FEM-Simulation of “Die-Less Hydroforming” using LS-DYNA

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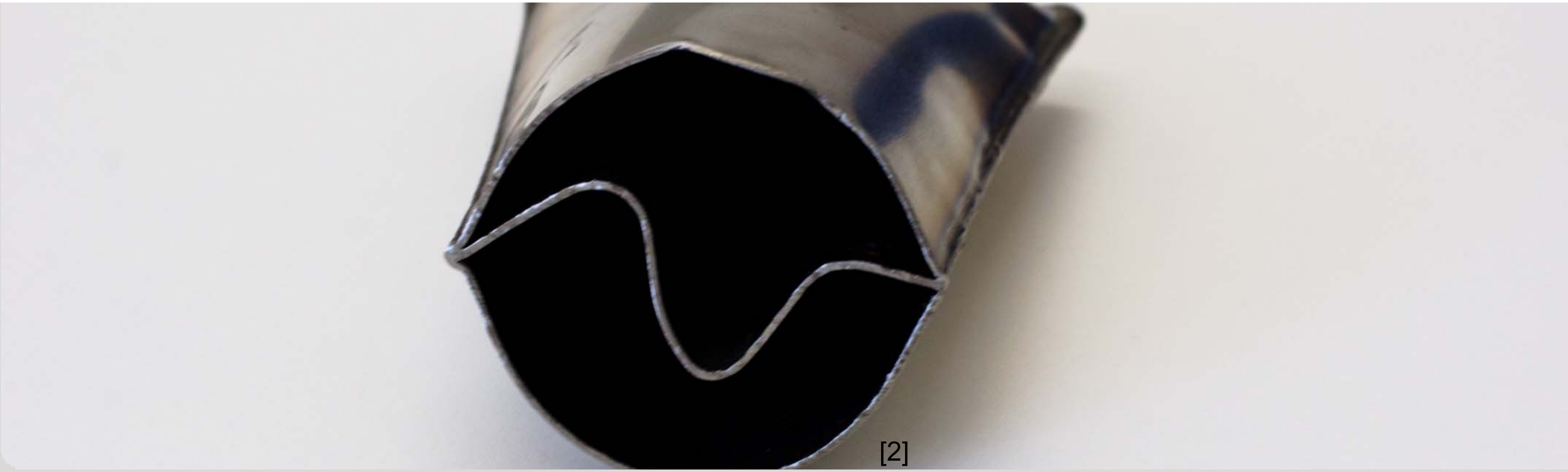
13. LS-DYNA FORUM 2014, 6. – 8. Oktober, Bamberg

KIT Stahl- und Leichtbau   Versuchsanstalt für Stahl, Holz und Steine



[2]

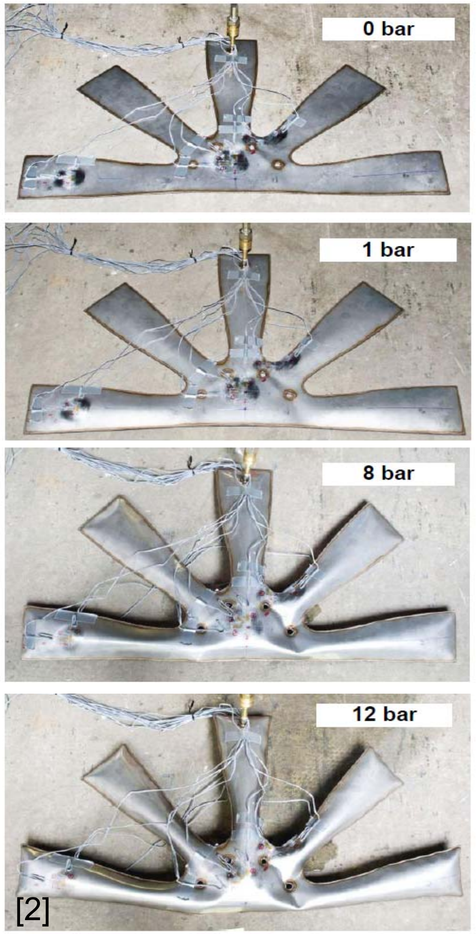
Outline

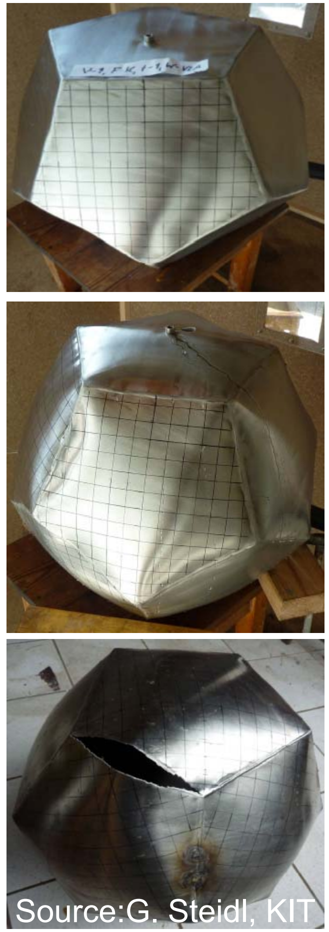
- Introduction to „Die-Less-Hydroforming“
- Examples from „all over the world“ (in extracts)
- Our Proposal: Future Application in Architecture and Civil Engineering
- FE-Model (LS-DYNA) for Simulation of Die-Less-Hydroforming
- Results of the Simulations and Experimental Prototypes
- Numerical Results of some Parameter Studies in extracts
- Conclusions and Outlook
- References

Types of Hydroforming

- conventional **with** die (mould)
    - well known in Mechanical Engineering (e.g. Automotive Branches), see, for example, [6] for further details about Tube Hydroforming

