PRESS HARDENING OF TUBES BY HOT METAL GAS FORMING

VALIDATION OF NEW MATERIALS

2nd Sino-German Workshop

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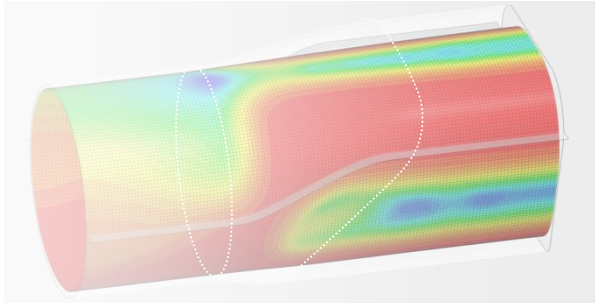
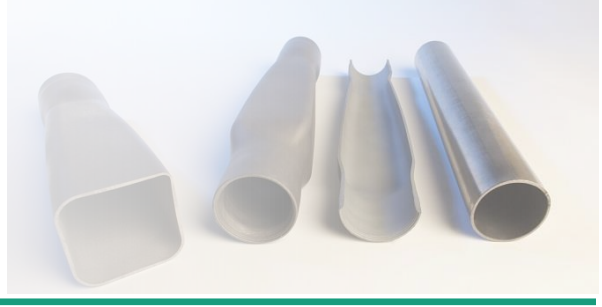
AGENDA

- Media based forming at Fraunhofer IWU
- Introduction in HMGF-PH
- Validation of new materials
- Conclusion and Outlook





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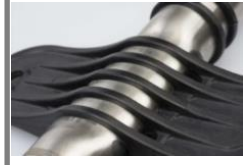
Media based forming at Fraunhofer IWU

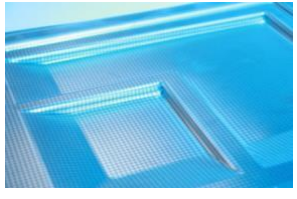
Over 20 years of expertise in hydroforming

Hybrid processes for hybrid parts



Hot Metal Gas Forming (HMGF) / press hardening (HMGF-PH)

Hydroforming with heated oil



Hydroforming at room temperature with water

1995 2001 2006 2011 2018

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Media based forming at Fraunhofer IWU

Equipment

Equipment for media based forming

- 2 Hydroforming presses
- 2 Gas pressure units from Maximator
- Control units for electrical tool heating and cooling
- Automated handling system with robot
- Heating devices

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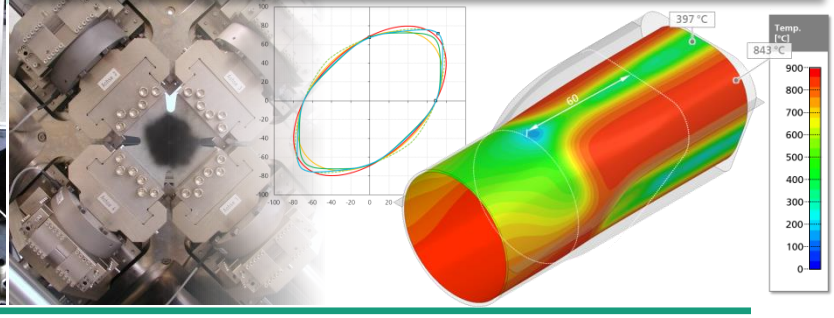
Possible media based forming processes

- Hydroforming
- Superplastic forming
- Hybrid forming
- **Hot Metal Gas Forming (HMGF)**

Simulation-based process design

- Different software for forming simulation
- Facilities for thermal and mechanical material testing (strain-rate and temperature effects)
- Metallographic laboratory
- Optical measurement systems



APT DUNKES SCHULER Member of the ANDRITZ GROUP MAXIMATOR Maximum Pressure. Fraunhofer IWU

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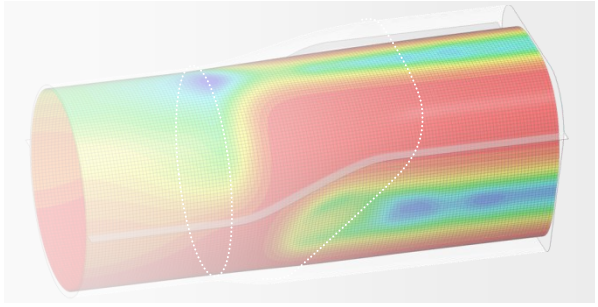

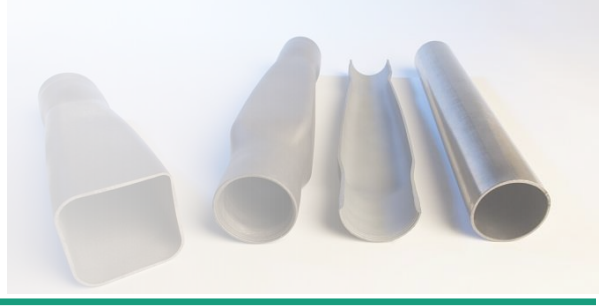

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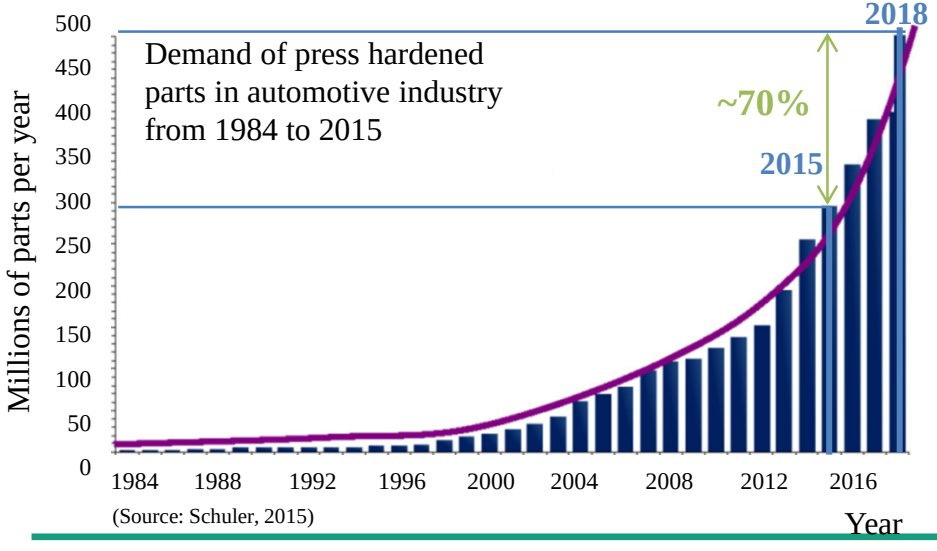
Hot Metal Gas Forming - Press Hardening

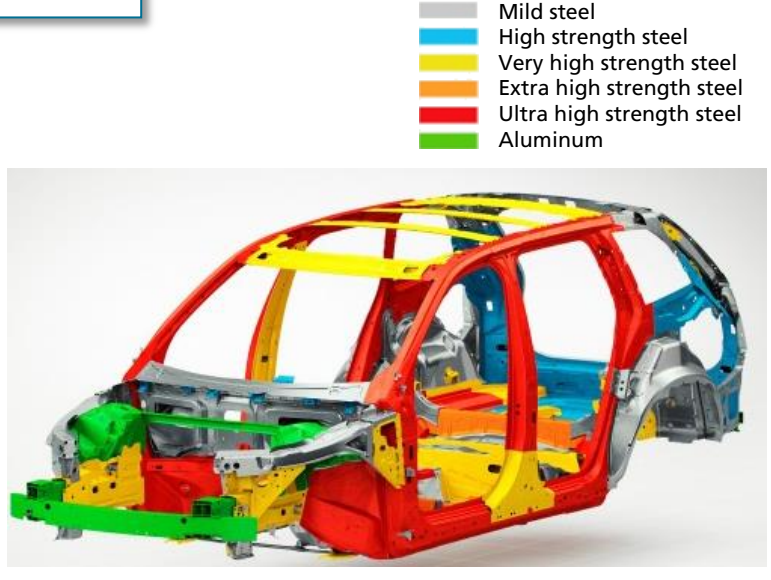
Motivation

Motivation

- Strong and **increasing demand** of **lightweight** and **high-strength structures** for dynamic applications (automotive and aerospace)



