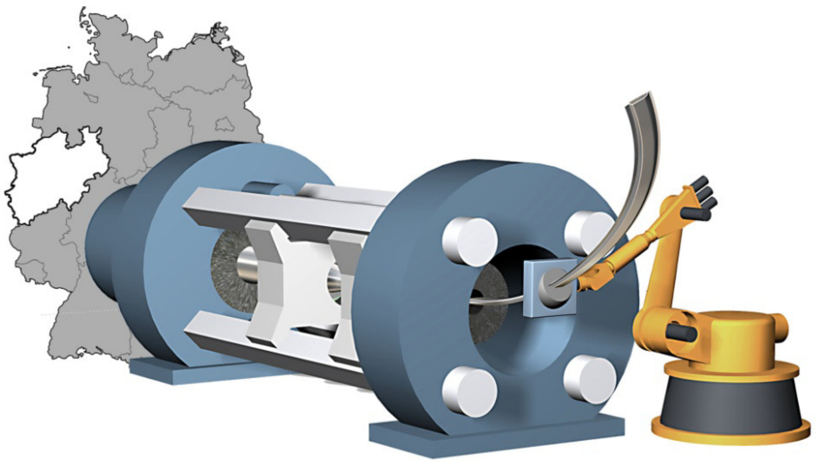
DFG Transregional Collaborative Research Center / TR10

Integration of forming, cutting, and joining for the flexible production of lightweight space frame structures



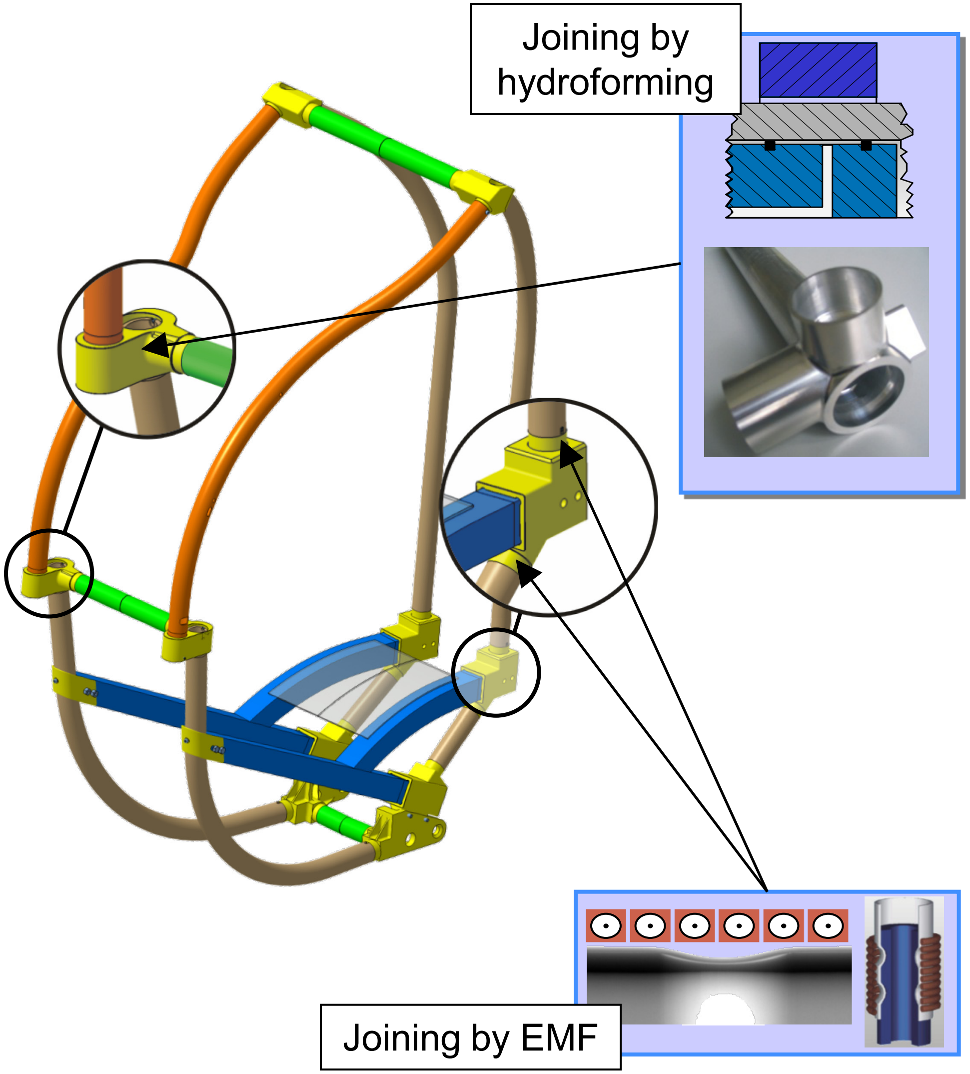
4th International Conference on High Speed Forming

Columbus, Ohio, USA
March 9th and 10th, 2010

Development of design principles for form-fit joints in lightweight frame structures

C. Weddeling, S. Woodward, V. Psyk, J. Nellesen, M. Marré, A. Brosius, A. E. Tekkaya, W. Tillman

- **Introduction**
- **Motivation**
- **Experimental setup and procedure**
- **Results**
- **Summary and outlook**



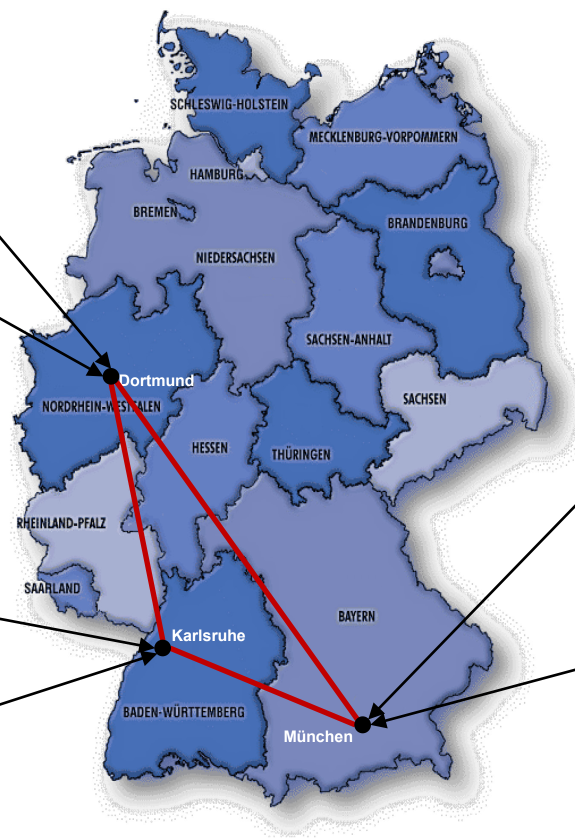
Transregional Collaborative Research Centre SFB/TR10

Institute of Forming Technology and Lightweight Construction
Technische Universität Dortmund
Prof. Dr.-Ing. M. Kleiner
Prof. Dr.-Ing. A. E. Tekkaya

Institute of Machining Technology
Prof. Dr.-Ing. D. Biermann

Institute of Production Science
Prof. Dr.-Ing. G. Lanza
Prof. Dr.-Ing. V. Schulze
Dr. C. Munzinger

Institut für Werkstoffkunde I
Prof. Dr.-Ing. A. Wanner
Prof. Dr.-Ing. P. Elsner
Prof. Dr.-Ing. V. Schulze



Institute of Lightweight Structures
Prof. Dr.-Ing. H. Baier

Institute for Machine Tools and Industrial Management
Prof. Dr.-Ing. M. Zäh

Technische Universität Dortmund | Karlsruher Institut für Technologie | Technische Universität München

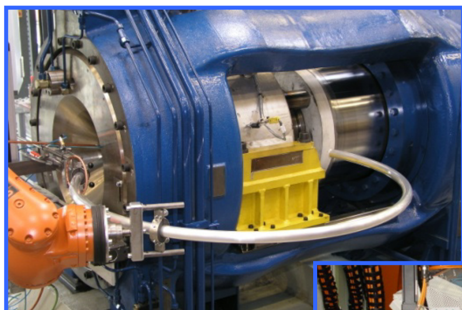
Process chain SFB/TR 10

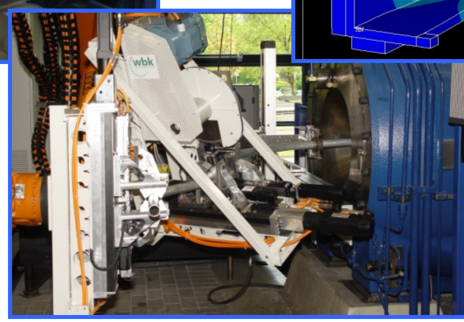
Integrated process chain

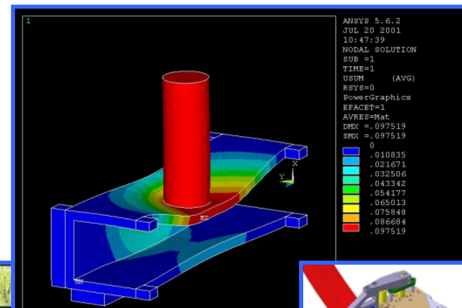
Forming
Extrusion of 3D curved and reinforced profiles

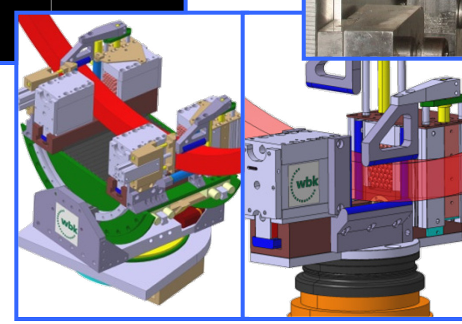
Cutting
Machining of lightweight frame components

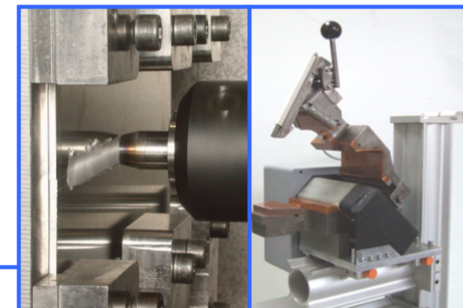
Joining
Laser beam welding, FSW, EMF, joining by hydroforming