- **without** die (mould)
    - 2D flat blank or 3D hollow body





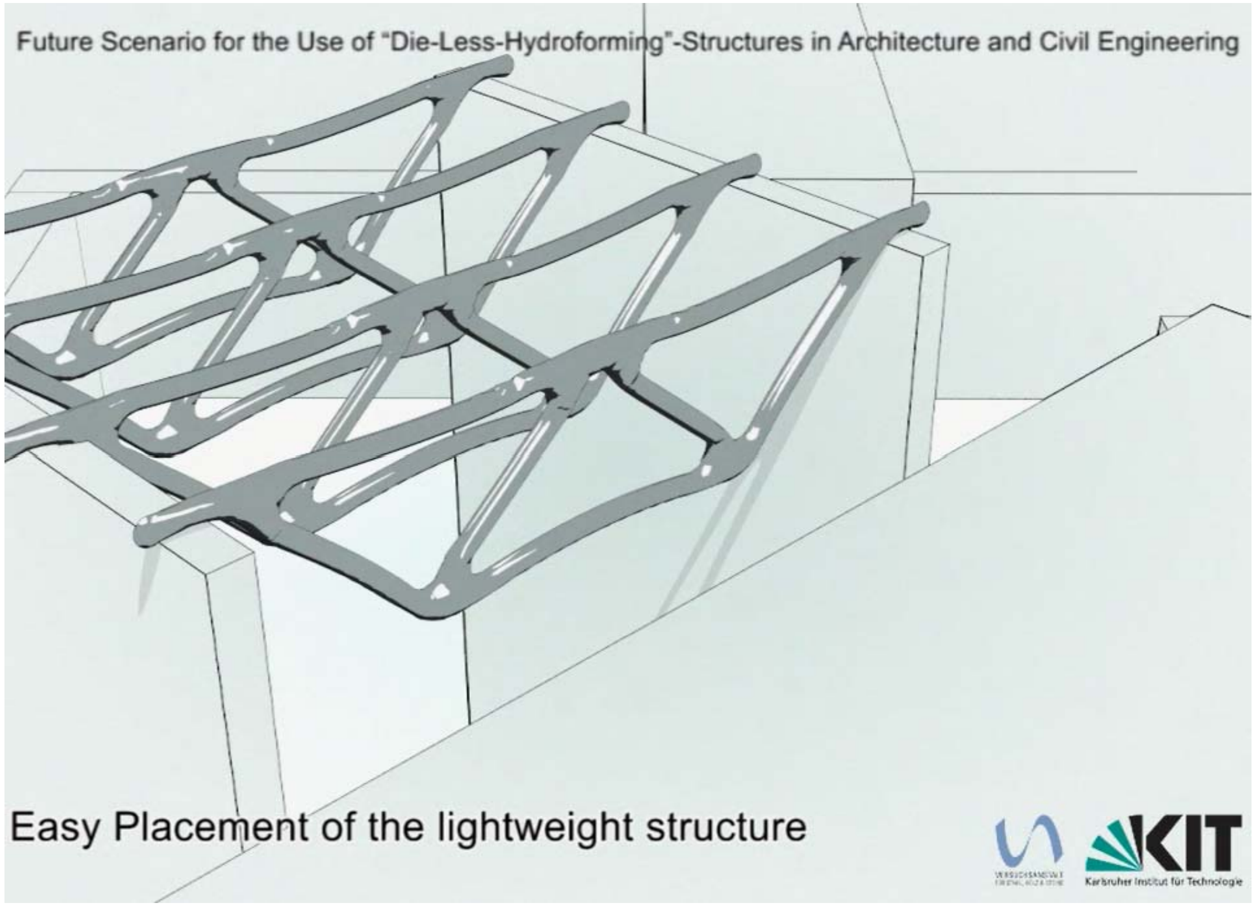
Examples of Die-Less Hydroforming I (in excerpts)

- B. Rawlings (University of Sydney, since 1967)
  - B. Rawlings: Inflated Ductile Metal Structures (1967) [10]
  - C. J. Moore and B. Rawlings: Inflated Metal Structures – some small and large scaled tests (1972) [11]
- Switbert Greiner, Jörg Schlaich, Frei Otto (Universität Stuttgart)
  - SFB 64 „Weitgespannte Flächentragwerke (since 1970)
  - Switbert Greiner: Thin Sheet Metal Membrane Structures (1983) [12]
- Z.R. Wang et al. (China, Harbin Institute of Technology) [15]
  - New Method of Forming Pressure Vessel (Chinese InventionPatent, 1985)
  - Called "Integral Hydro-Bulge Forming (IHBF)" by Travis in 1996 [15]
- Matthias Kleiner, Bernd Viehweger, et al. (BTU Cottbus)
  - Fosta P 354 Mobile manufacturing of lightweight and simple steel pipes by hydroforming (1998) [13]
  - Fosta P 457 Investigation of the manufacturing of lightweight steel pipes by hydroforming (2002), in cooperation with FQZ Oderbrücke, Eisenhüttenstadt [14]

Examples of Die-Less Hydroforming II (in excerpts)