(Source: Schuler, 2015)



Car body of a Volvo XC 90 (2015)
almost 40 % press hardened parts (red), (Source: Volvo)

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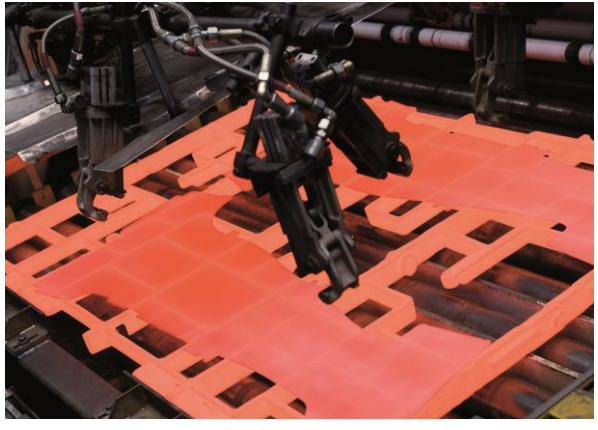
Hot Metal Gas Forming - Press Hardening

Motivation

Material lightweight design

- Press hardening

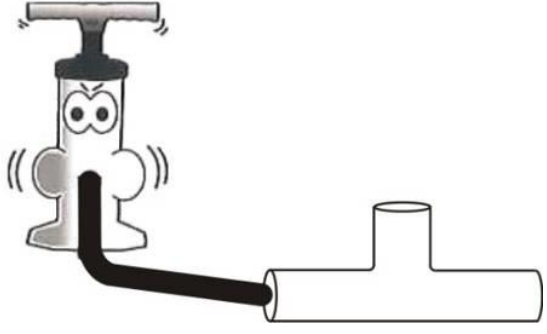


- forming and heat-treatment in a single process step
- materials of high strength
- structural components with a high shape accuracy

+

Structure lightweight design

- Hydroforming



- good producibility of complex geometries
- structural components with high stiffness at a lower weight

= high potentials for media based press hardening of closed profiles

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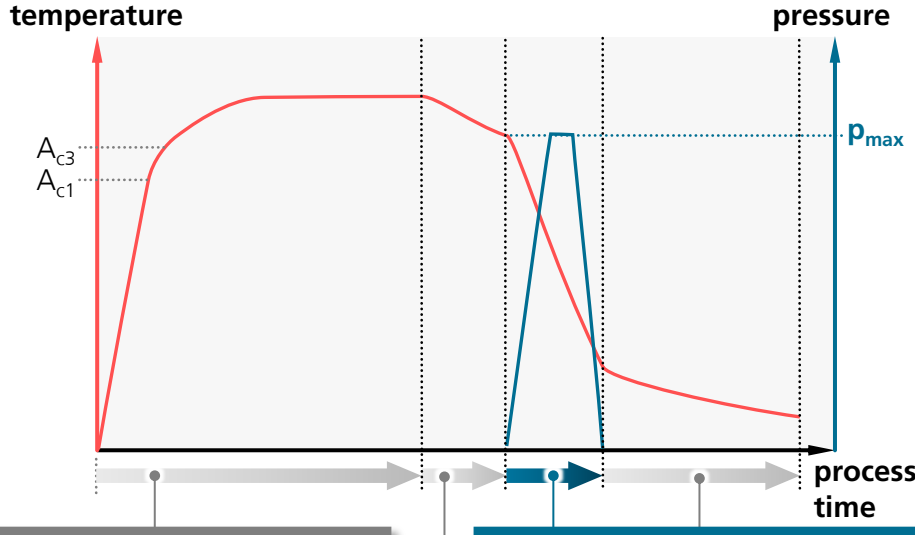
Hot Metal Gas Forming - Press Hardening

Working principle



Heating phase

- Austenitization by heating up above A_{C3}-Temperature

Transfer phase

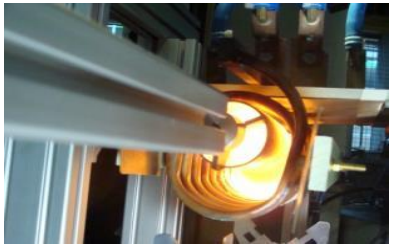
- Transfer of the tube into the tool, press closing and sealing

HMGF-PH

- Hot Metal Gas Forming by pressure built up, holding and pressure release

Part removal

- Part removal, cooling on air



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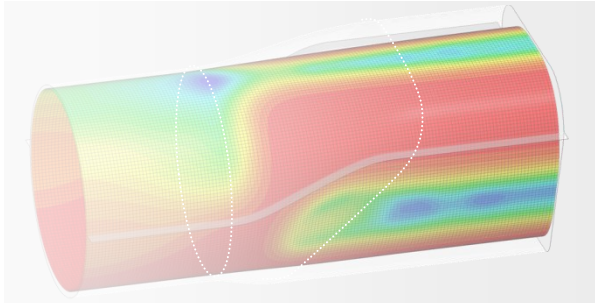

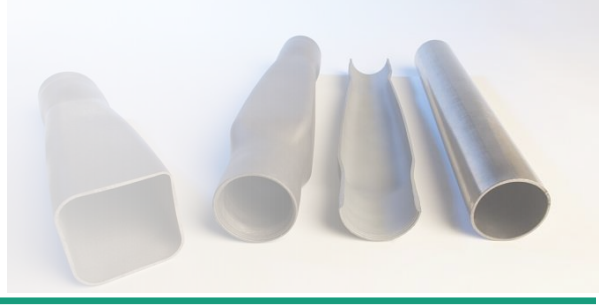

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Motivation and Objective

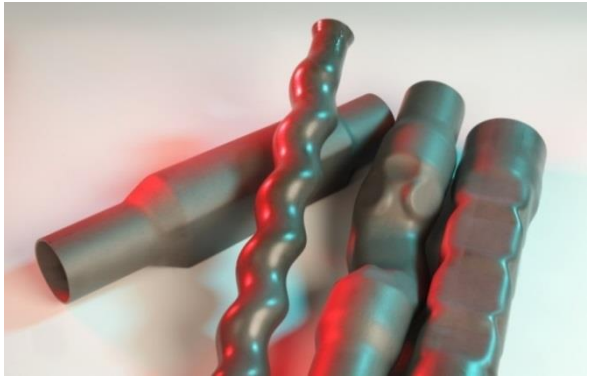
Motivation

- New press hardening steels from SSAB AB **Docol®1800 Bor and Docol®2000 Bor** available as tube **for the first time**
- At the moment no experience in Hot Metal Gas Forming-Press hardening **(HMGF-PH)** for these materials
- No reliable material models for numerical process design

Objective

- Prove of practicability in HMGF-PH, identification of forming limits
- Development of suitable material models as basis for Numerical simulation of HMGF-PH processes and validation with experimental investigations

Robust HMGF-PH process design in future applications with Docol 1800 Bor and Docol 2000 Bor



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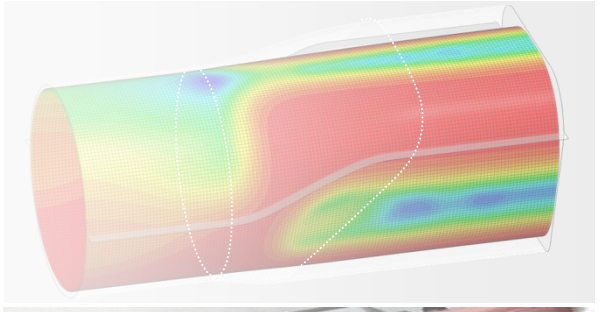