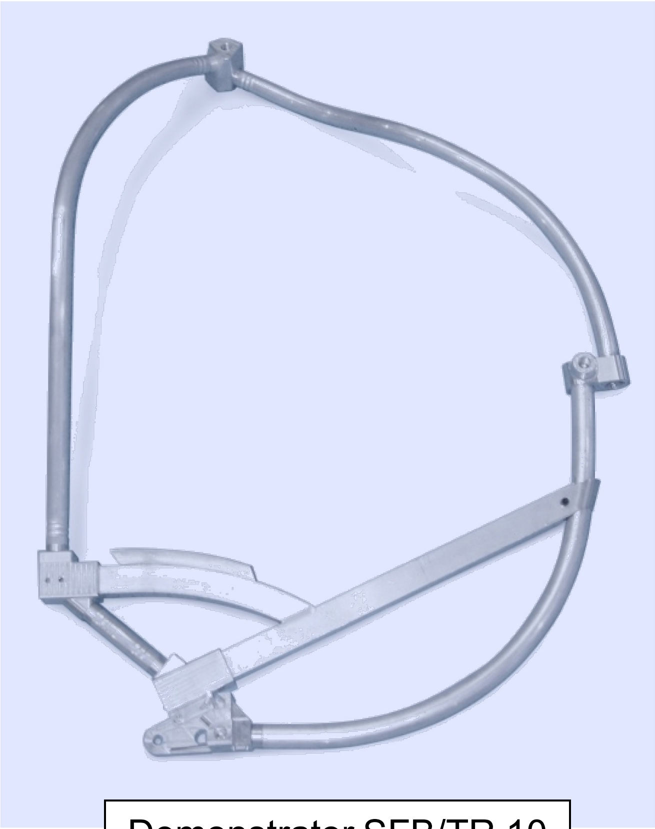


Handling
Integration of handling and machining

Continuous and integrated simulation and design

Subproject A10 - Objectives

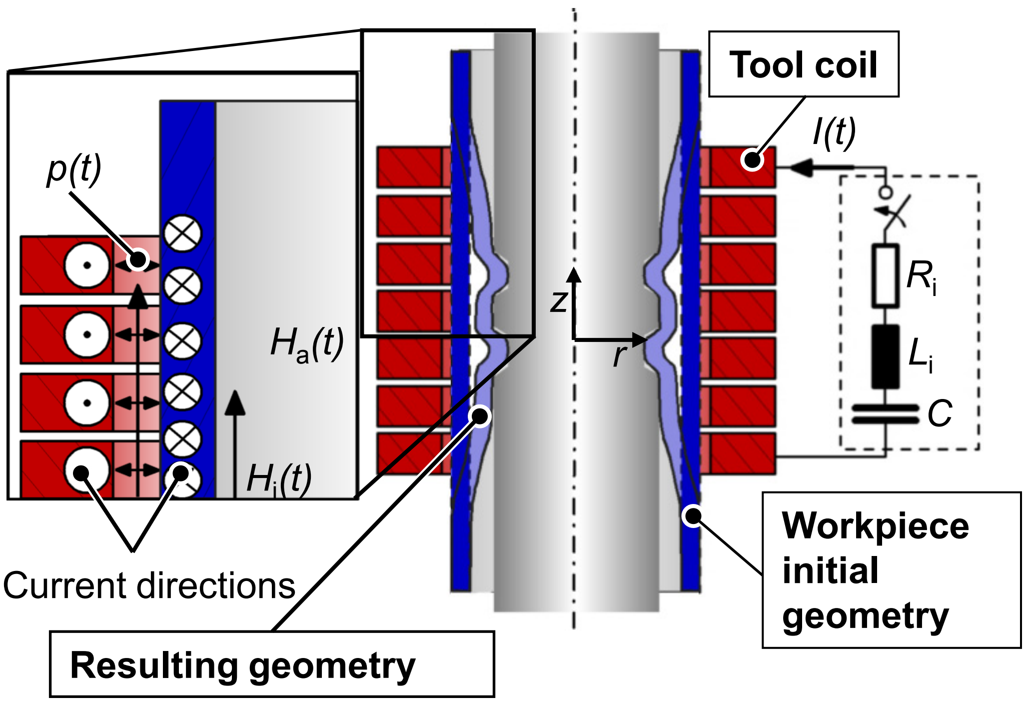
- Fundamental technological investigations concerning “Joining by forming”
- Processes: electromagnetic compression (EMF) and expansion by hydroforming
- Focus on form-fit and interference-fit connections
- Development of joining strategies for lightweight frame structures
- Creation of general design principles for the joining zone.
- Integration of the joining processes in the flexible process chain of the SFB/TR 10

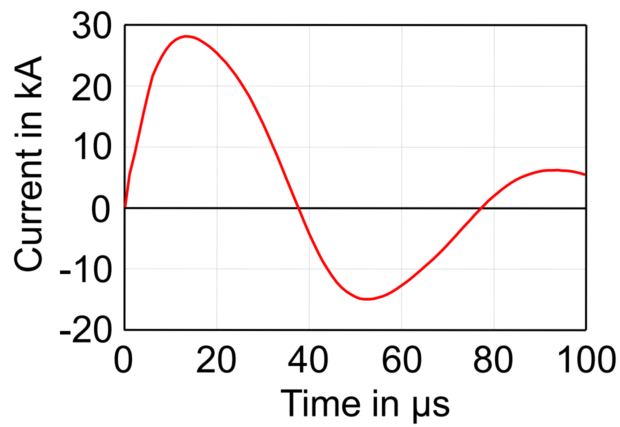


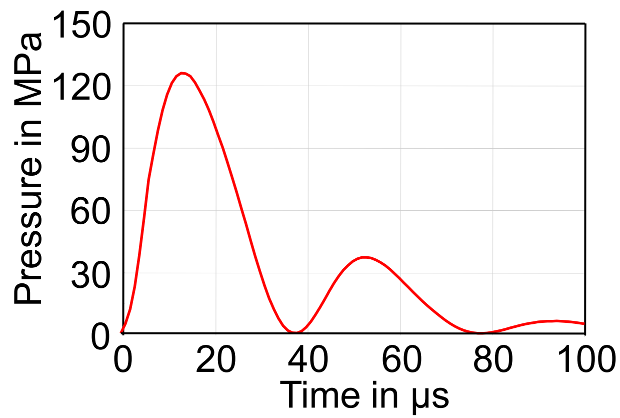
Demonstrator SFB/TR 10

EM-Compression – Process Principle

- Electromagnetic forming (EMF) is a high velocity technology
- Energy density of pulsed magnetic fields is used to apply a pressure to workpieces made of materials of high electrical conductivity
- Workpiece material has to have a electrical conductivity







$$p(z,t) = \frac{1}{2} \cdot \mu_0 \cdot \left(H_a^2(z,t) - H_i^2(z,t)\right)$$

- Form-fit connections are based on an undercut of tube and mandrel

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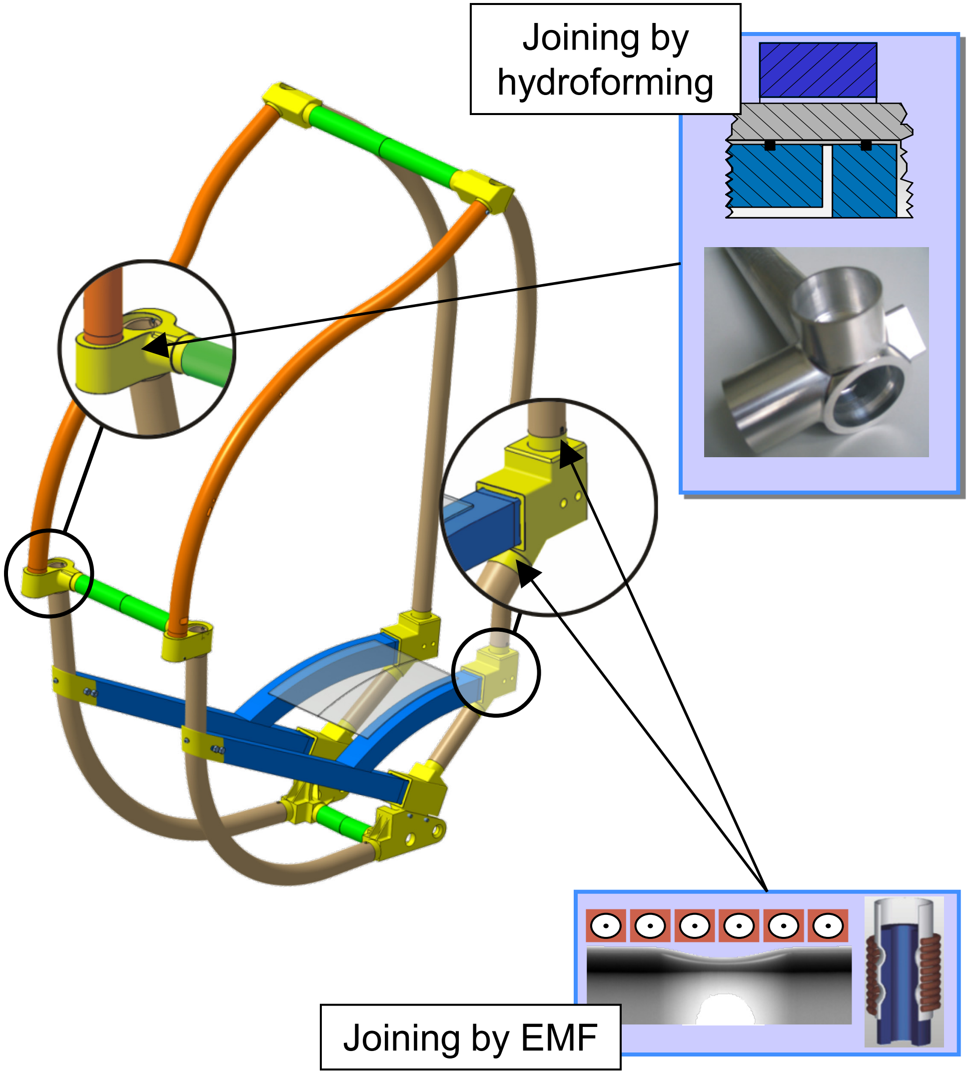
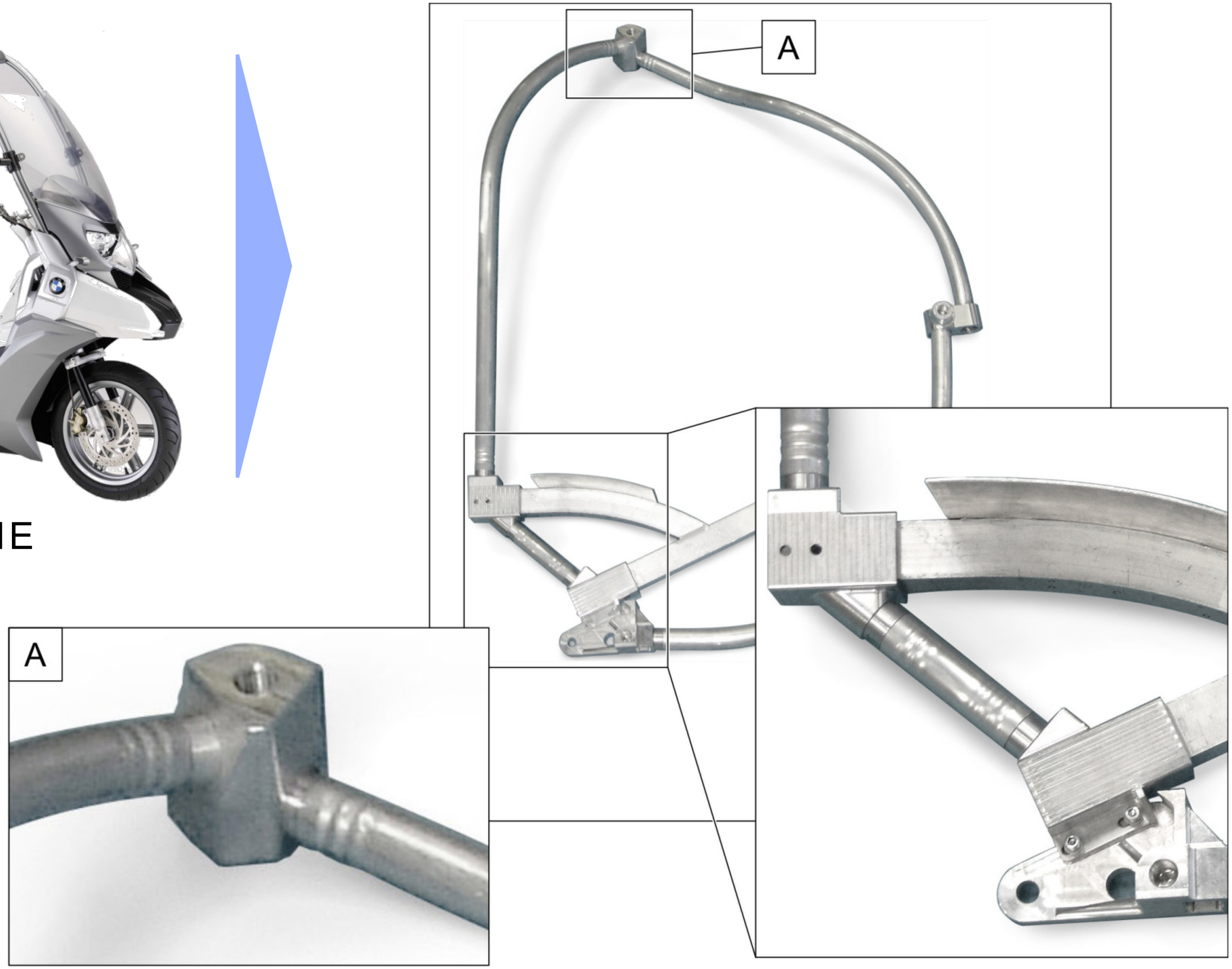