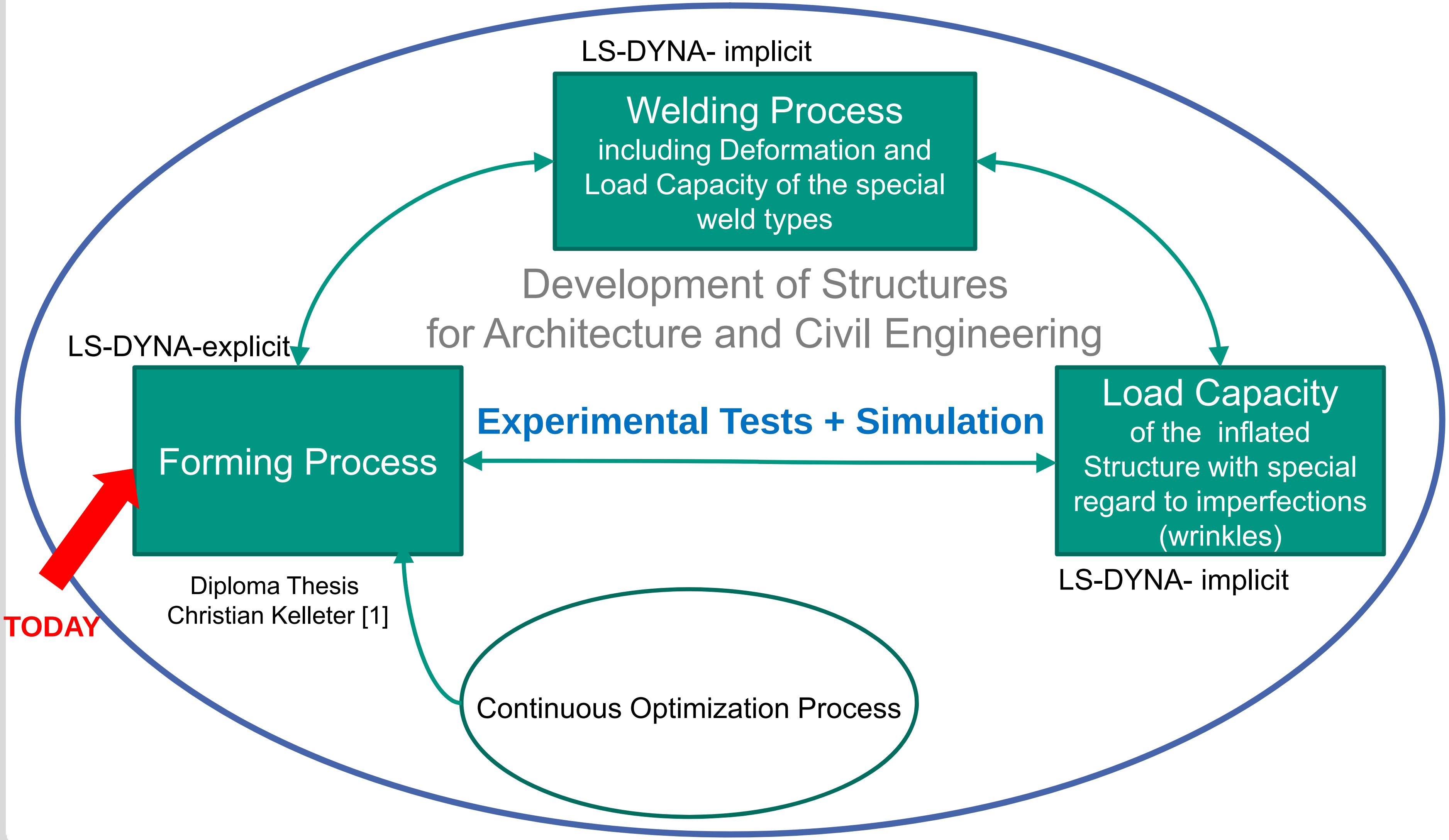
- Franz Bahr (German Metal Sculptor, Designer, since 1990s [7])
  - Pneumatic Pillows and Sculptures [8], [9]
- Stephen Newby (Great Britain, since 1995, Full Blown Metals [16])
  - Presumably the first Designer using Die-Less Hydroforming for Furniture(stool)
- Oskar Zieta (ETH Zürich, Polish Architect and Designer, since 2003 [4])
  - FiDU (“Freie Innendruck Umformung”; engl: “Internal Pressure Forming”) [21]
  - Zieta Prozessdesign [22]
- Jose Emilio Fuentes Fonseca (JEFF) (Cuba, Buena Vista quarter) [17]
  - 12 inflatable metal Elephants (2009 *Havana Biennial*) [25] and other sculptures
- Andrew Schrock (US-Artist, since 2010, [18])
  - Hydroform sculptures
- Mercedes-Benz “Sicherheitsexperimentalfahrzeug ESF 2009” [20]
  - PRE-SAFE® Structure
- And many others…..

Our Proposal for Use of Die-Less Hydroforming



See: http://youtu.be/4dlEzD6FkBI [5]
Visualization by Ioan Donca, Student Research Assistant at KIT Stahl- und Leichtbau, Versuchsanstalt für Stahl, Holz und Steine

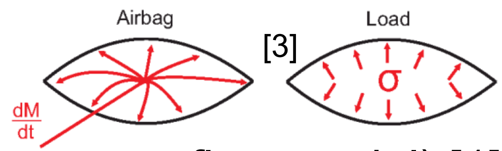
Our Research Contents and Aims



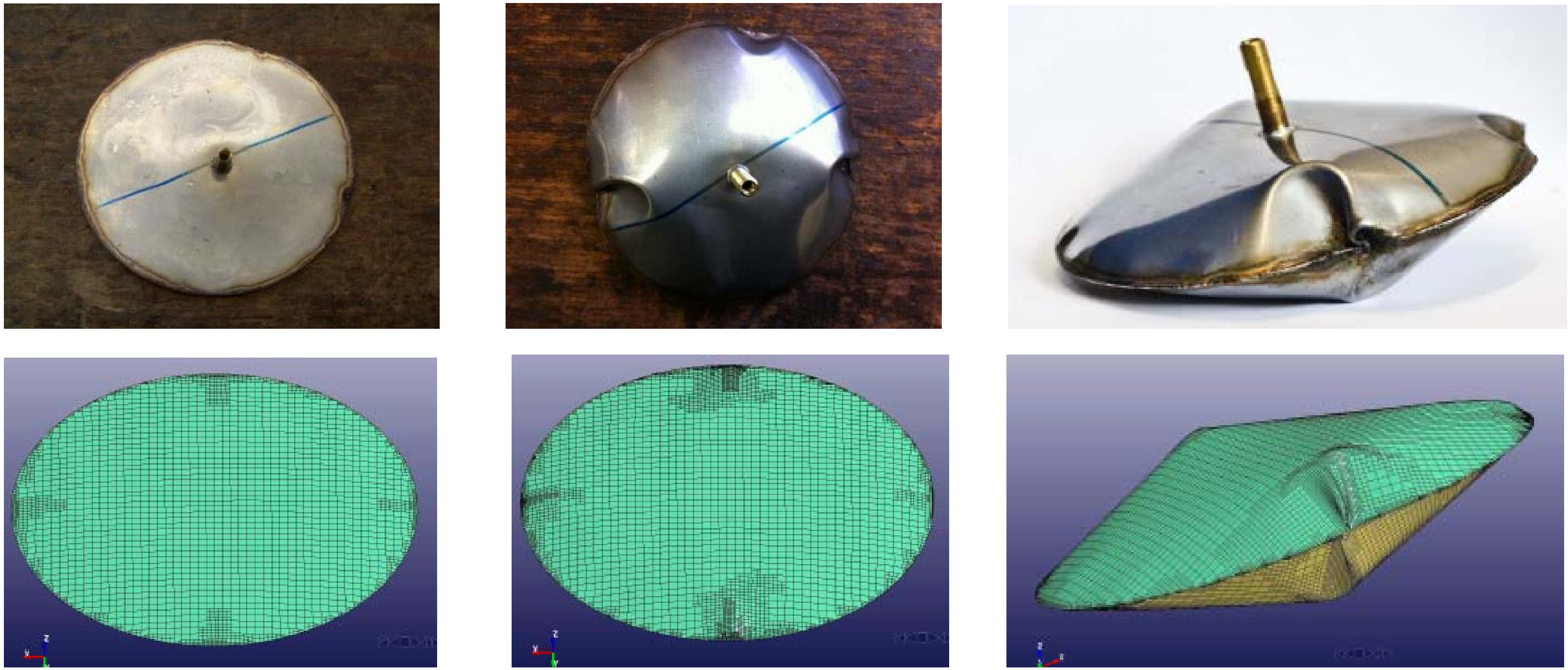
General FE-Model for “Die-Less Hydroforming” I