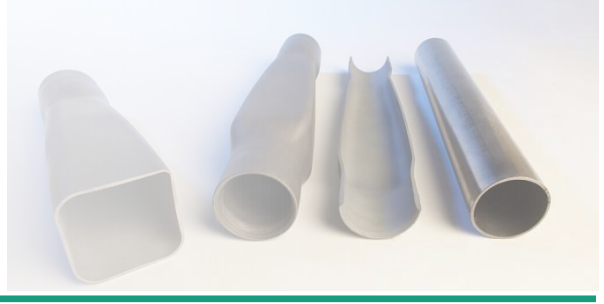

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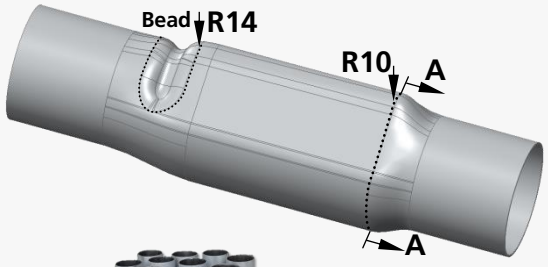
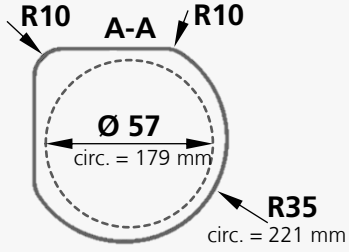
Experimental investigations

Demonstrator part and experimental setup

Demonstrator part DP1

- Available tool for **experimental investigations** of HMGF-PH
- Different cross section areas with several radii causes various degrees of longitudinal and radial strains



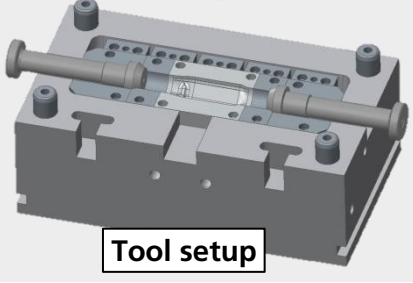


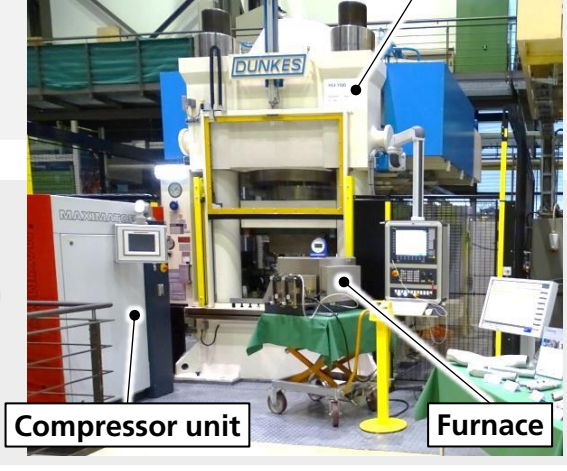
Docol®2000 Bor and 1800 Bor tubes

- Provided by **SSAB AB**
- Welded tubes, initial outer diameter 57 mm
- Wall thickness 1.5 mm

Experimental setup

- Furnace heating of the tubes to target temperature, manual handling
- Segment-based press hardening tool
- Dunkes/AP&T press HS3-1500
- Maximator compressor DLE 75-2





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Experimental investigations

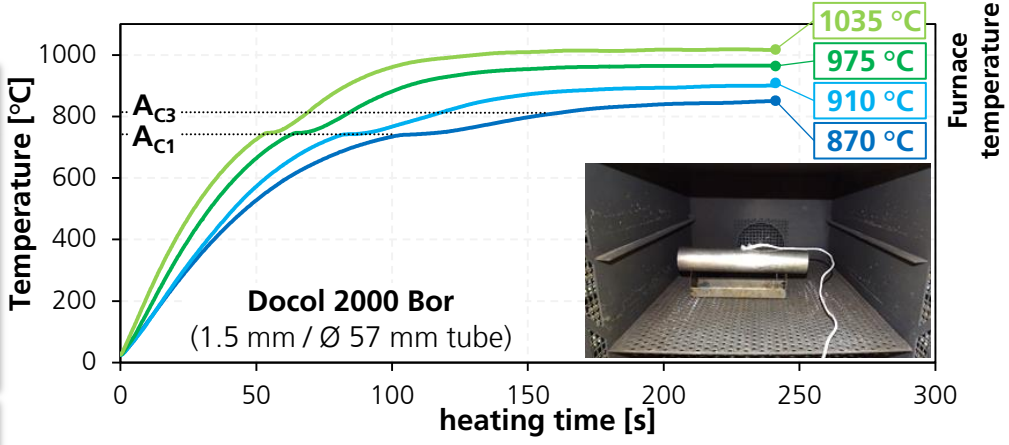
Preliminary studies

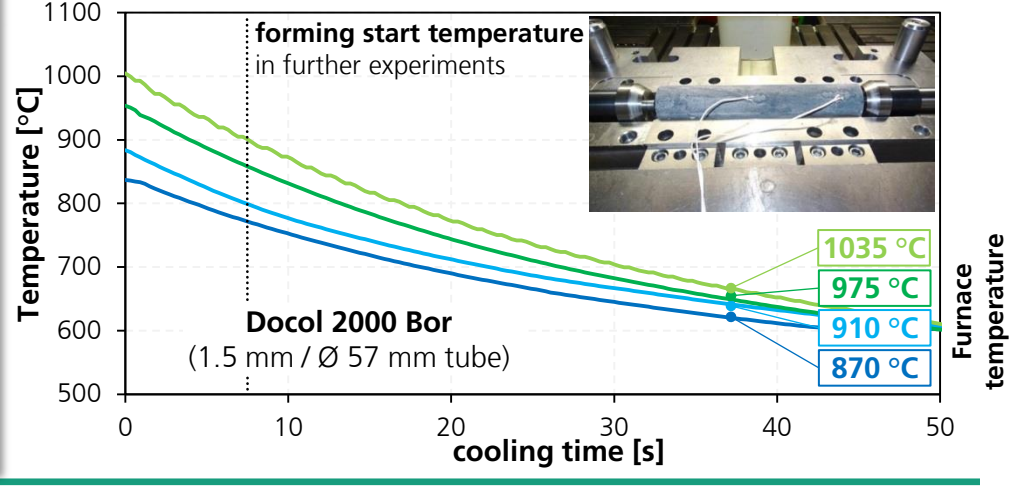
Preliminary study: heating behaviour

- Temperature measurement during furnace heating phase with spot-welded thermocouples
- Identification of furnace times for fully **austenitized** microstructure
  - Docol 1800 Bor: A_{C3} = **847 °C**
  - Docol 2000 Bor: A_{C3} = **813 °C**

Preliminary study: cooling behaviour

- Temperature measurement after furnace heating with spot-welded thermocouples
- Identification of cooling behaviour during manual handling and positioning in the opened tool
- Important data basis for simulation validation
- Starting point for setting up the right furnace temperatures to achieve **specific forming start temperatures** for further HMGF-PH experiments
- Identification for fully **martensitic** microstructure
  - Docol 1800 Bor: M_S = **367 °C,** M_F = **169 °C**
  - Docol 2000 Bor: M_S = **341 °C,** M_F = **186 °C**





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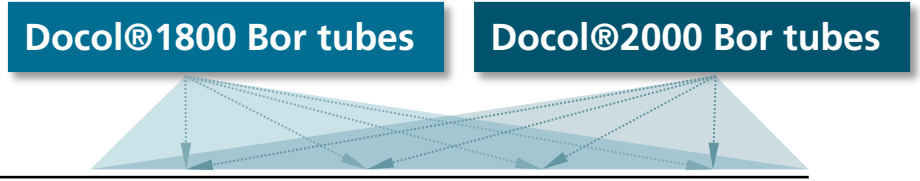
Experimental investigations