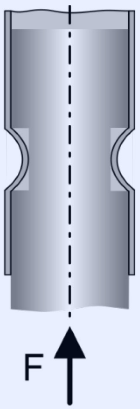
Motivation

BMW-C1E

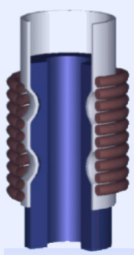


Motivation

Bühler (1968 and 1971)



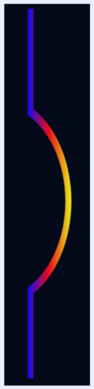
$$p_{\min} = 3 \cdot k_f \cdot \left(\frac{s}{w}\right)^2 + k_f \cdot \left(\frac{s}{R}\right)$$

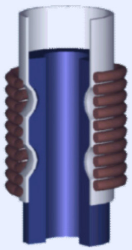


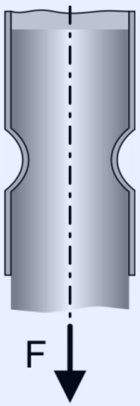
Parameter

- Groove depth
- Groove width

Golovashchenko (2001)







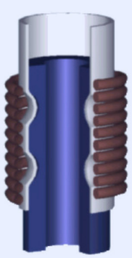
Parameter

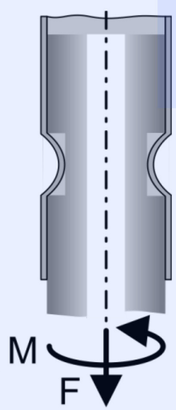
- Groove depth
- Groove width

$$\rho \frac{d\sigma}{d\rho} + \sigma_\rho - \sigma_\theta - \frac{f \cdot \rho}{\sin\alpha}\left(\frac{\sigma_\rho}{R_\rho} + \frac{\sigma_\theta}{R_\theta}\right) = 0$$

Parameter

- Groove depth
- Groove width
- Edge radius
- Multiple grooves





Park et. al. (2005)

Motivation

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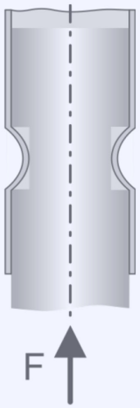
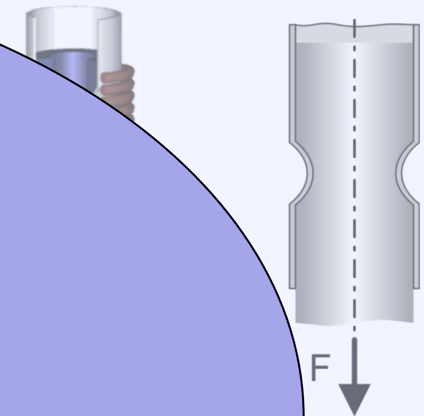
Bühler (1968 and 1971)



$p_{min} = 3 \cdot k$ ...

Golovashchenko (2001)



... $+ \frac{\sigma_\theta}{R_\theta} \Big) = 0$

Joining strategy

Required joint characteristics

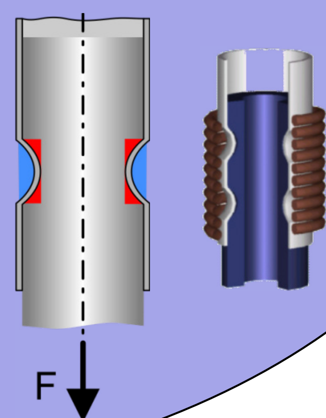
→Characteristics of the joining zone

→Required process parameters

Investigation of the influence of the

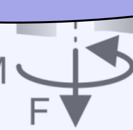
- groove **depth and width** and
- groove **shape** on

the strength of **solid** and **hollow** mandrel



- Edge...
- Multiple grooves

Park et. al. (2005)



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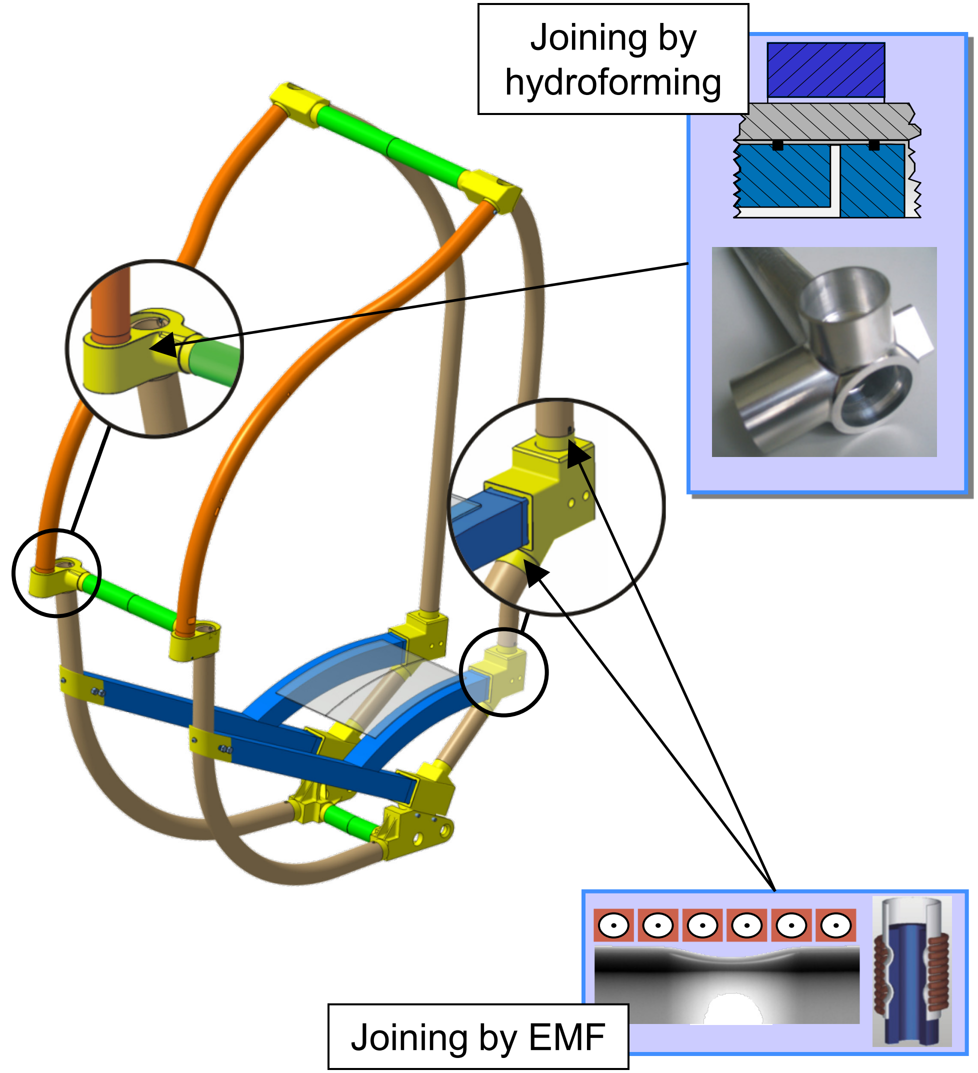

Experimental setup

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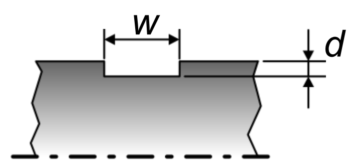
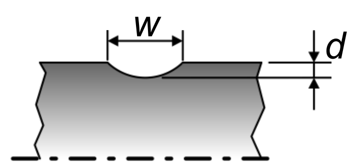
Tube	
Material:	EN AW-6060
Outer diameter:	40 mm
Wall thickness:	36 mm

Mandrel	
Material:	EN AW-6060
Outer diameter:	36 mm
Groove depth:	1, 1.5, 3 mm
Groove width:	12, 16, 20 mm