- Development by Christian Kelleter in the frame of his DiplomaThesis [1] using LS-DYNA, kindly advised by DYNAmore Support Stuttgart
  - General Model for initial 2D-flat blanks as well as 3D hollow Bodies
  - Non-Linear-Calculation
    - geometrical (large deformation)
    - Material (plastic hardening)
    - Structure (self-contact of wrinkles)
- 4-Node Belytschko-Tsay Shell Elements, for further details see [23]
  - Reduced Integration using LS-DYNA Hourglass-Control
  - 5 integration points through thickness of the shell
- Material Stainless Steel, bi-linear material model
  - Materialmodell 24 *MAT_PIECEWISE_LINEAR_PLASTICITY
  - Values taken from a 1-axial tension test
- Modelling of Contact (e.g. for self-contact in wrinkles)
  - CONTACT_AUTOMATIC_SINGLE_SURFACE
- Adaptive Mesh

General FE-Model for “Die-Less Hydroforming” II

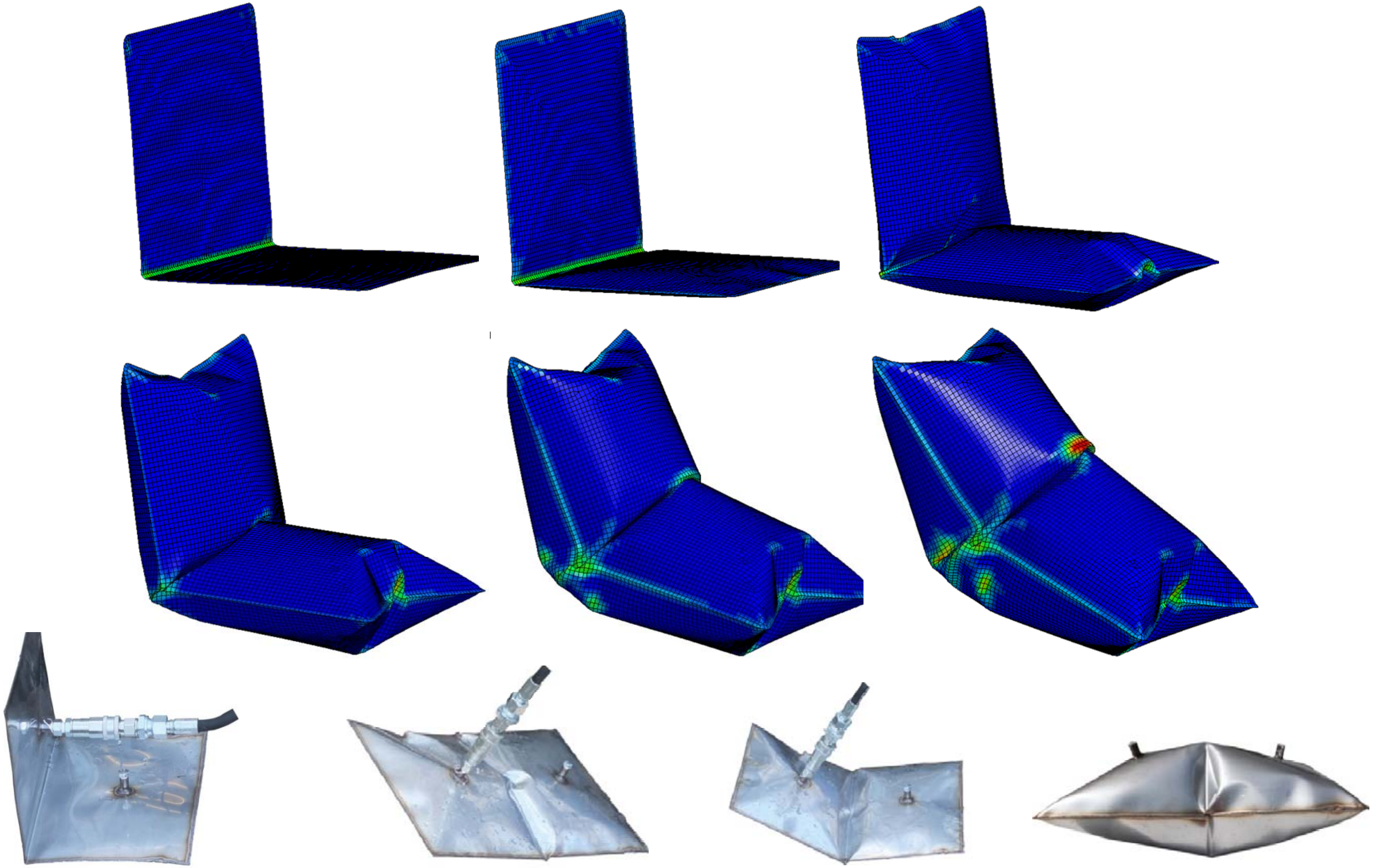


- Load model for the internal pressure forming
  - Existing AIRBAG Model in LS-DYNA (uniform pressure mass flow model) [1]
  - Simple surface load model (added in [3])