Experimental design



Furnace temperature	[°C]	870	910	975	1035	**Thermal process parameters**
Furnace time	[s]	210	180	180	180	
Max. temperature in center of tube	**[°C]**	**842**	**889**	**961**	**1013**	
Transfer time	[s]	8	8	8	8	
Forming start temperature	[°C]	769	796	855	896	
Internal pressure	[MPa]	18.5, 37, 67	67	67	67	**Forming parameters**
Pressure build-up rate	[MPa/s]	20, 40	20, 40	20, 40	40	

Objective

- Identification of the **basic forming behaviour** of Docol 1800 Bor and Docol 2000 Bor tubes
- Investigation of influencing **process parameters**
- Creating data basis for **validation** of numerical simulations

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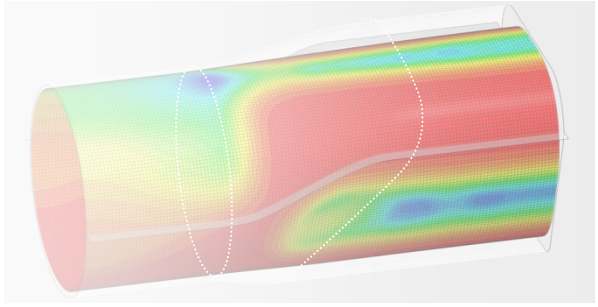

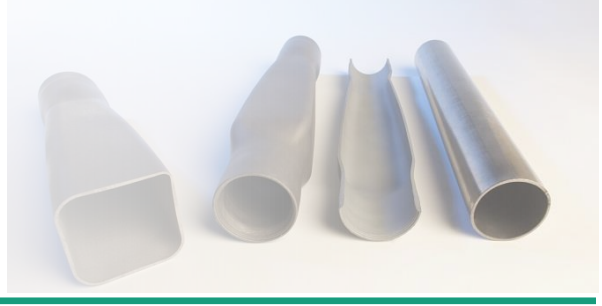

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Numerical investigations

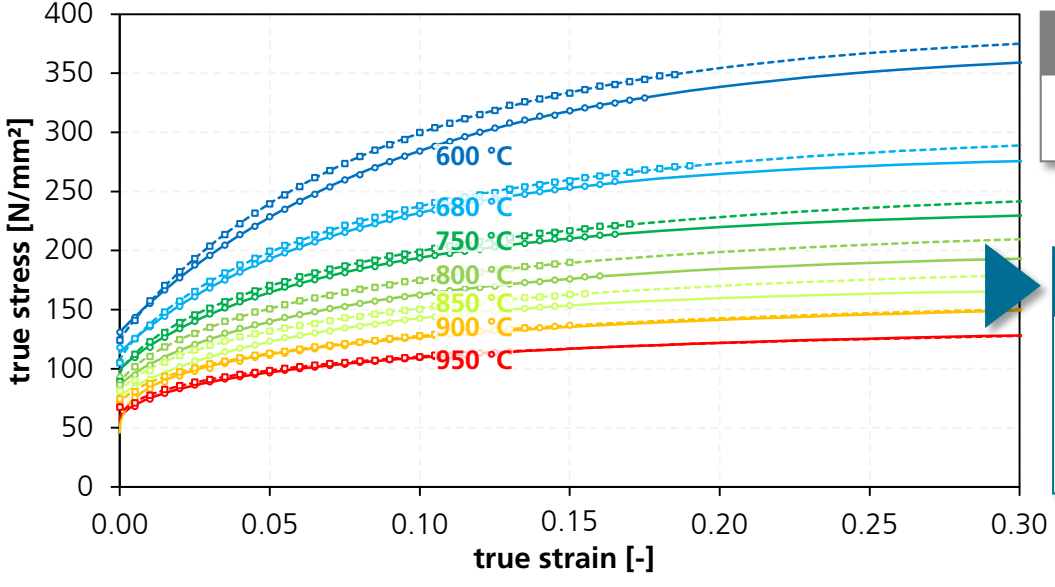
Material testing – temperature dependent flow curves

Hot tensile tests

- Carried out by project partner University of West Bohemia, Faculty for Mechanical Engineering
- Tensile testing after austenitization for different isothermal test **temperatures and strain rates**

Further steps in data preparation

- Conversion into true stress-true strain-curves
- Thinning out of curves, creating supporting points
- **Approximation** (Swift / Hockett-Sherby)



Hot tensile tests
(averaged support points from measured data)

- ○ Docol 2000 Bor
- □ Docol 1800 Bor

Approximations

- —— Docol 2000 Bor
- ---- Docol 1800 Bor

results

- Higher flow stress level for Docol 1800 Bor up to 850 °C
- Comparable **strengthening behaviour**
- Only slight differences in general

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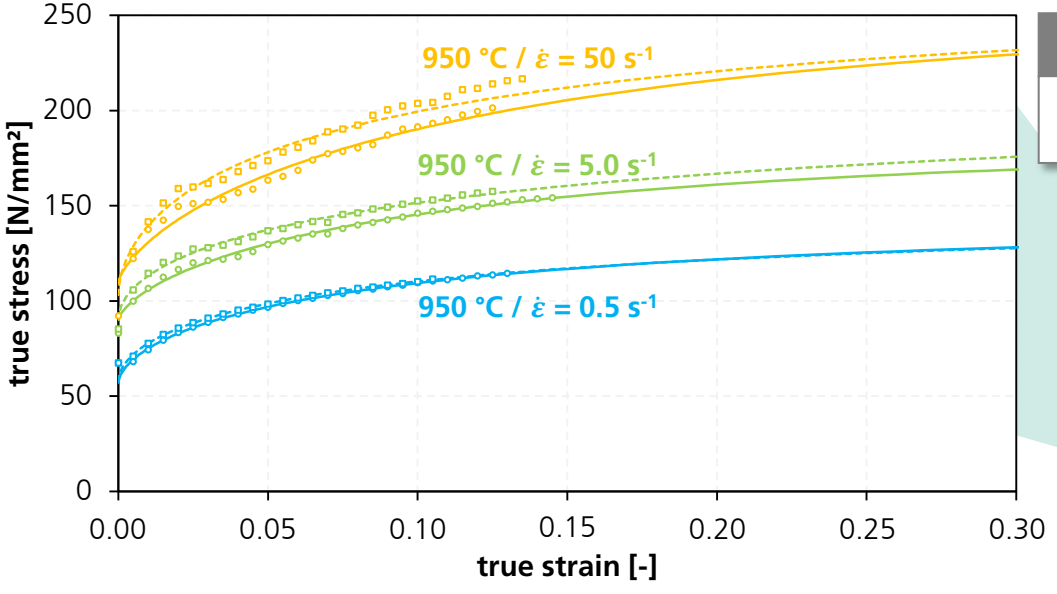
Numerical investigations

Material testing – strain rate dependent flow curves



Hot tensile tests
(averaged support points from measured data)

- ○ Docol 2000 Bor
- □ Docol 1800 Bor

Approximations

- —— Docol 2000 Bor
- ---- Docol 1800 Bor

Flow curve data basis

- 21 measured combinations of
  - ➢ temperature (950, 900, 850, 800, 750, 680, 600 °C)
  - ➢ strain rate (0.5, 5, 50 s^{-1})
- Extrapolated flow curves for quasi-static strain rates

