Bending with hydroforming – an alternative to bending with mandrel

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Abstract

This contribution will give an overview of the process Bending with Hydroforming (BWH) with the positive and negative sides linked to this methodology. Short cycle times, good repeatability, cost-efficient manufacturing and bending of thin-walled tubes with bending ratio smaller than 0.8 is possible using BWH. On the negative side we have limited flexibility and limited tuning possibilities in comparison to classic bending with mandrel, and therefore also narrower process possibilities.

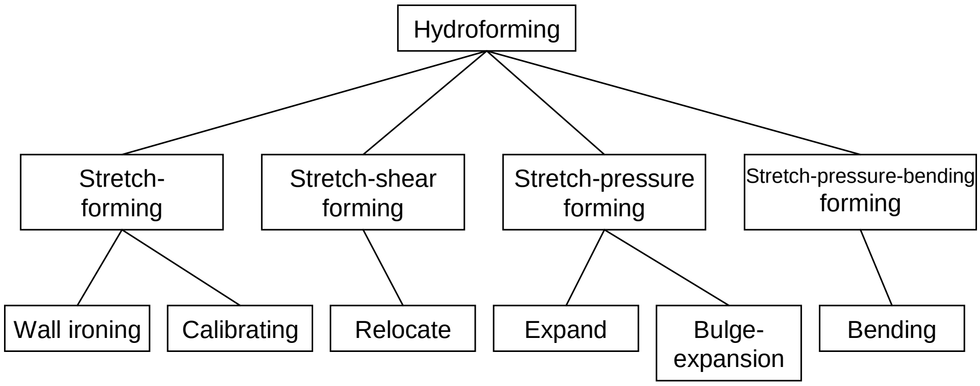
1 Introduction

The requirements on bent tubes in the automotive industry are described increasingly with thin-walled materials in different materials and critical and complex to form geometries. This combination puts special challenges to the forming process. Since 1991 first theoretical developments of a process variation of hydroforming are known, using interior high pressure forming to make a bending of tubes possible.

Using the example of an EGR part the BWH is to be described from the design using simulation to the realization during the series process. A goal is it to manufacture the part as a multiple part with small process-determined scrap and short cycle times. The part has a constant diameter of 25mm and is bent 90° with a bending radius of 18mm. That corresponds to a bending ratio (bending radius: tube diameter) of 0,7. The minimal wall thickness in the outside is 0,5mm. A material of the quality 1,4301 is used.

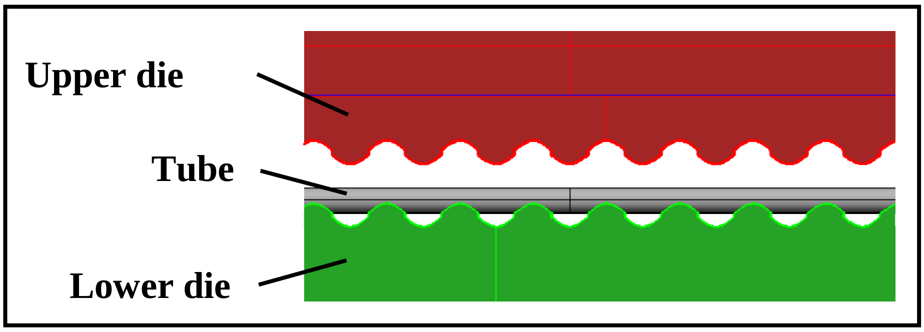
2 Bending with hydroforming

Bending with hydroforming counts as one of the expansion forming variations and can be classified using the main type of stresses in the forming zone. Picture 1 shows the classification of process variations using internal pressure.
In this process variation, the bending stresses are the main type, so this has a special place in the classification.



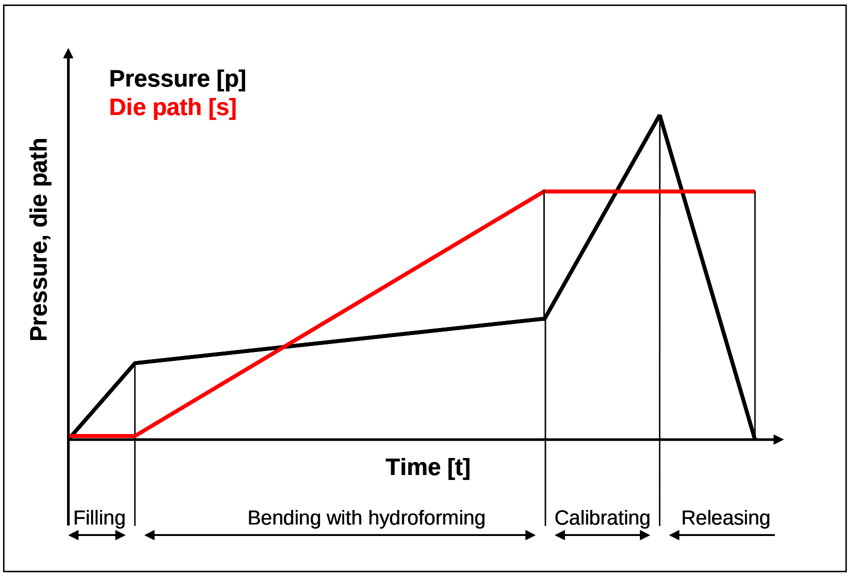
Picture 1: Classification of the different hydroforming variations after the effective stresses /1/