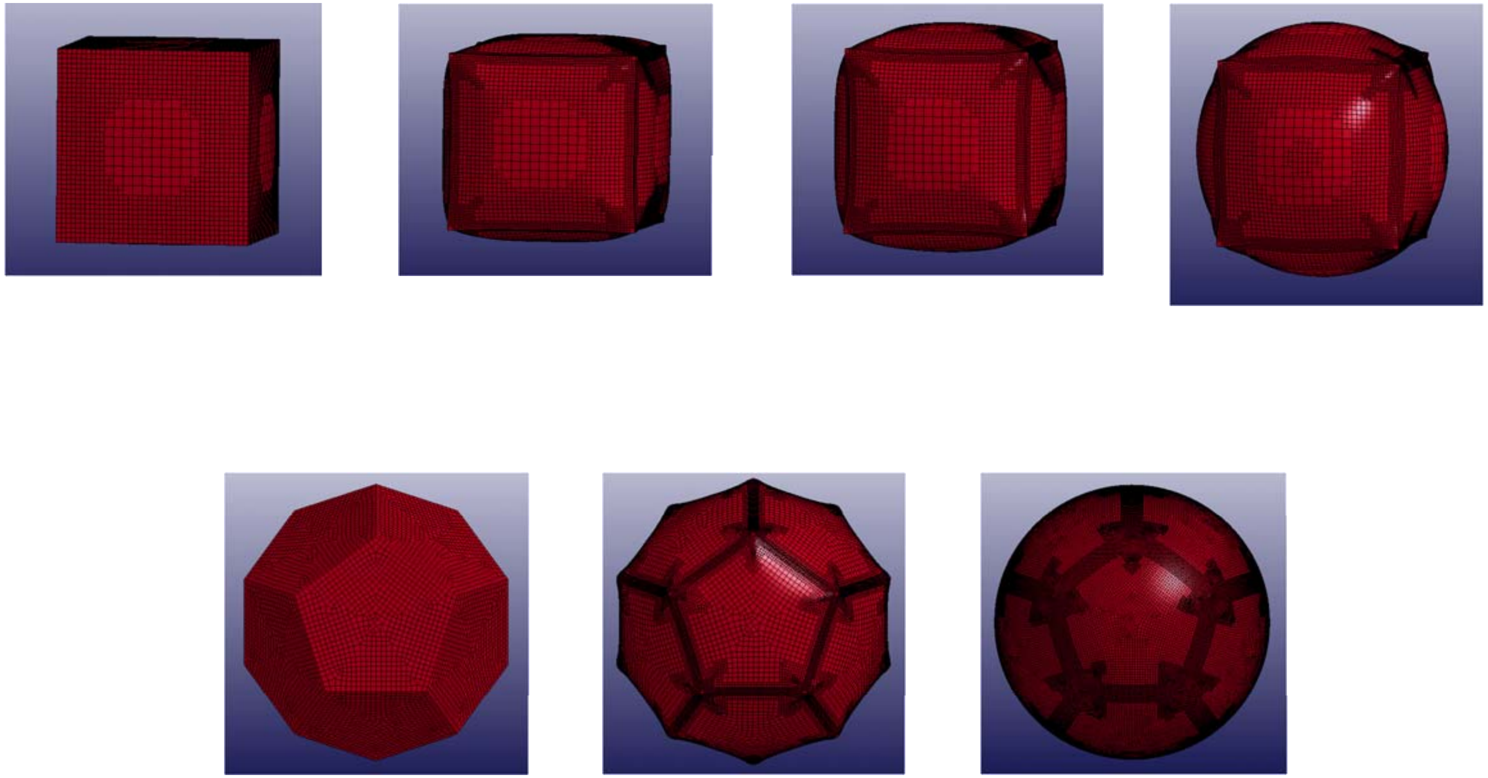
Photos and LS-DYNA Simulation from [1]

A Combined Bending & Inflating Simulation [26]



Photos and LS-DYNA Simulation from [26]

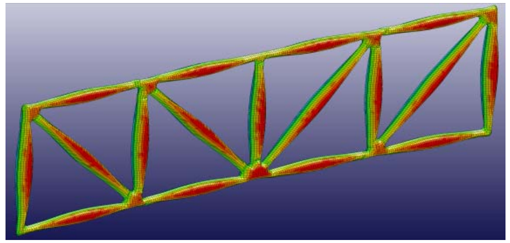
Die-Less Hydroforming of initial 3D-hollow Bodies [24]

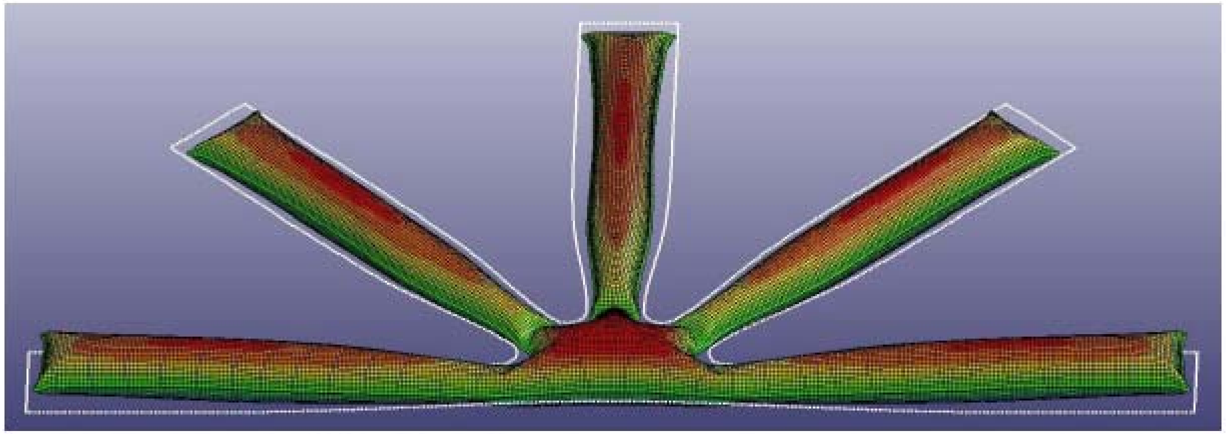


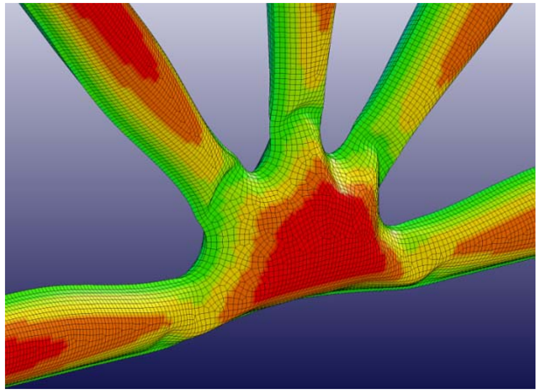
LS-DYNA Simulation from [24]

