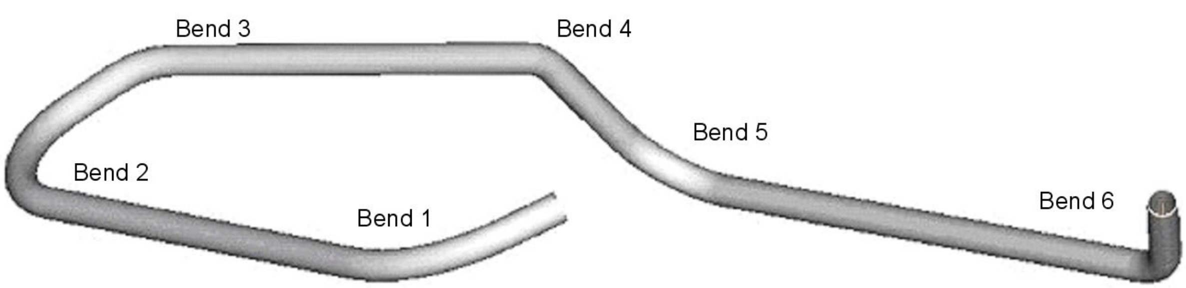

Figure 7: A Steel tube which was bent with the Free-Bending technique

For the simulation of the Free-Bending process the tube is meshed with fully integrated quad shell elements with 5 integration points through the thickness. The dies are meshed with under-integrated shell elements and are defined as rigid bodies. The feed of the ring is defined by movement curves in the X and Y direction and the contacts between the dies are defined with a CONTACT_SURFACE_TO_SURFACE contact definition. The process parameters for the several movement curves in the simulation (e.g. the movement of the ring and the axial feed of the tube) were taken from the CNC controller of the bending machine. Each bend was simulated separately and was then compared with the measured tubes.

The comparison of the results

For a comparison of the simulation results with the measured values from the bent tubes the results of the simulation were reconstructed into the Pro/ENGINEER® CAD system by means of a special program (Gantner et al, 2003). The Table 1 shows the results of the bending angles from simulation in comparison with the measured angles from the bending tests.

Table 1: Comparison of the bending and simulation results

	Bend 1	Bend 2	Bend 3	Bend 4	Bend 5	Bend 6
Measured angle	54.7°	95.0°	33.1°	Spline	Spline	54.7°
Simulated angle	63.6°	102.7°	38.4°	-	-	61.6°

Summary and future work

In this paper two bending technologies and their appropriate simulation models were presented. Rotary Draw Bending is a technology which is often used to produce the pre-bent tubes for hydroforming processes. For a safe and producible design of hydroformed components it is essential to simulate all the process steps including the bending to get close-to-reality results. The conformance of the results from the bending simulation and the bending tests shows that also the simulation of extreme bend factors and bending angles provides accurate results.

The new Free-Bending technique which was presented in the second part of the paper offers a high degree of capability concerning the bending geometry and bending speed. These advantages are very interesting for an application in the field of hydroforming. However, the simulation model for this bending technology has considerable deviations in the bending angles. Therefore it is intended to accomplish some further bending tests with different bending angles to improve the simulation model.

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