Material modelling

- Adding flow curves to LS-DYNA material models

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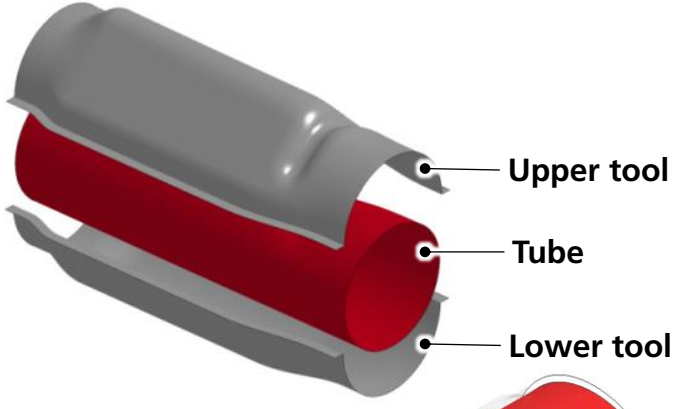
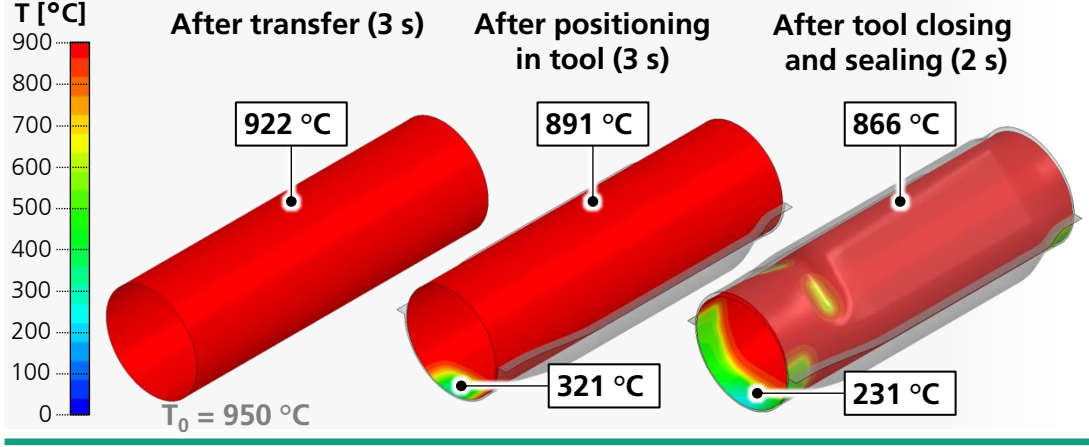
Numerical investigations

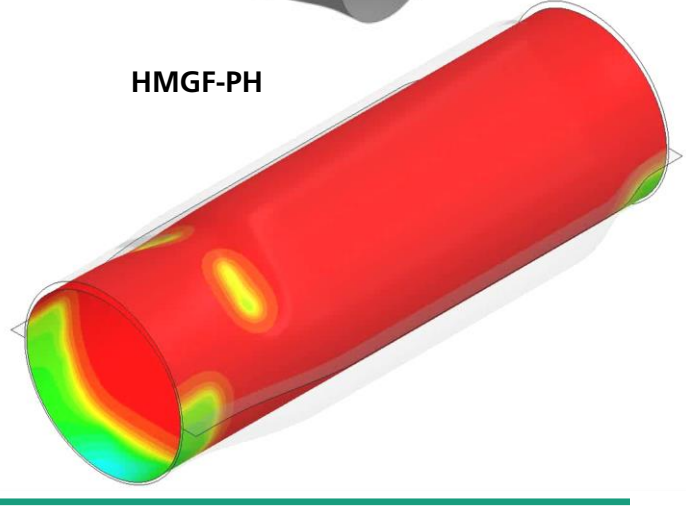
Forming simulation setup

LS-DYNA simulation model

- Rigid-surface-based model
- Process specific constraints were matched to the real process conditions
- Computation of all relevant **preliminary stages**
- Static coefficient of friction μ = 0.35
- Tube mesh: Belytschko-Tsay shell elements, initial length 0.75 mm
- Adjusted temperature- and strain-rate-dependent **material models** for Docol 1800 Bor and Docol 2000 Bor (MAT243 – Hill90)
- Computation of all relevant **heat transfer mechanisms**







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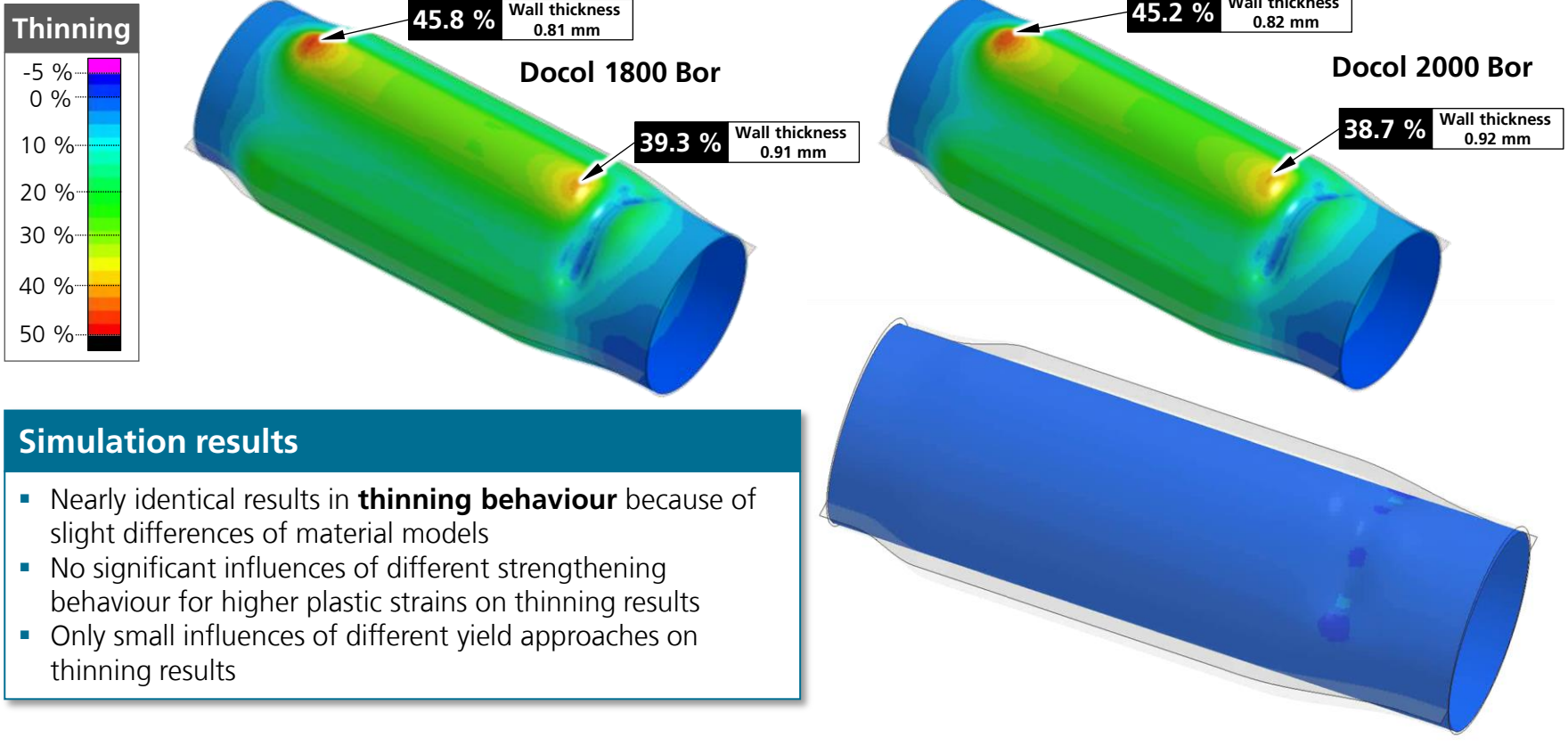
Numerical investigations

Forming simulation results



Simulation results

- Nearly identical results in **thinning behaviour** because of slight differences of material models
- No significant influences of different strengthening behaviour for higher plastic strains on thinning results
- Only small influences of different yield approaches on thinning results