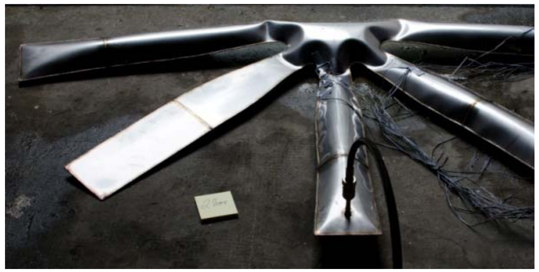
Detail of the Structure–type trussed framework [2]

- Very good accordance in a qualitative way
- Quantitative check is in progress





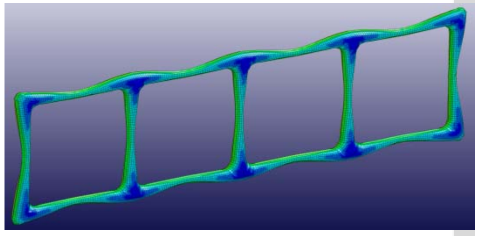


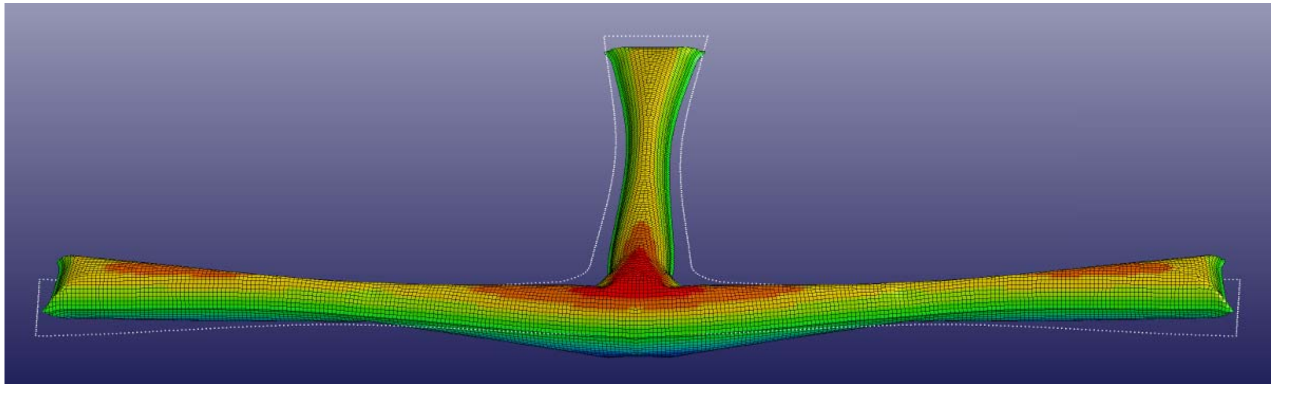


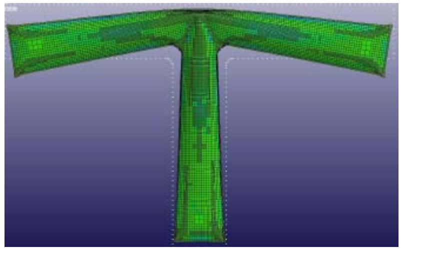
Photos and LS-DYNA Simulation from [2]

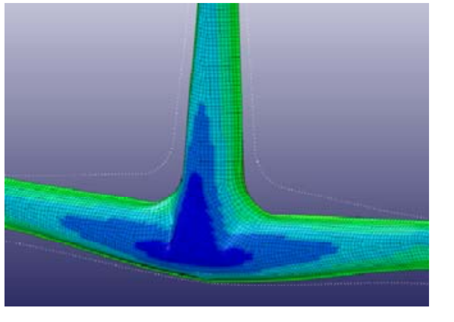
Detail of the Structure–type Vierendeel girder [2]

- Optimazation of the Vierendeel girder node
- Reduce wrinkling in comparsion to a regular T-joint





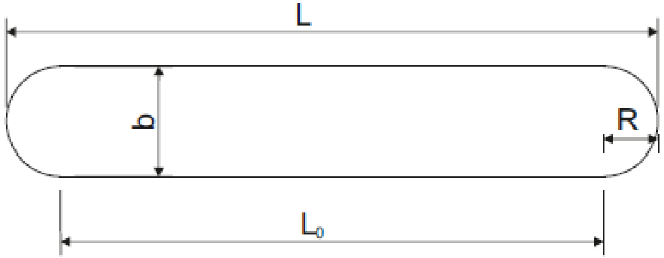




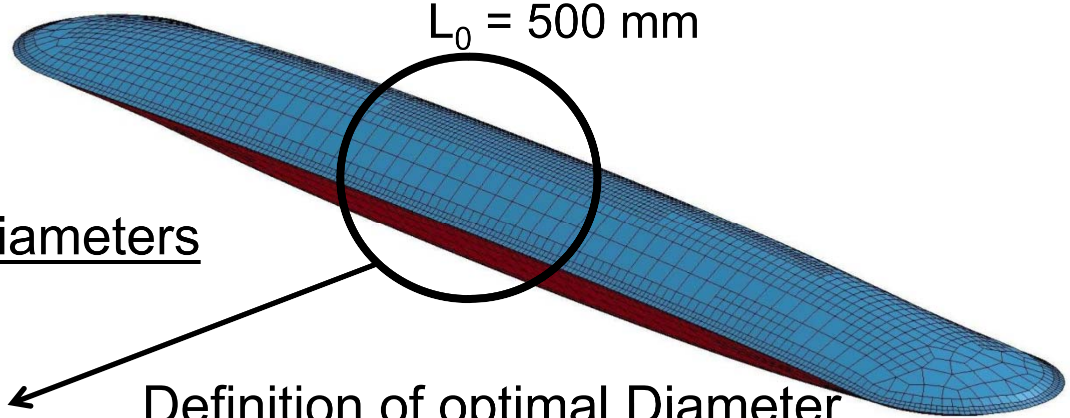
Photos and LS-DYNA Simulation from [2]