In the bending with hydroforming process, a straight piece of tube is formed in one step to a three-dimensional part with bent axis and section wise changing cross section. /2/
The bent tube is put into a negative shaped die with a separating plane. The negative shape is equivalent to the geometry of the final part (see picture 2). The negative shape describes a BWH-line in which several equal parts are contained. The single bends are joined together at the end of the bends to make up a line.



Picture 2: Tools with straight tube

After the filling of the tube with the high pressure liquid in the opened dies, the ends of the tube are sealed against the pressure from the internal fluid. Then the dies are closed. The forming process is done in two phases. First the tube will be bent by closing the dies with a given pressure increase curve. The internal pressure will act as a support from the inside and prevents wrinkles from occurring. In the second phase, the tube will be calibrated with increased internal pressure, whilst the dies remain closed (see picture 3).



Picture 3: Process parameters

The influence of the bending geometry in BWH was checked on forming feasibility and documented in a process diagram.

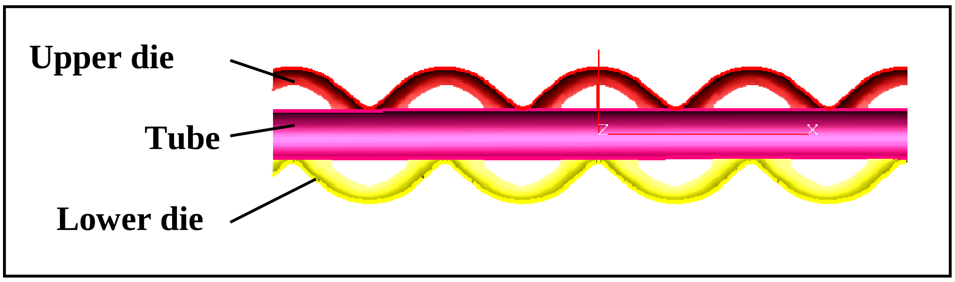
3 FEM-Simulation

3.1 Model description

Bending with hydroforming

For the feasibility study of the forming process BWH und to check the optimization of the process parameters, FEM simulations were performed using the software PAM-Tube 2G.

The initial tube with a diameter of 24mm and a wall thickness of 1mm was meshed using 40 shell elements in the circumference. The tools were defined as rigid bodies. The simulation was done using coulomb friction with a value of 0.1 between tools and the tube. Picture 4 shows the tool arrangement used in the simulation. The objective is to simulate the process as close as possible to the reality. Therefore an autopositioning was performed at the beginning of the simulation to have a realistic picture of the tube being put into the tools until the first contact with the dies.

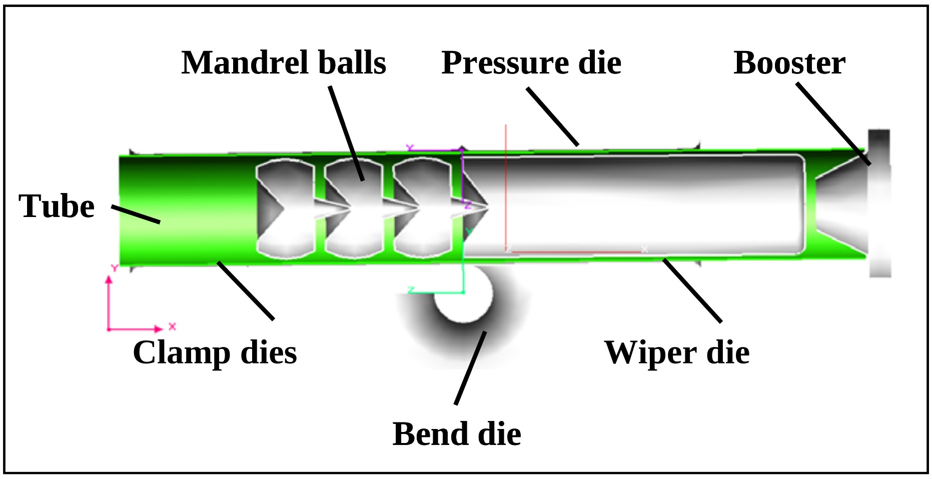


Picture 4: Simulation model BWH

Before the closing of the upper die, meaning the bend forming, an internal pressure was applied to the tube, which is low enough to not expand the tube. During the following bending process the internal pressure was increased at a predefined rate. In the closed dies, the tube was pressed against the dies to reach the defined geometry by adding a calibration pressure.