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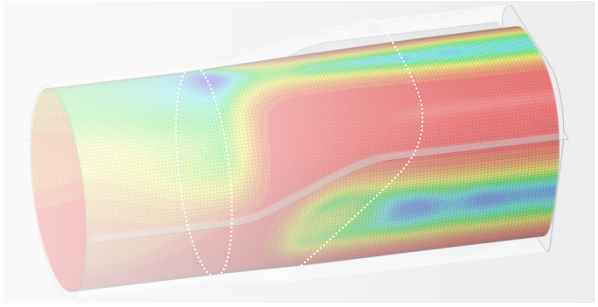

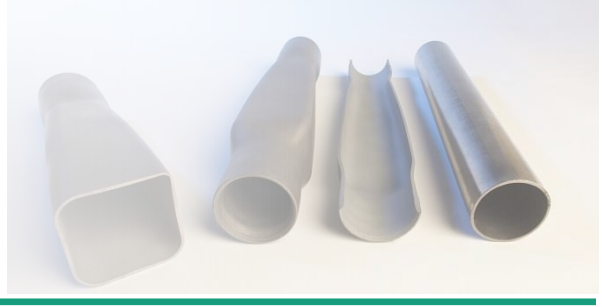

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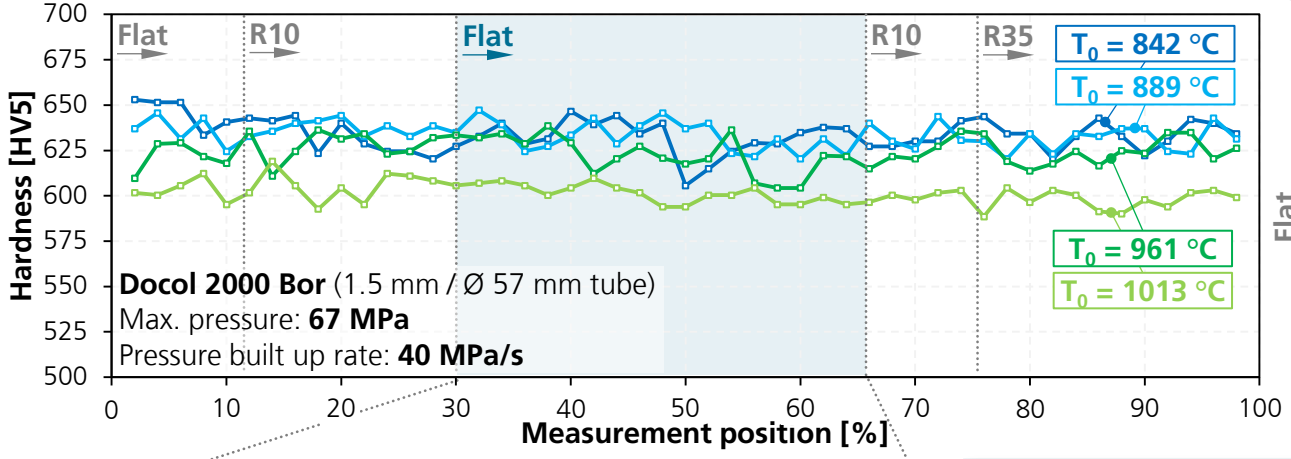
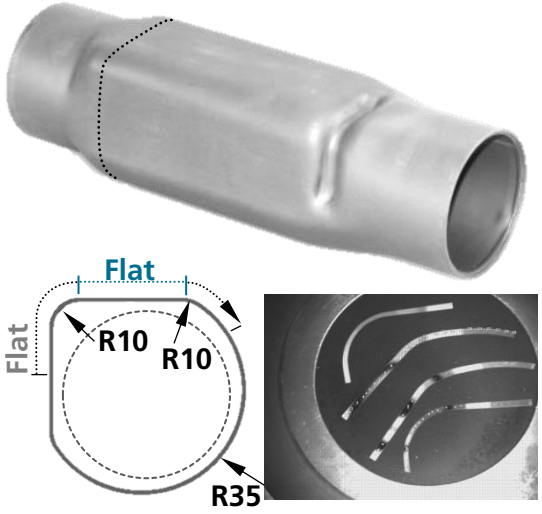
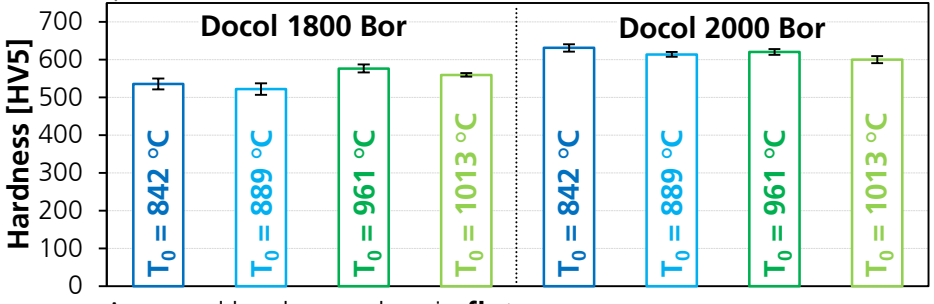
Forming results

Hardness measurement







Averaged hardness values in **flat area**
Max. pressure: **67 MPa**, pressure built up rat: **40 MPa/s**

Results

- **Fully martensitic** phase transformation was proven
- In general **minor spread width** of hardness values for each measured cross section
- Highest hardness levels for Docol 1800 Bor at initial tube temperature **961 °C**
- Highest hardness levels for Docol 2000 Bor at initial tube temperature **842 °C**

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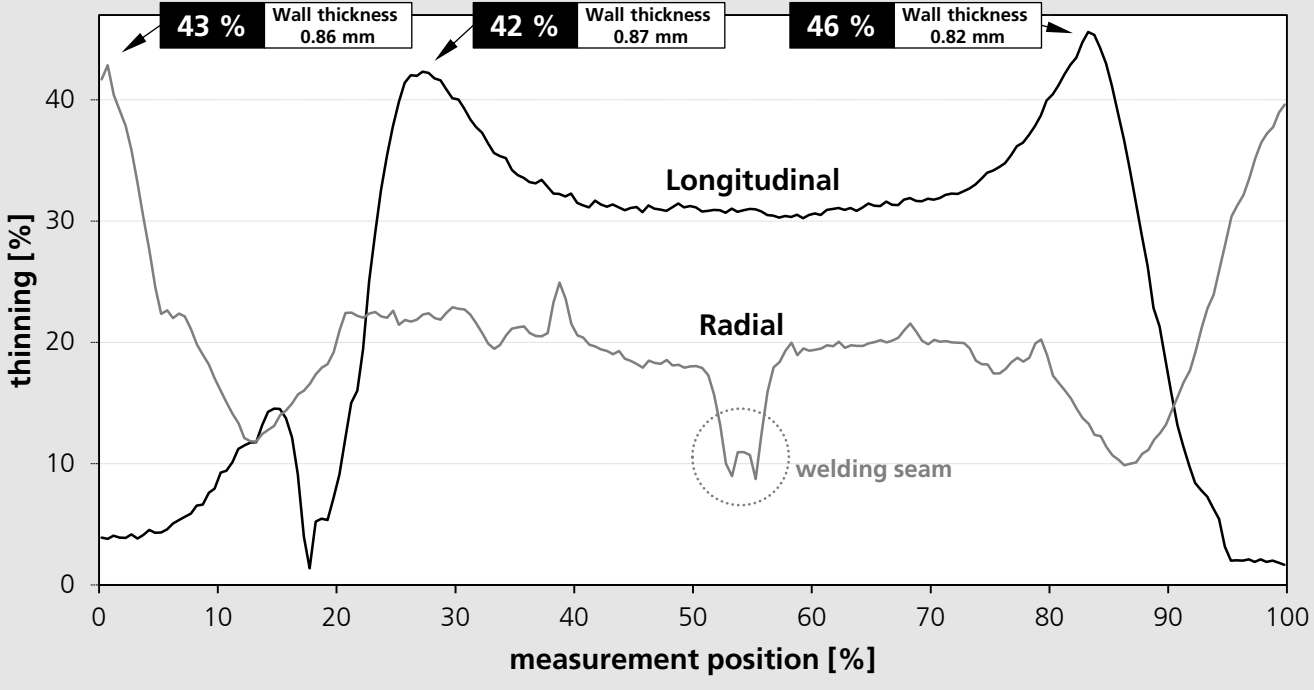
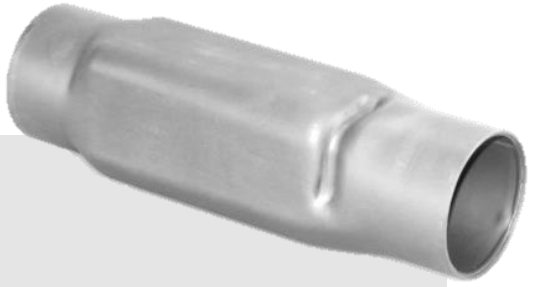
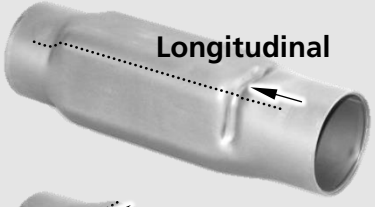
Forming results