Study of the Circularity – Diameter [3]

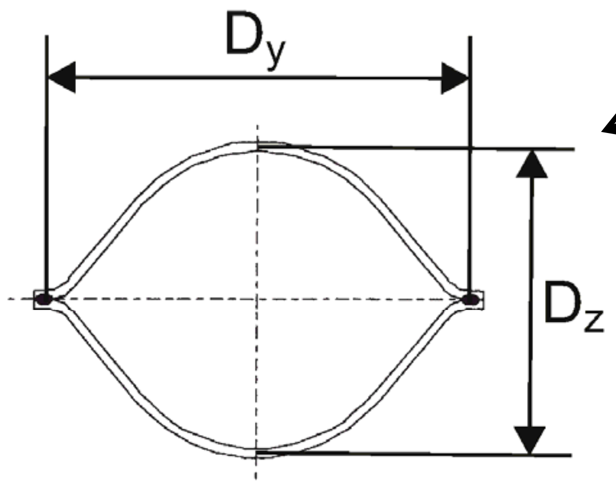
- Main Parameter: Thickness and pressure
- Evaluation in the middle section



Material: 1.4301 stainless steel
b = 100 mm
R = 50 mm
L = 600 mm
L_0 = 500 mm



Definition of the circularity by diameters



Definition of optimal Diameter
(no plastic strain, only bending)

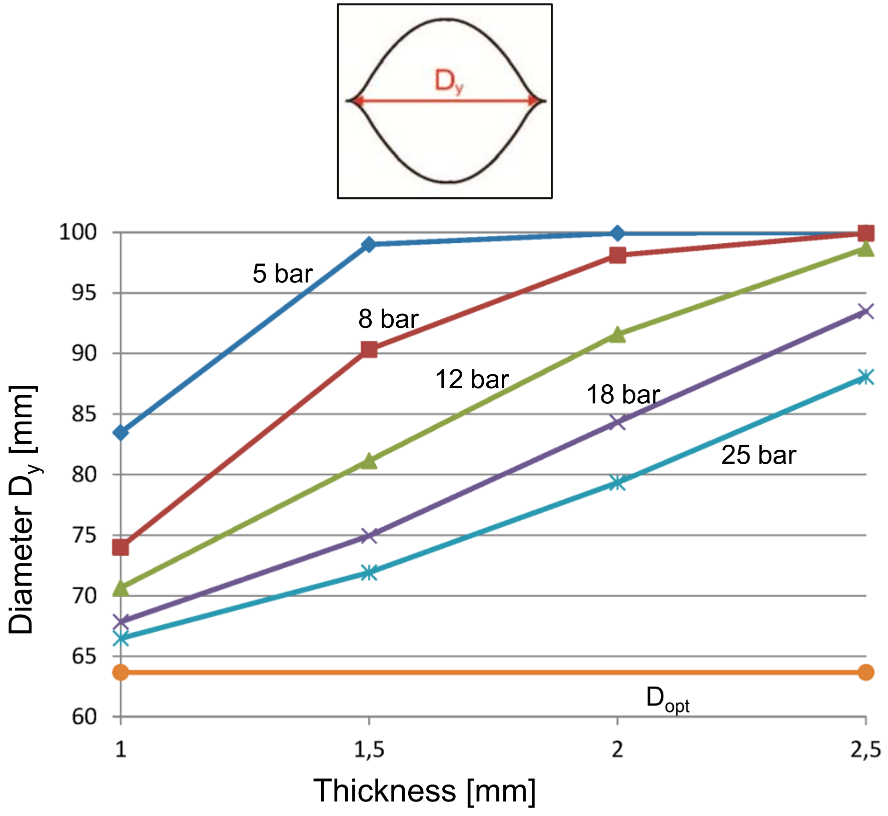
$U = 2 \cdot b$

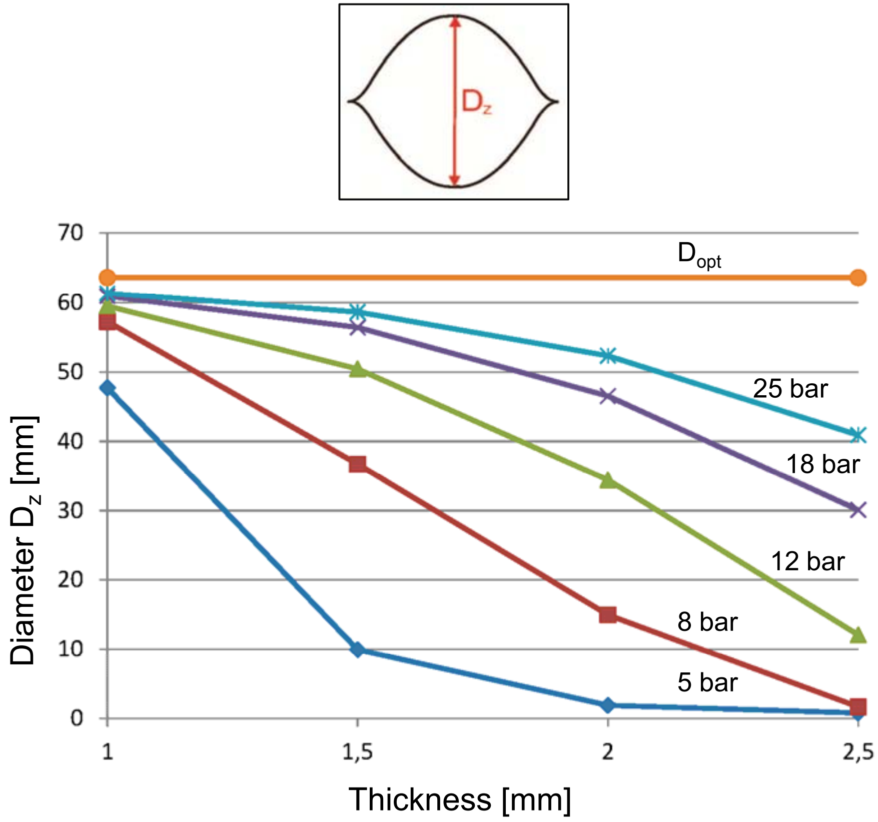
$\pi \cdot D = 2 \cdot b$

$D_{opt} = 2 \cdot b / \pi$

Here: D_{opt} = 63,66 mm

Study of the Circularity – Diameter [3]