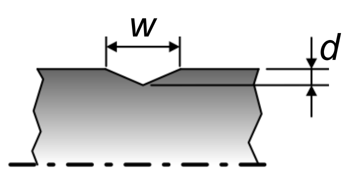
Groove shape's



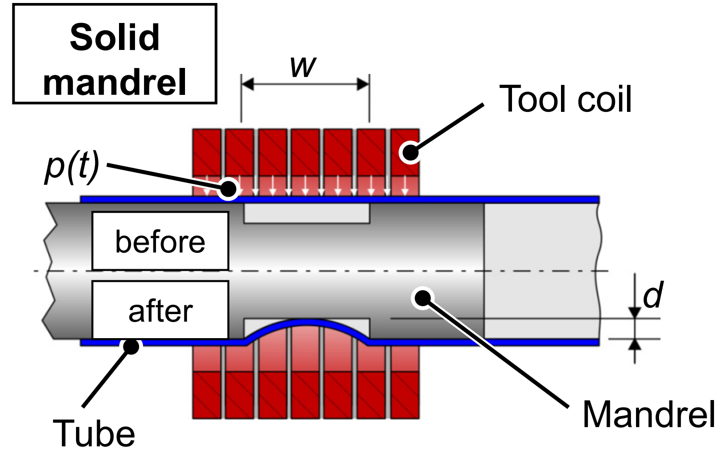
Rectangular

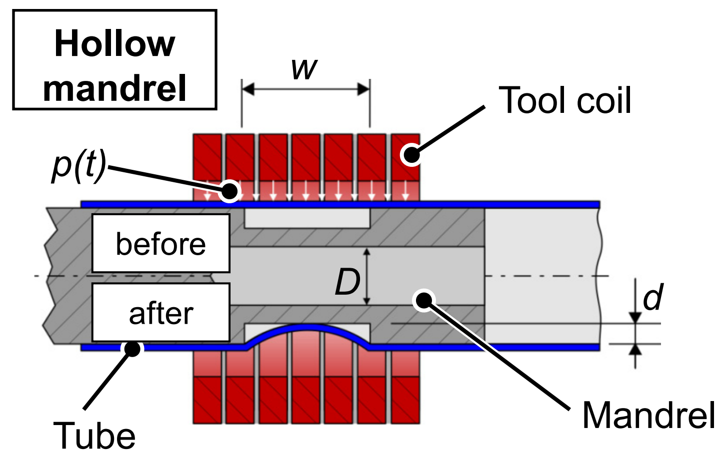


Circular

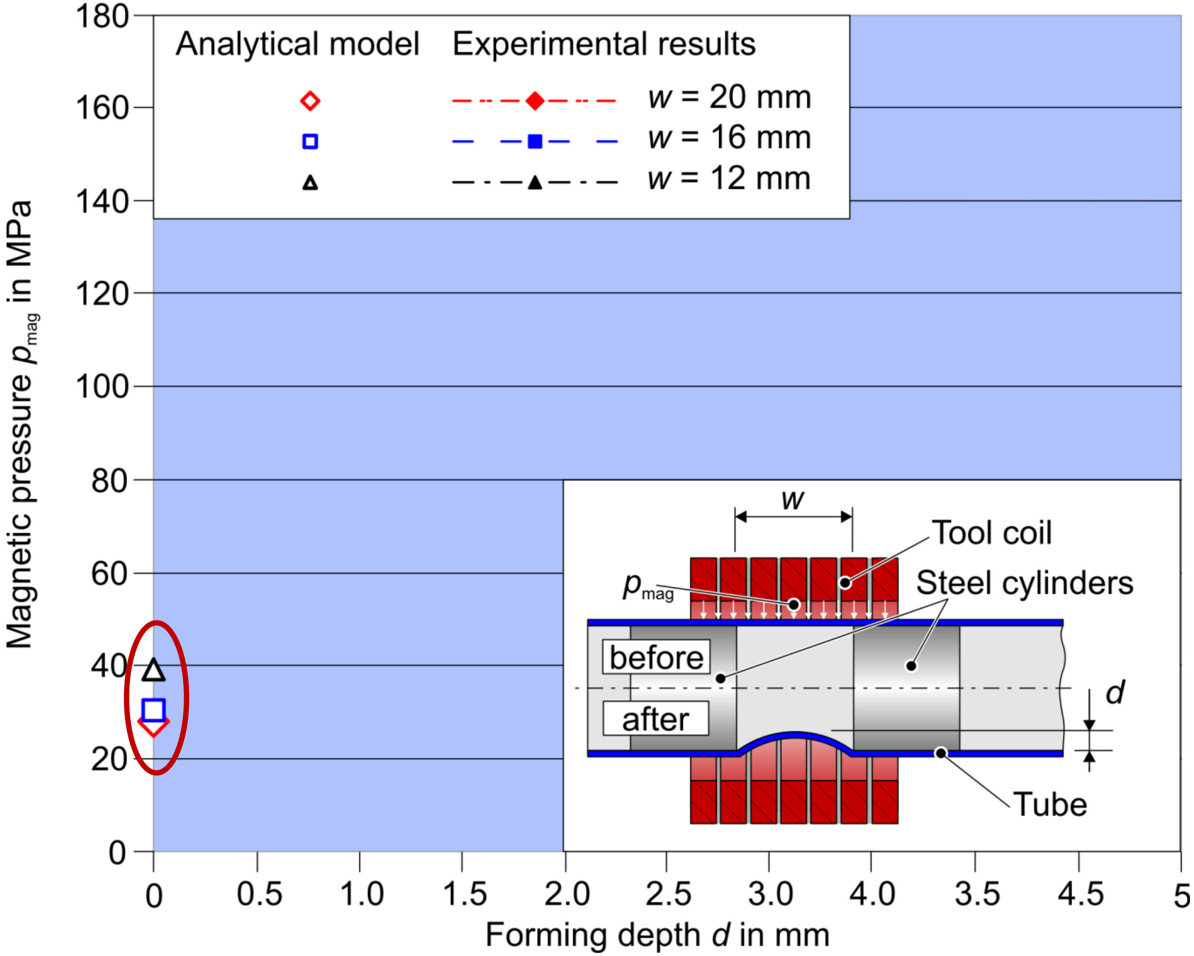


Triangular





Pressure Determination

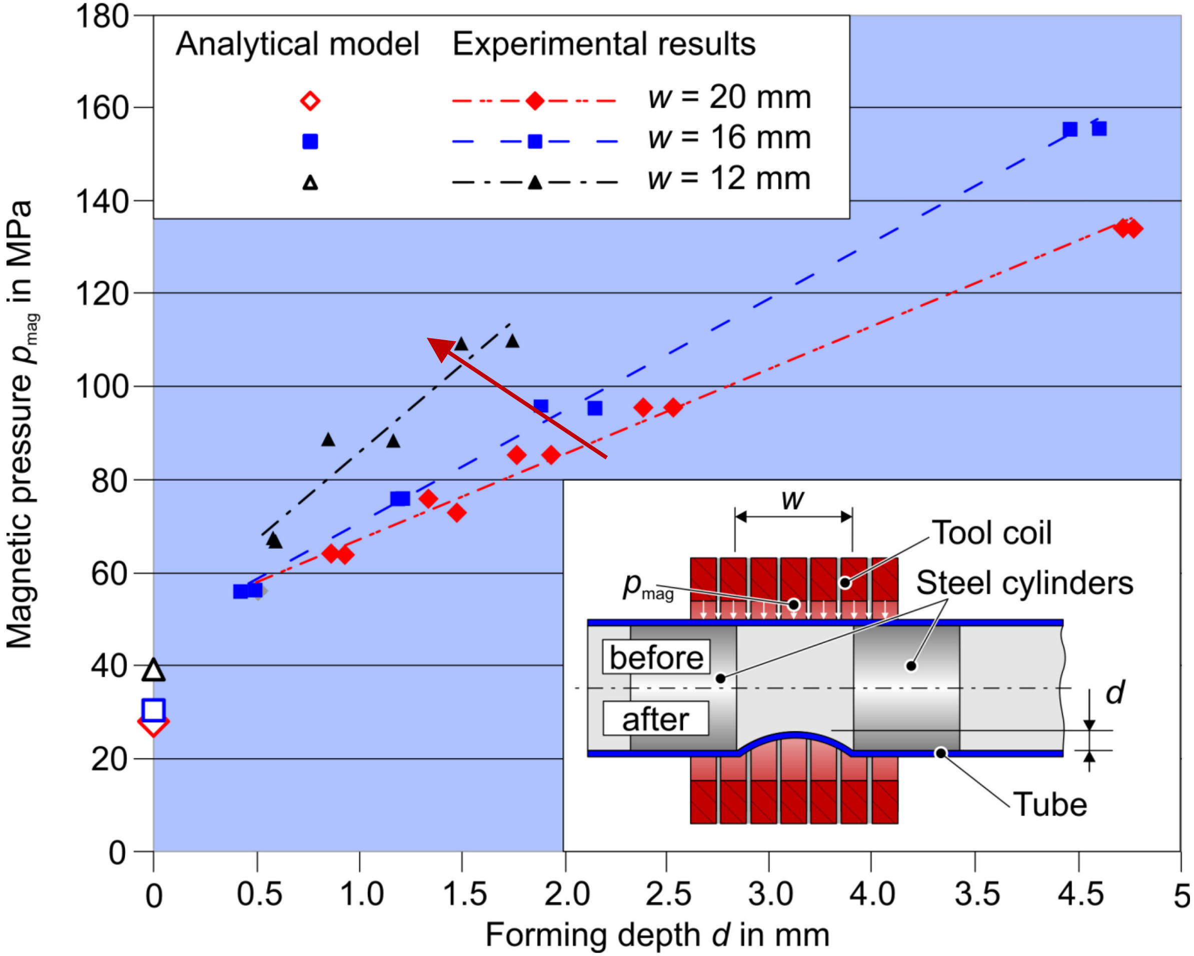


Beginning of plastic deformation (Bühler 1971):

$$p_{\min} = 3 \cdot k_f \cdot \left(\frac{s}{w} \right)^2 + k_f \cdot \left(\frac{s}{R} \right)$$

p_{min}	minimum pressure
k_f	flow stress
s	wall thickness (tube)
R	tube outer radius

Pressure Determination



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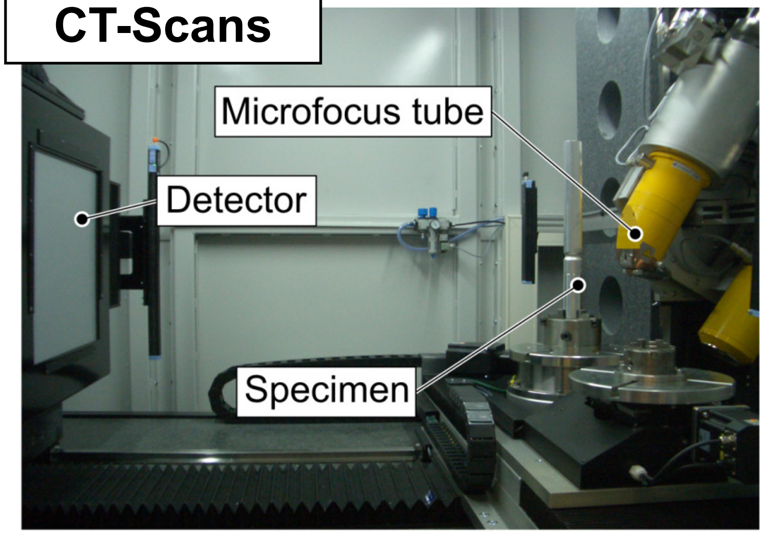
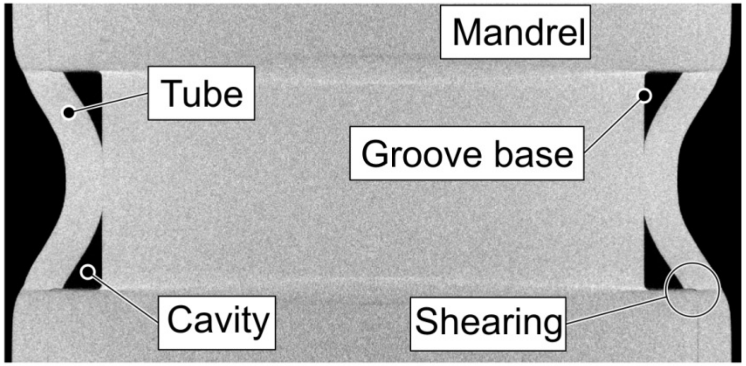
CT-Scans and pull-out tests