Bending with mandrel

The normal mandrel bending as partly competing methodology to the bending with hydroforming was investigated in terms of feasibility and process risks. To do that, the simulation model was generated using the tubemaker module inside PAM-Tube 2G. Only one bend was considered. The geometrical parameters were: length of clamp dies 70mm, movement of pressure die 20mm, pressure die force 98N. The clamp die force was defined as rotating follower force at 98N in a close to reality way. The tube was also modelled using 40 shell elements around the circumference. The tools were defined as rigid bodies. Picture 5 shows the tool model as a 3D-cut through the tube axis.

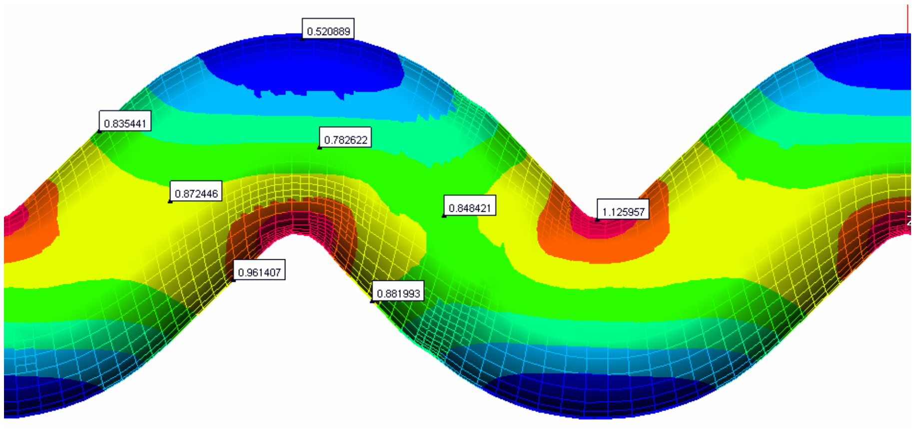


Picture 5: Simulation model mandrel bending

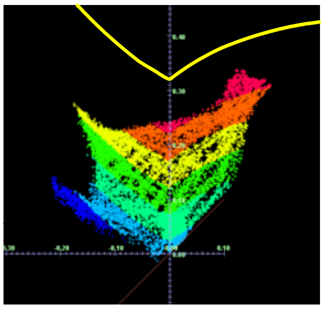
3.2 Results of the FEM-simulation

Bending with hydroforming

As a result of the FEM-simulation, the thickness distribution after the BWH-process are shown (picture 6). The BWH with different pressure-die-path curves were simulated. It could be shown that elimination of wrinkles and waves in the tube sides whilst keeping a minimal thickness of 0.5mm on the outside can be performed.



Picture 6: Simulated thickness distribution

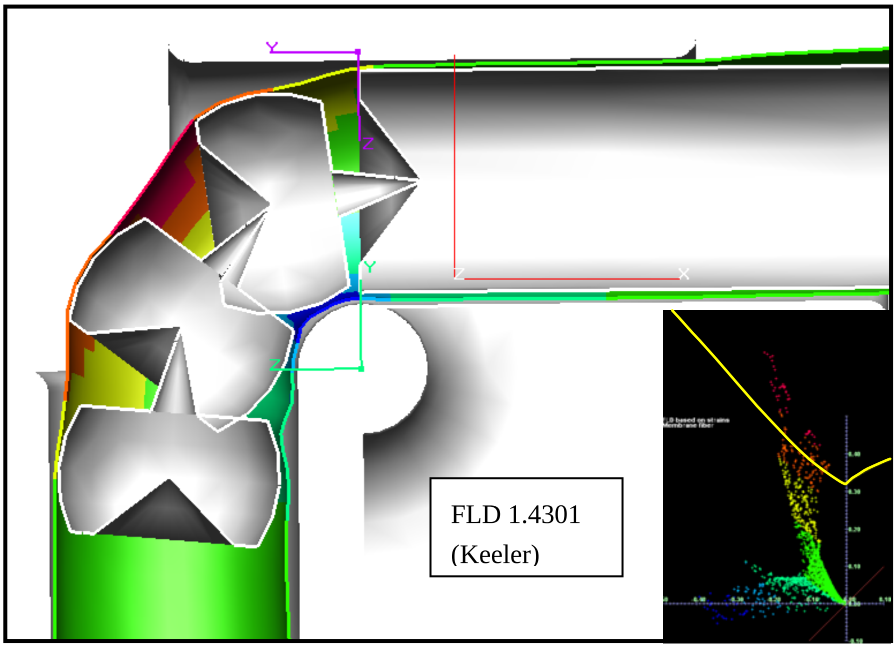


Picture 7: Forming limit diagram (FLD by Keeler) 1.4301

The feasibility versus cracks can be shown using the forming limit diagram (FLD). All the elements are well below the forming limit curve (FLC) (see picture 7). The tool geometries and process parameters could be confirmed by the simulation. The part will not fail in the forming process.