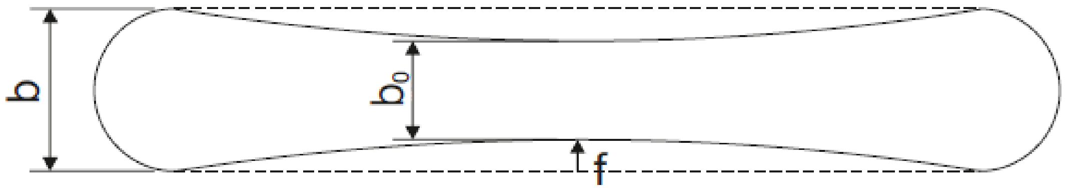


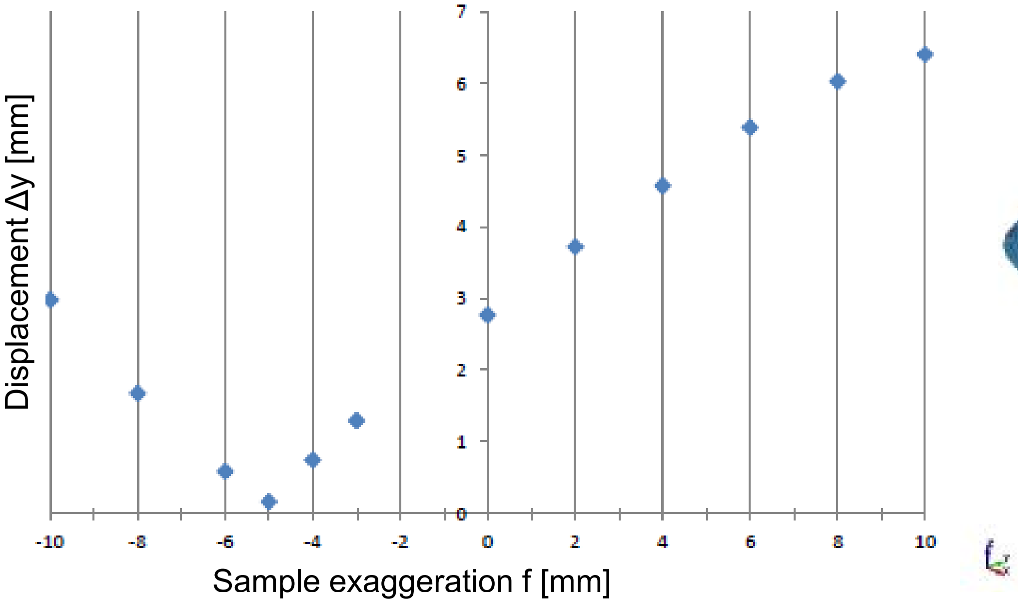


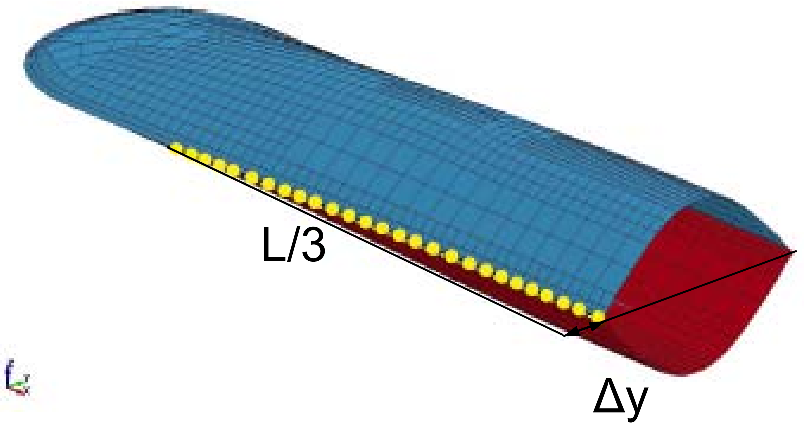
Study of the Circularity – Straightness [3]

- Optimization of initial blank to avoid “bone shape”
- Additional Parameter: Sample exaggeration f

Material: 1.4301 stainless steel
P = 20 bar
b = 50 mm
R = 25 mm
L = 300 mm
L_0 = 250 mm
t = 0,5 mm
$b_0 = b – 2 \cdot f$







Conclusions and Outlook

- Definition of Die-Less Hydroforming
- Examples for “practical Application” of Die-Less Hydroforming
- Our future proposal for the use of Die-Less Hydroforming
- FE-Model (LS-DYNA)
- Simulation Results compared to Prototype in a qualitative way
- Numerical Results concerning circularity and “bone-shape”
- Continuing with Improvement and Upgrading of the existing FE-Model for Die-Less Hydroforming
  - Optimization of the cutting shape of the intial Blanks to avoid wrinkles
- Further Testing of the FE-Model by parameter Studies and quantitative Comparisons to Results of Prototypes measured with Strain Gauges
- Welding Simulation
- Investigation of loading capacity of Die-Less Hydroforming Structures
  - Simulation and experimental Investigations
  - Special Regard to the Influence of Imperfections like wrinkles

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Thank you for your kind attention.

If you have any questions or advices,

do not hesitate to contact me by email.

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[2]

Special Thanks to our involved Students:

Viola Sielisch
Christian Kelleter
Michael Rzepecki
Benjamin Seyfried
Tanja Berg
Sebastian Schweigert
Kathrin Hamm
Ioan Donca
Fabian Haas
Lars Freudigmann