CT-Scans

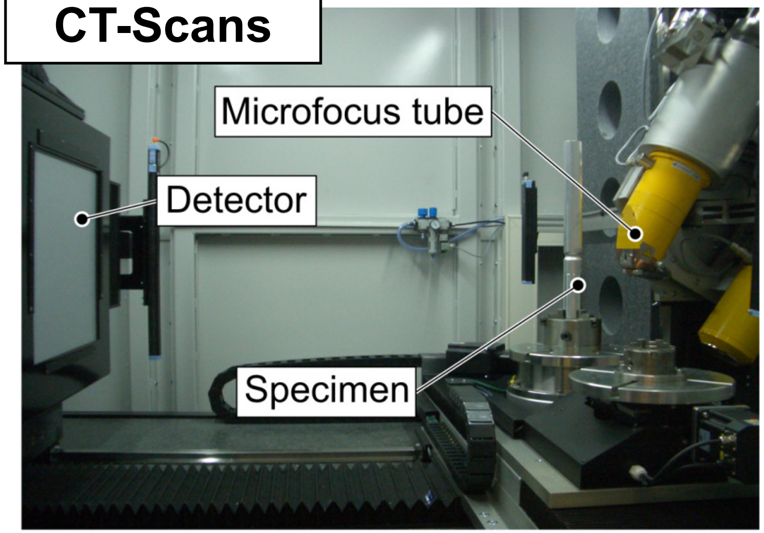


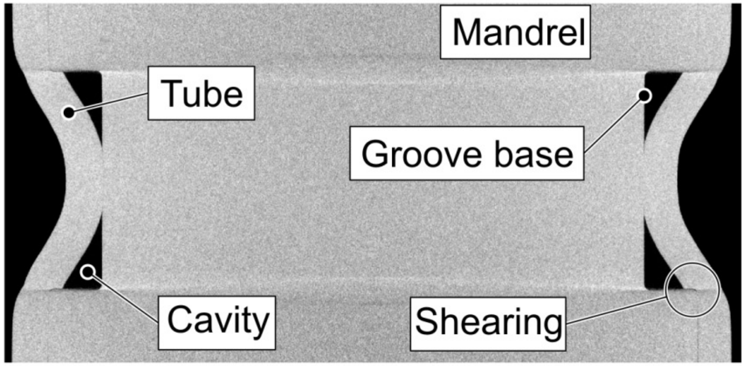


Groove width:	20 mm
Groove depth:	3 mm
Groove shape:	Rectangular

CT-Scans and pull-out tests

CT-Scans





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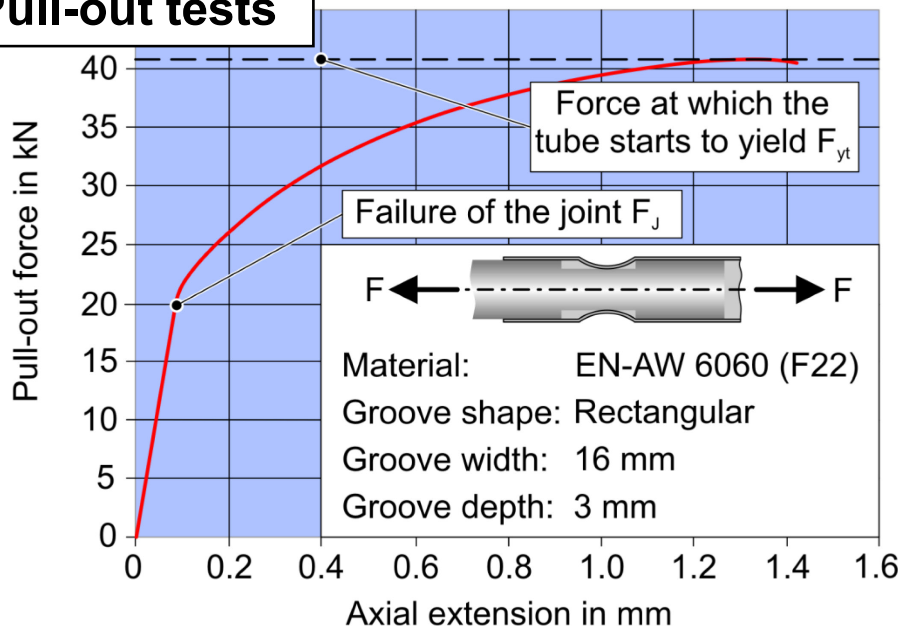

CT-Scans and pull-out tests

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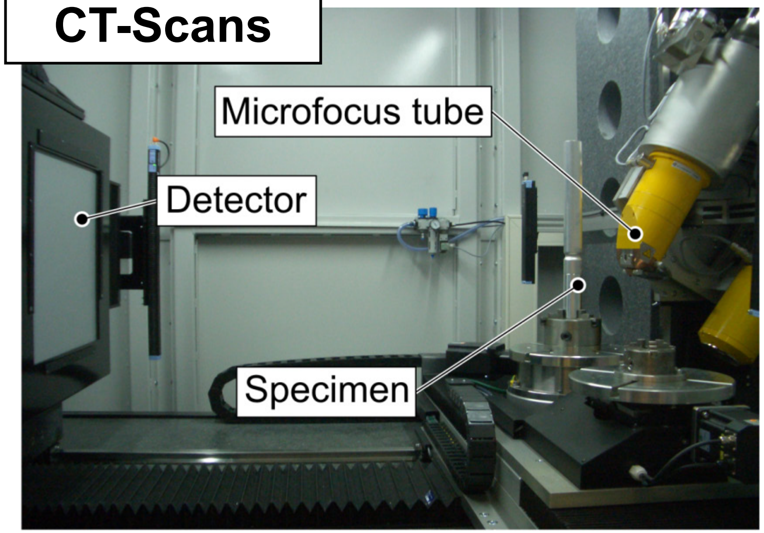
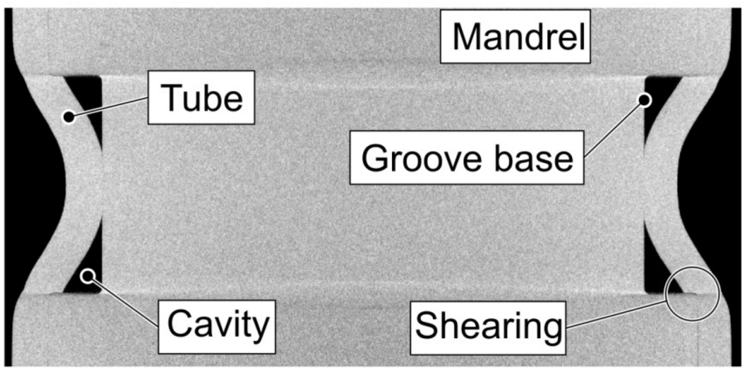
CT-Scans





Groove width:	20 mm
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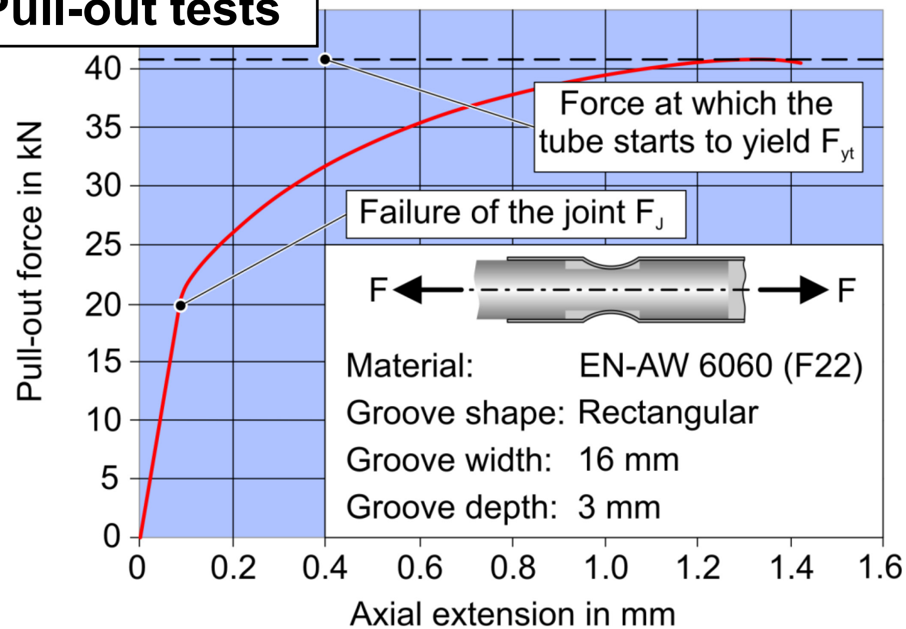