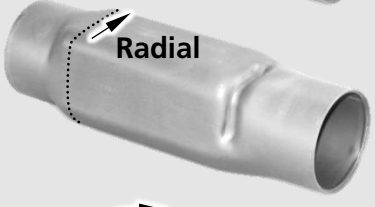
Wall thickness

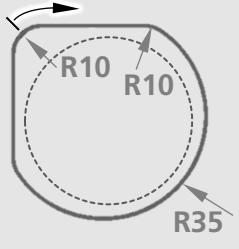
Docol 2000 Bor (1.5 mm / Ø 57 mm tube)
Max. pressure: **37 MPa**
Pressure built up rate: **40 MPa/s**
Initial tube temperature T_0: **975 °C**











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AGENDA

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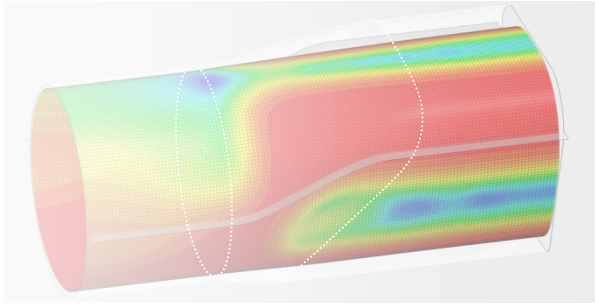

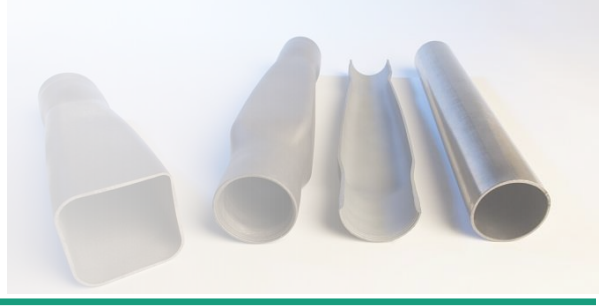

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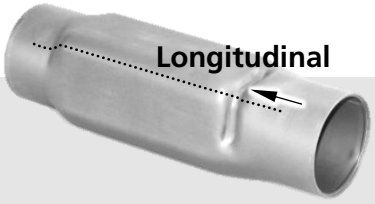
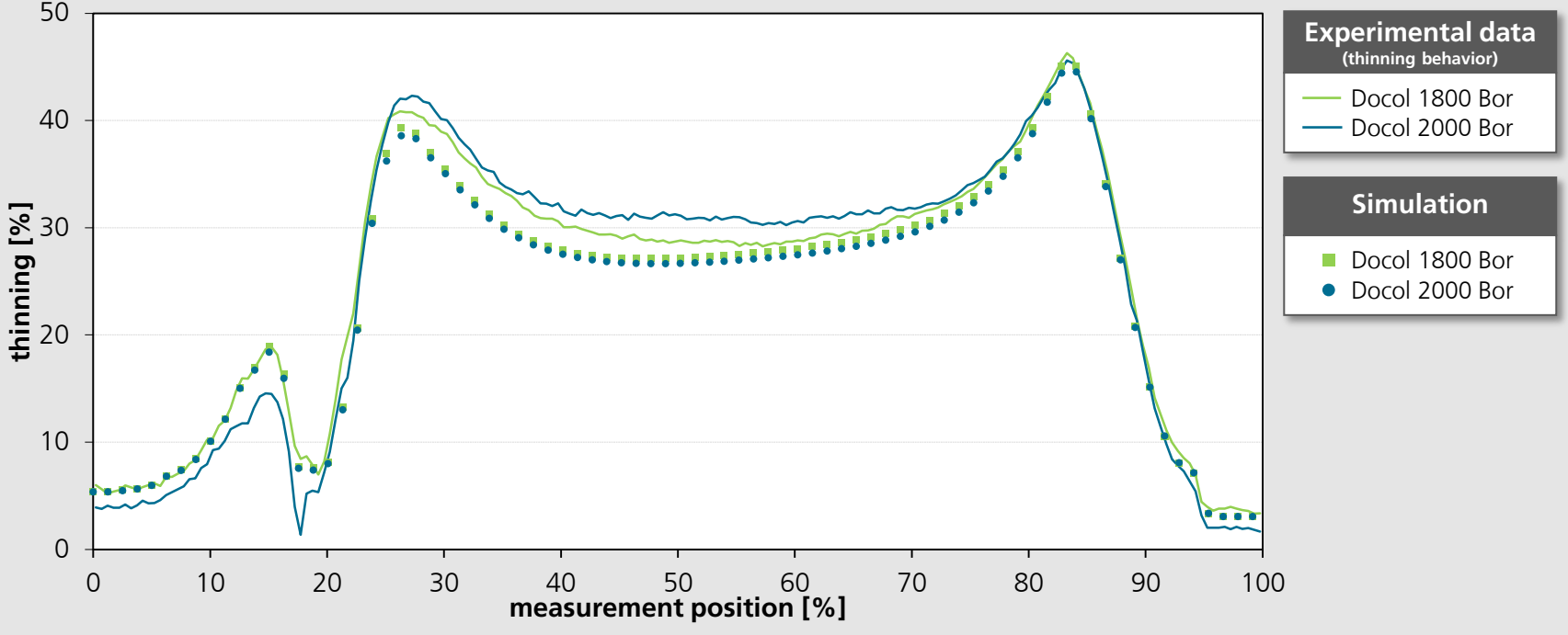
Validation of numerical simulation

Comparison of thinning behaviour



Docol 18000 Bor (1.5 mm / Ø 57 mm tube)
Max. pressure: **67 MPa**
Pressure built up rate: **40 MPa/s**
Initial tube temperature T_0: **975 °C**

Docol 2000 Bor (1.5 mm / Ø 57 mm tube)
Max. pressure: **37 MPa**
Pressure built up rate: **40 MPa/s**
Initial tube temperature T_0: **975 °C**



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Validation of numerical simulation

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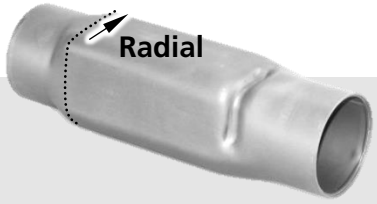