Bending with mandrel

The results of the bending with mandrel simulation show strong wrinkle tendency on the inside and cracks (red area) on the inside (see picture 8). The pressure on the clamp dies has prevented the opening of the tools during the bending. So the chosen pressure ins sufficient. Still, the tube has slid a bit in the clamp dies, which leads to a potential wrinkling which again is demanding a higher friction between the tube and the clamp dies. The pressure die loaded with a vertical pressure has locally deformed the tube. With the closed chain for the forces from pressure die to wiper die, the mandrel is used as a wrinkle preventor.

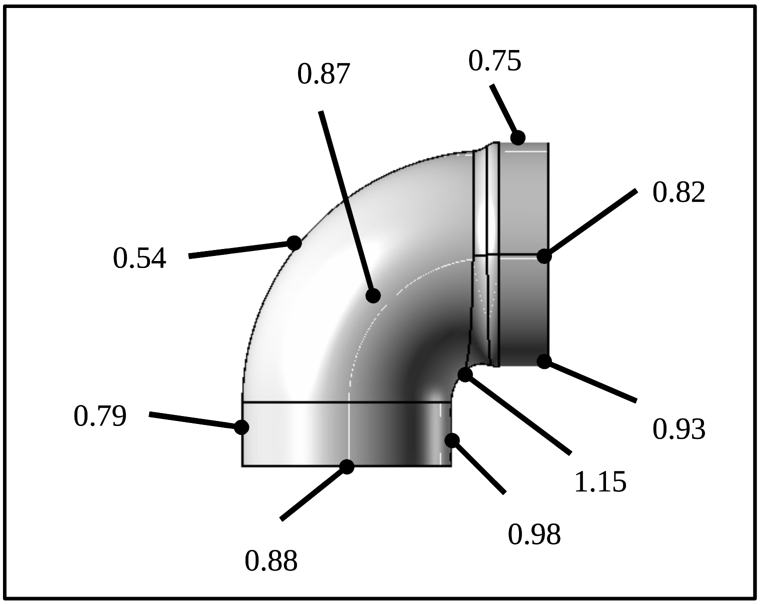


Picture 8: Results from the-simulation with FLD

An optimized tool geometry and/or process parameters would certainly improve the results. But the results clearly show the risks when trying to bend with mandrel tubes with a bend ratio smaller than 1. If a line of parts like shown in the BWH earlier is tried to be manufactured, the risks will multiply, since this type of bending is more critical concerning springback, shape- and position tolerances.

4 Prototyping / serial production

Using the process parameters found from the simulation results were used to design the BWH-tools and for the prototyping leading to the preparation for the serial production. The simulation results can be used to describe the real process. Without failure regarding cracks or wrinkles, the part could be manufactured in serial production. Picture 9 shows the thickness distribution of a real part taken out of the serial production.



Picture 9: Thickness distribution, real part

5 Summary

With BWH a substitution of the conventional bending with mandrel within the process limits is possible. The support of the bending by the internal pressure leads to a thickness distribution in the shown sample which is comparable to the thickness distribution of mandrel bending.

The described forming process can by described by simulation without having to use experiments. The variations in thickness distribution within the real parts was not taken into account. For the FEM simulation, the BWH process was calculated using the program PAM-Tube 2G and compared with the values of the real part (Table 1). Very good correlation between the FEM simulation and the serial production could be found.

Angle [°]	O-S [mm]	O-R [mm]	delta [%]	I-S [mm]	I-R [mm]	delta [%]
0	0.81	0.75	8.00%	0.88	0.93	-5.38%
45	0.52	0.54	-3.70%	1.13	1.15	-1.74%
90	0.81	0.79	2.53%	0.96	0.98	-2.04%

O-S	Outside simulation
O-R	Outside real part
I-S	Inside simulation
I-R	Inside real part

Table 1: Wall thicknesses comparison simulation - real part

Bending with hydroforming is used in serial production at the company fischer Hydroforming since many years. Both in small series as well as in large series independent of the tube diameter different shaped parts are manufactured.

The forming variation bending with hydroforming has been established in serial production and offers the following advantages:

- Reduction of the manufacturing costs
- Very good repeatability
- Manufacturing of multiple parts in one go is possible
- Minimal scrap rate
- High output
- Realisation of bends with bending ratio < 1
- Bending of thin-walled profiles
- Good shape and position tolerances

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