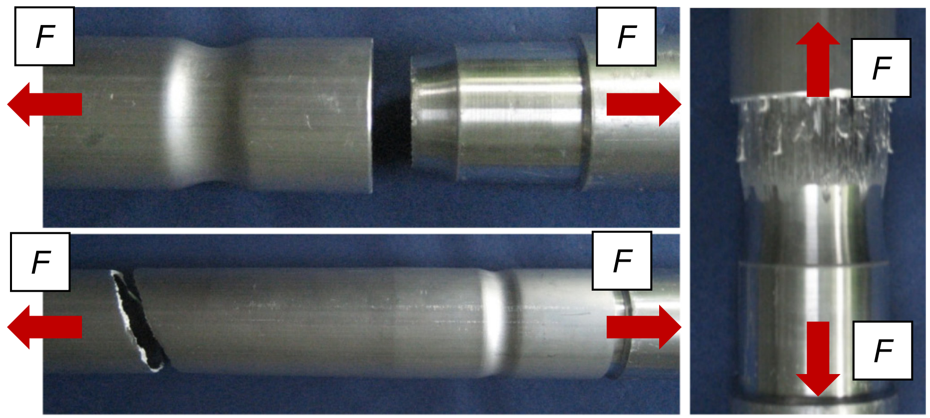

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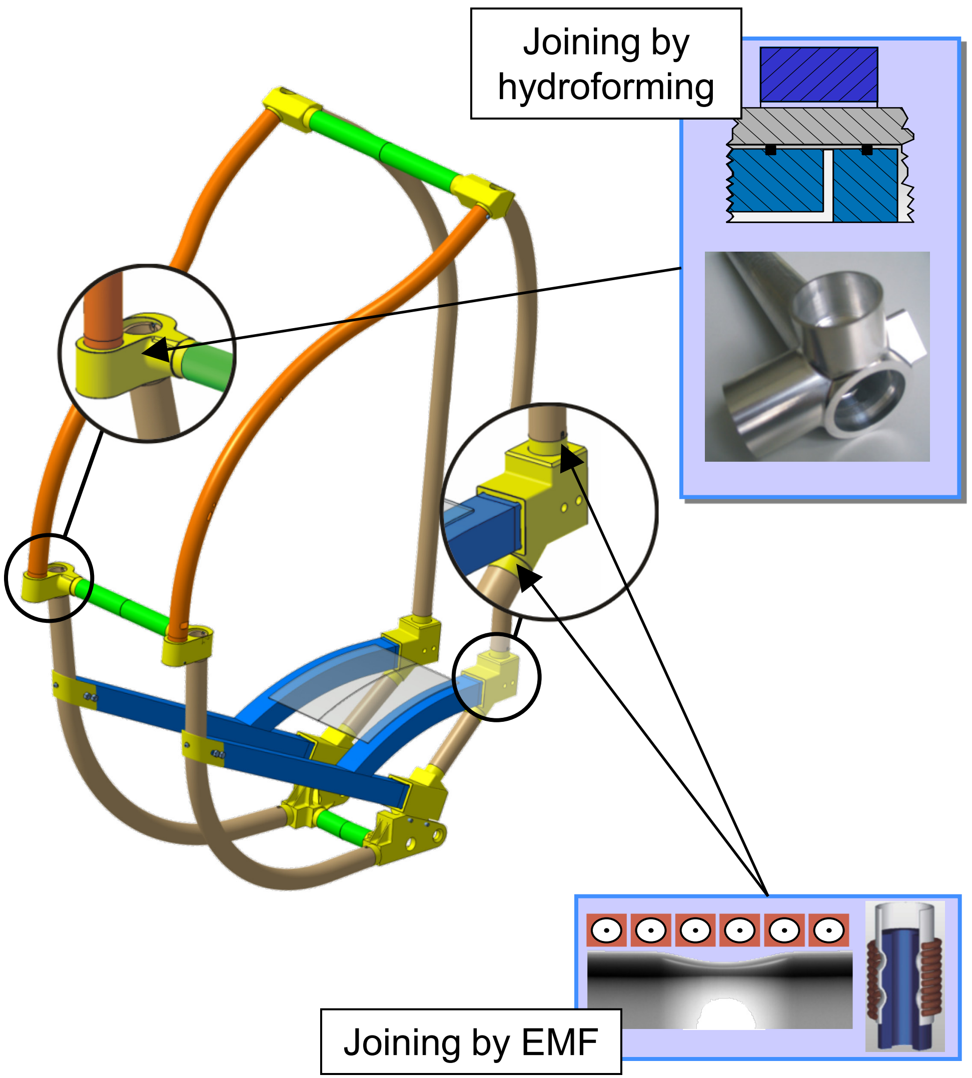
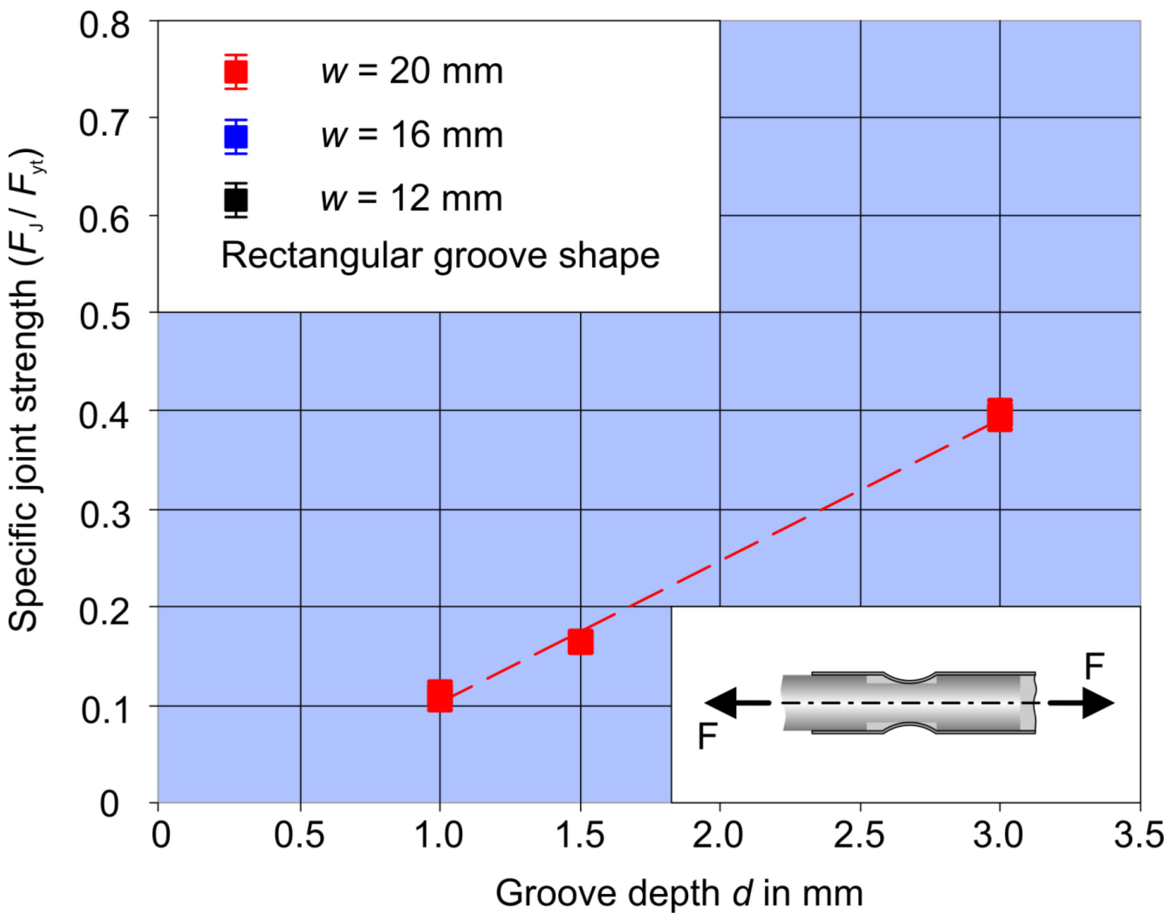


Results I – Influence of groove dimensions



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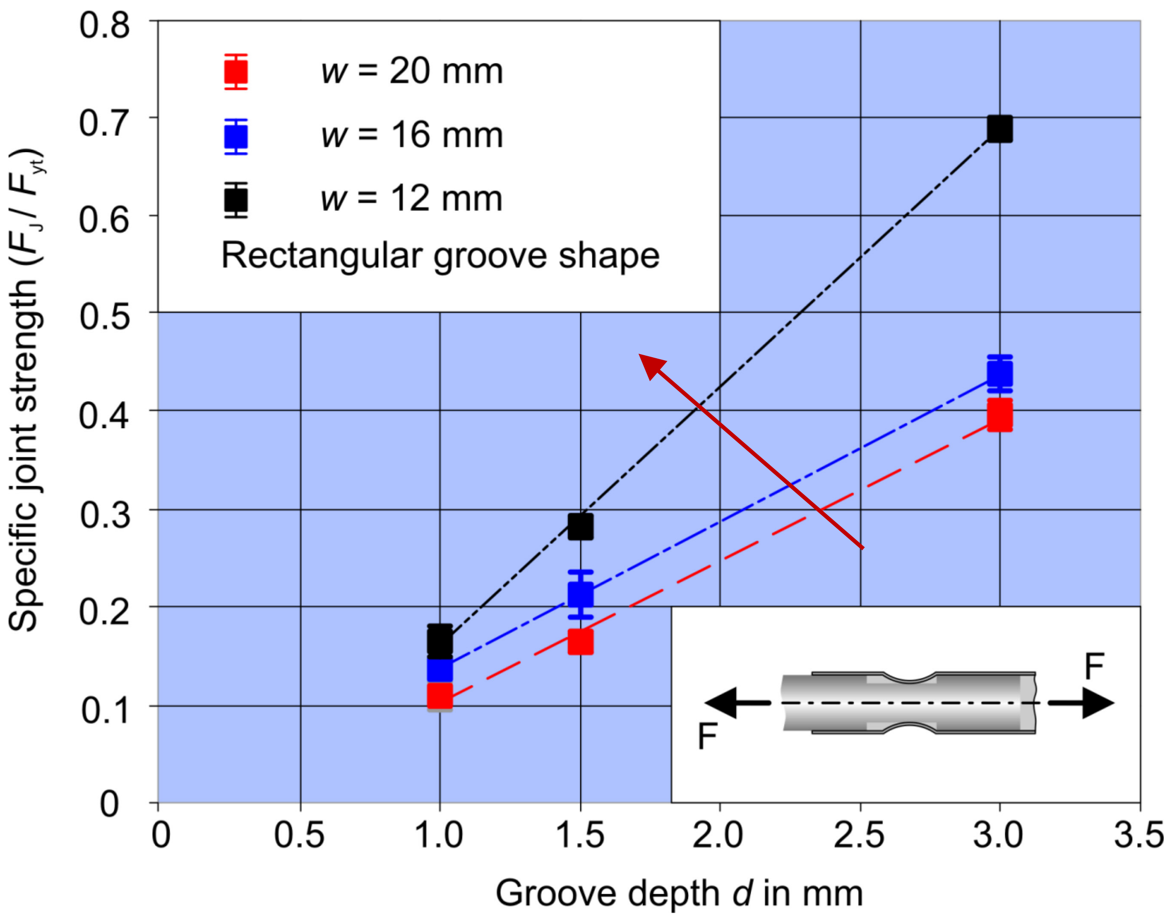
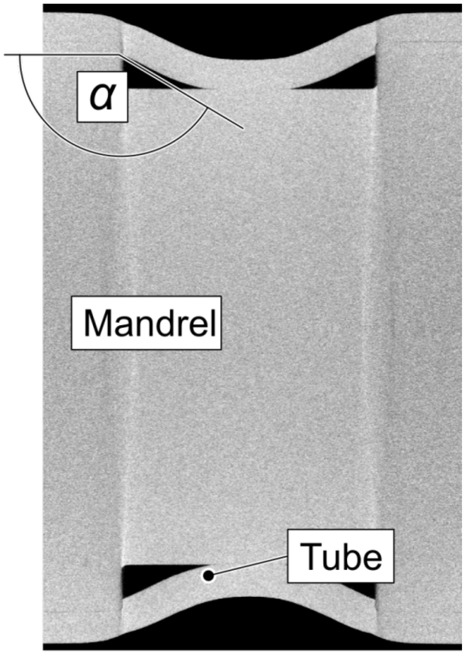
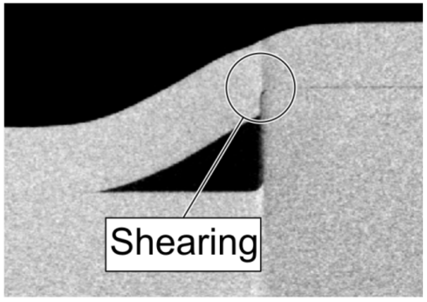
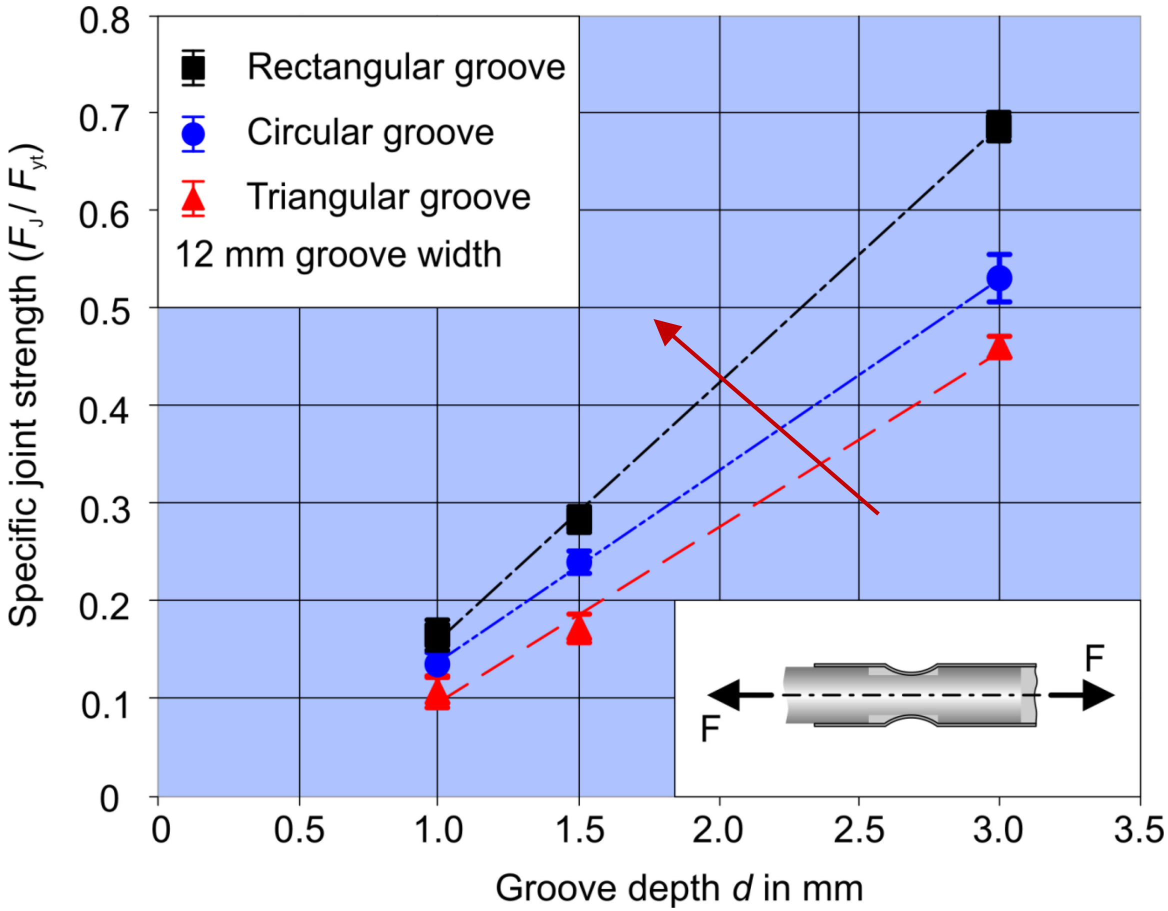
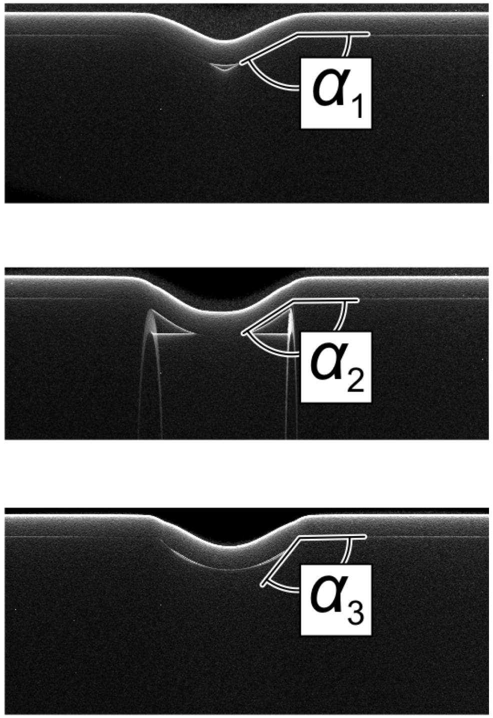