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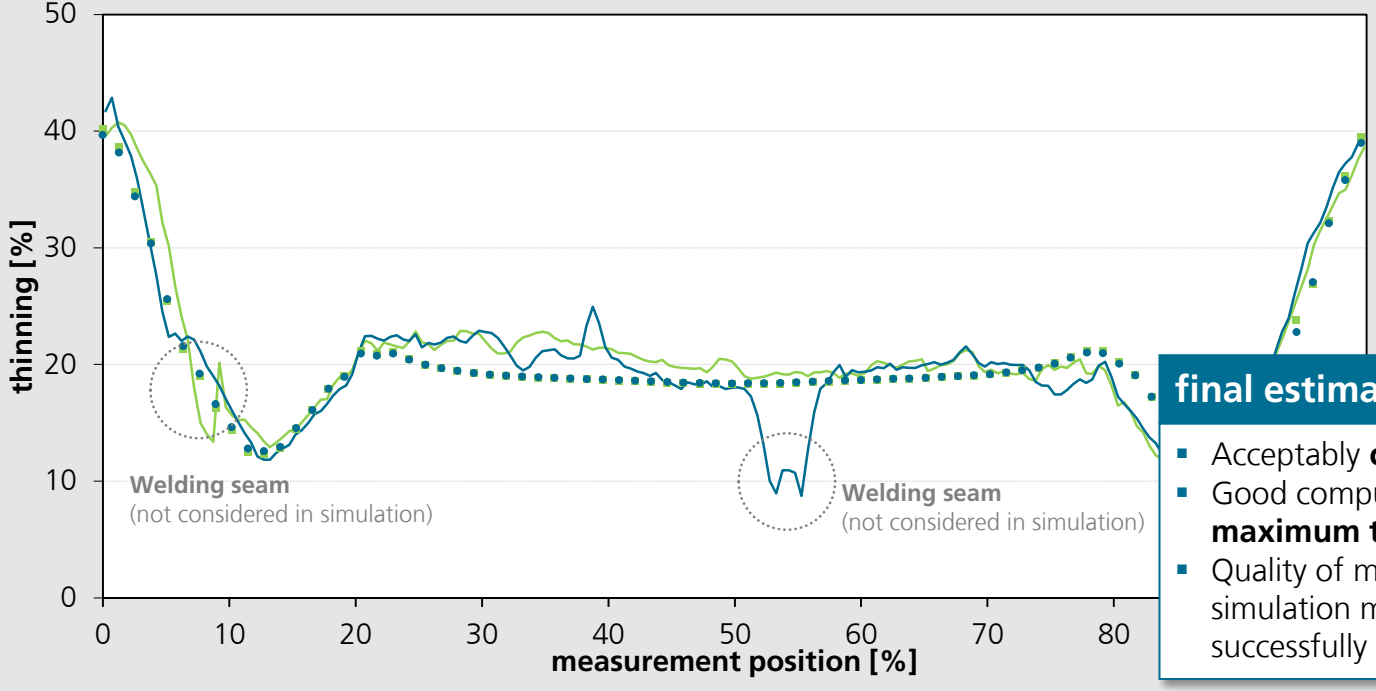

Experimental data
(thinning behavior)
- Docol 1800 Bor
- Docol 2000 Bor

Simulation
- Docol 1800 Bor
- Docol 2000 Bor

final estimation

- Acceptably **consistent results**
- Good computation of areas with **maximum thinning** for both alloys
- Quality of material models and simulation model in general was proven successfully

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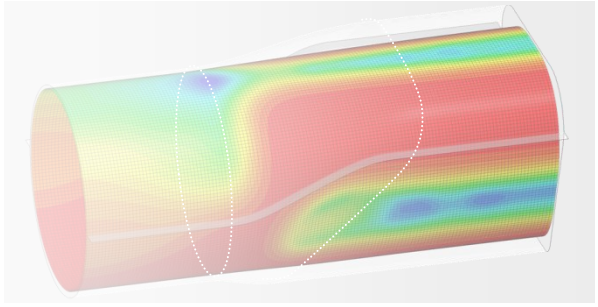

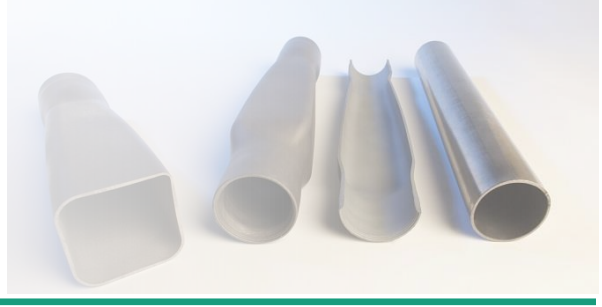

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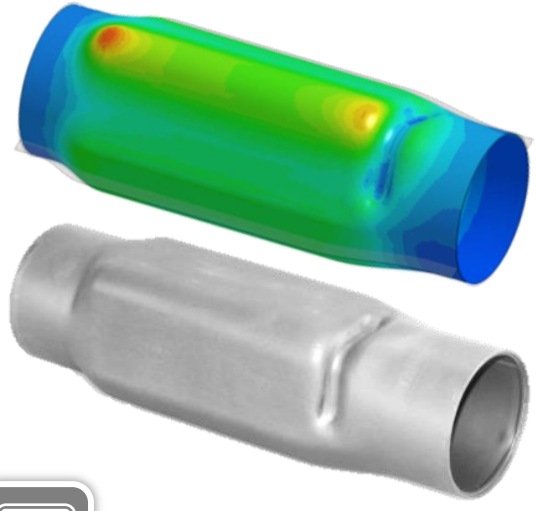
Conclusion and Outlook

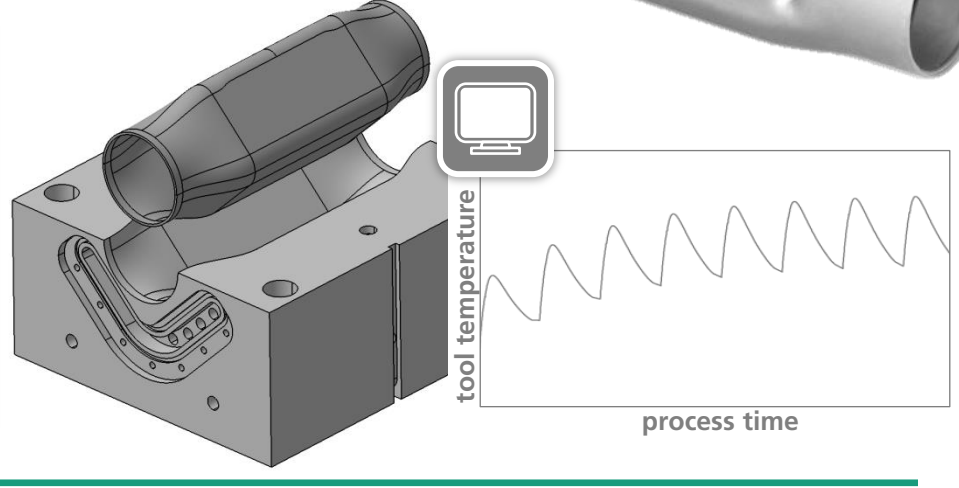
Conclusion

- **HMGF-PH** of Docol 1800 Bor and Docol 2000 Bor tubes has been practically proven
- Analysis of press-hardened tubes by **wall-thickness** and **hardness** measurement
- Reachable hardness of **580 HV5** (Docol 1800) and **634 HV5** (Docol 2000)
- Forming quality and thinning behaviour of Docol 1800 and 2000 is similar
- Setting up **thermo-mechanical forming simulation** for HMGF-PH
- Application of **temperature and strain-rate dependent material models** for both alloys
- Quality of material models and simulation model in general was proven **successfully**



Outlook

- Design of **measurement sensors** (forming temperature and forming path) for the new tool DP3
- **Cyclic forming simulations** with actively cooled tool made of the Rovalma steel HTCS23xx, validation of simulation model
- Evaluation of the resulting mechanical properties of the demonstrators after forming process at different temperatures



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References in hydroforming

Acknowledgment

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Thanks for your attention

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