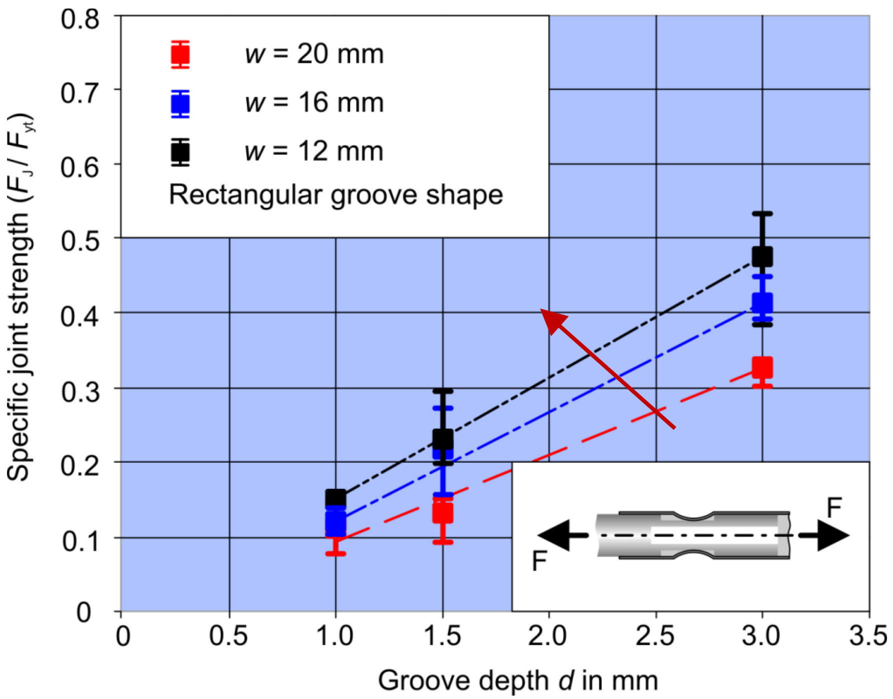
Results II – Influence of groove geometry





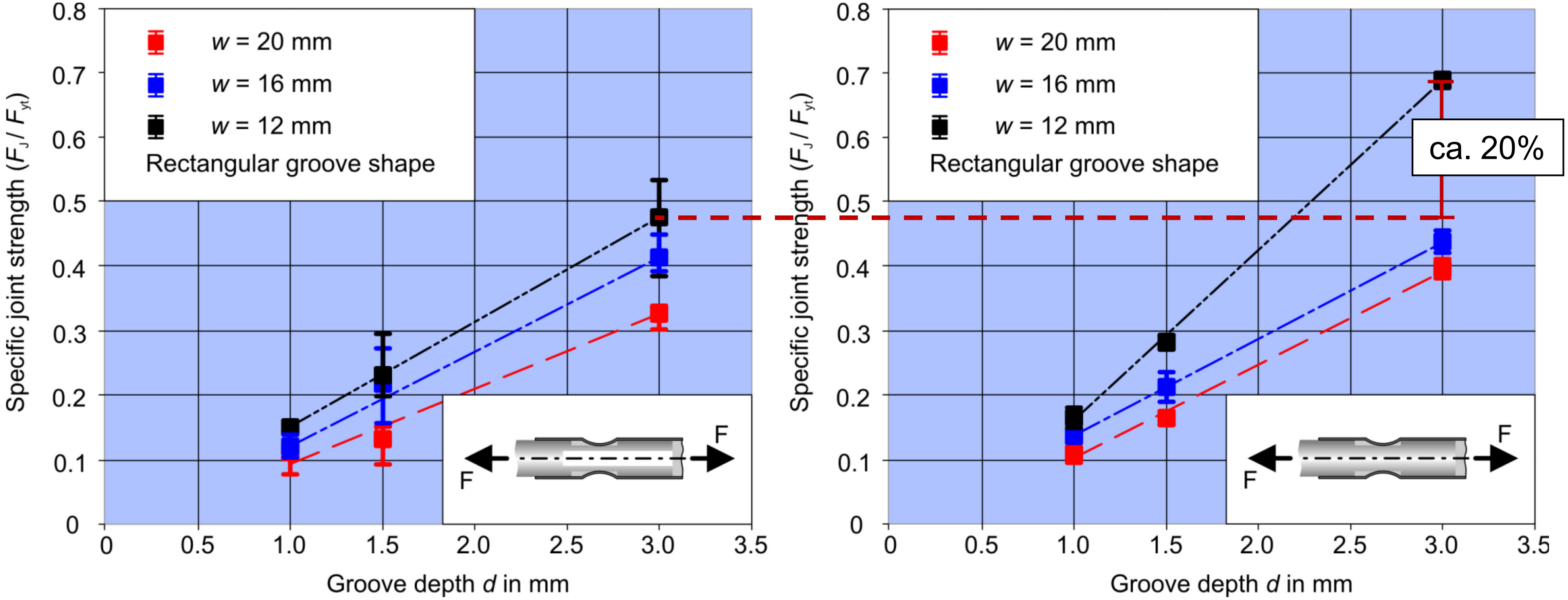
$\alpha_3 < \alpha_2 < \alpha_1$

Results III – Comparisons hollow and solid mandrels



- Hollow mandrel

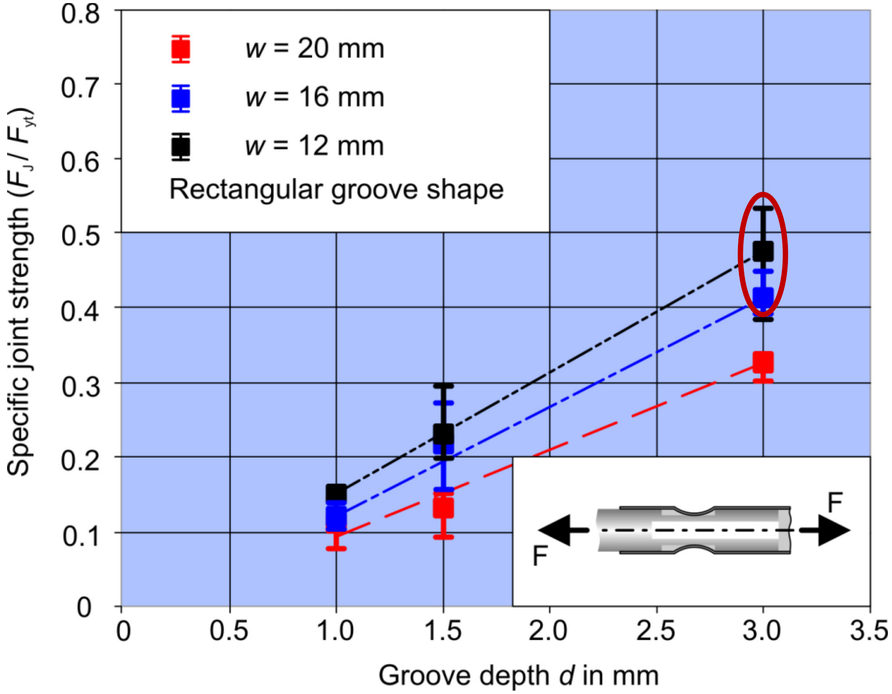
Results III – Comparisons hollow and solid mandrels

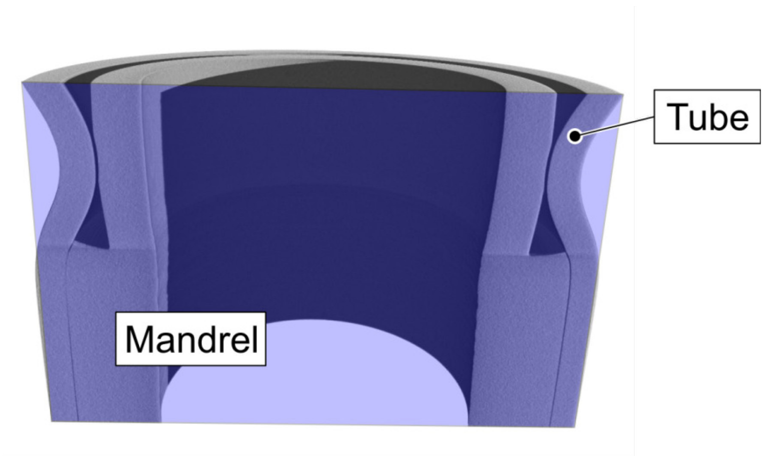


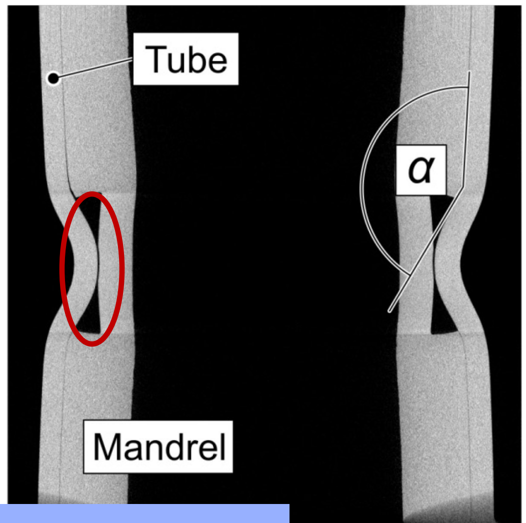
- Hollow mandrel
- Solid mandrel

→ Hollow mandrels show an up to 20% **lower** specific Joint strength

Results III – Comparisons hollow and solid mandrels



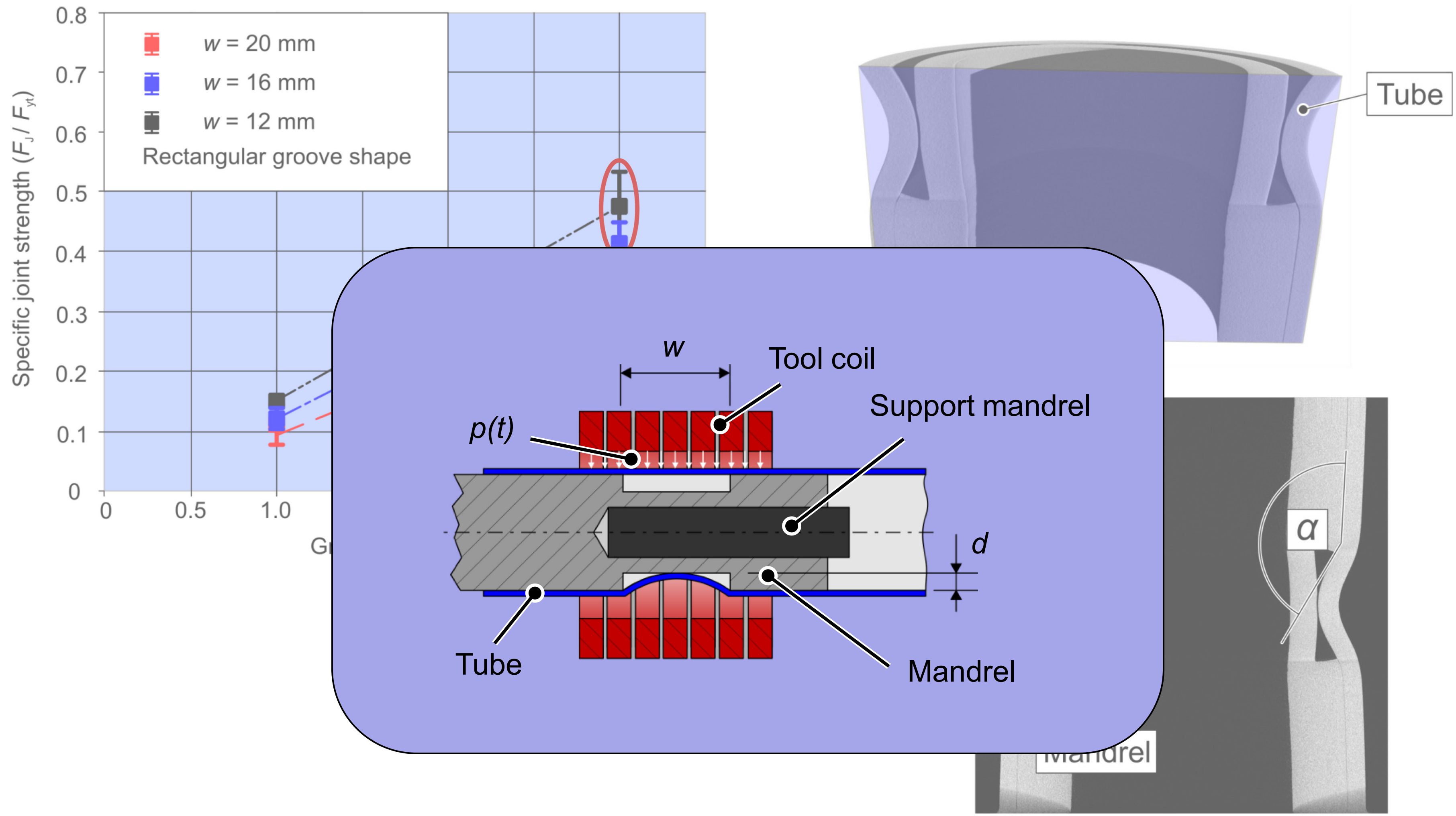




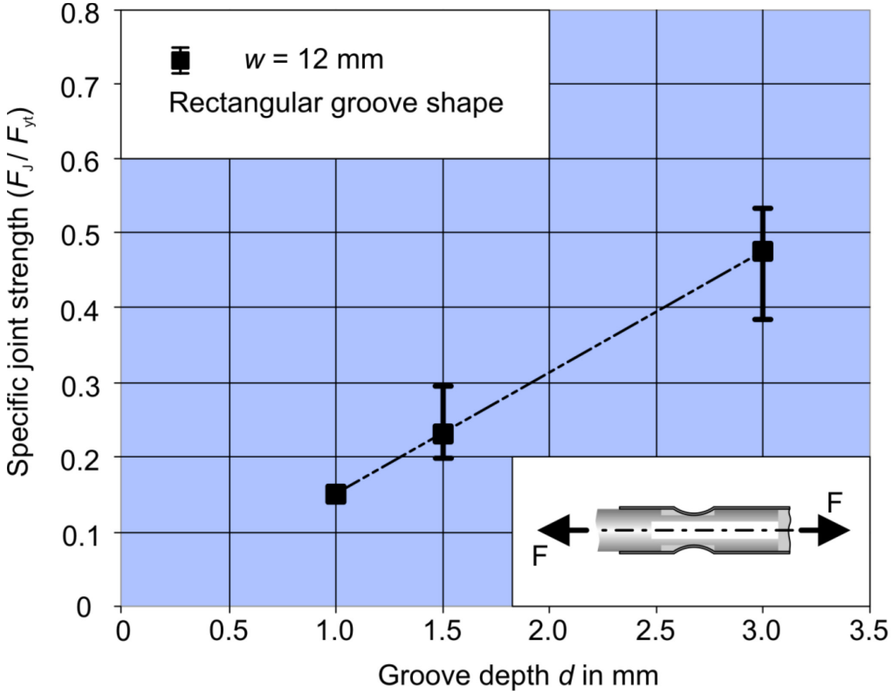
- An increase of the forming pressure leads to an increase of the mandrel deformation
- The deformation of the mandrel leads
  - to a **larger** angle *α* and
  - to **no contact** at the groove base

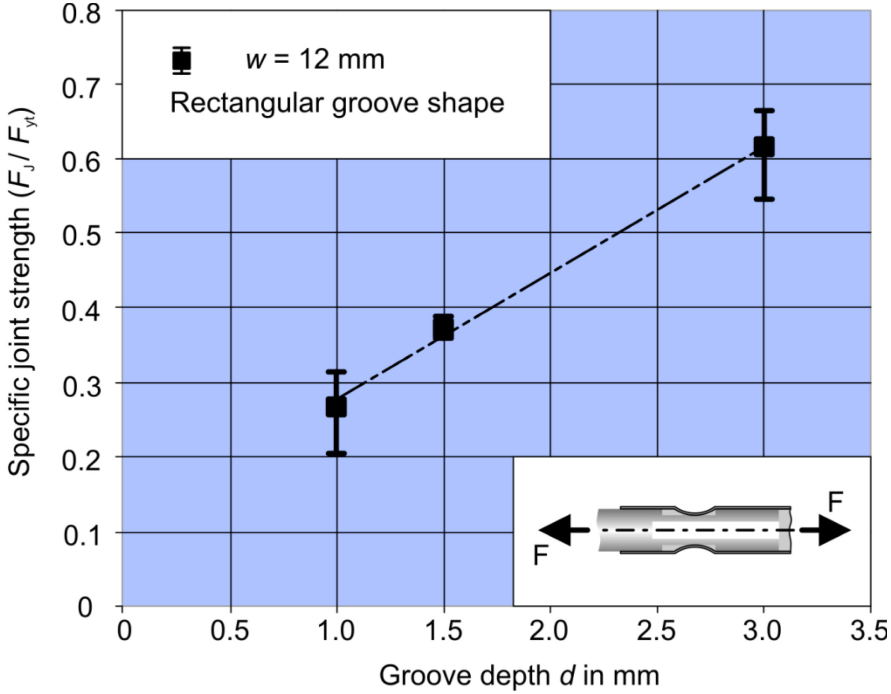
→ Decrease of joint strength

Results III – Comparisons hollow and solid mandrels



Results IV – Support mandrel

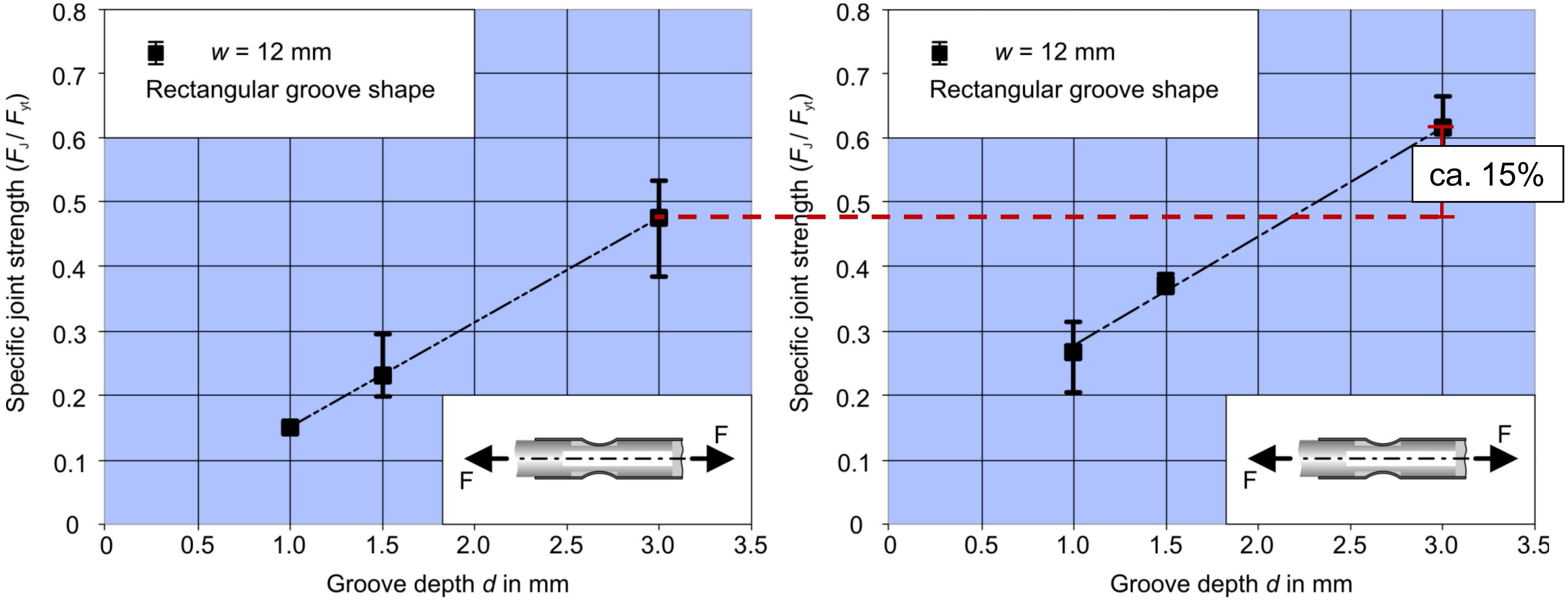




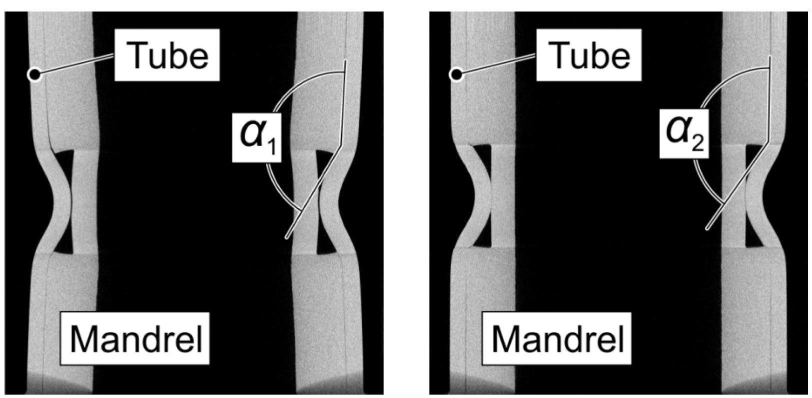
- Hollow mandrel

- Hollow mandrel joint with support mandrel

Results IV – Support mandrel



- Hollow mandrel



- Hollow mandrel joint with support mandrel

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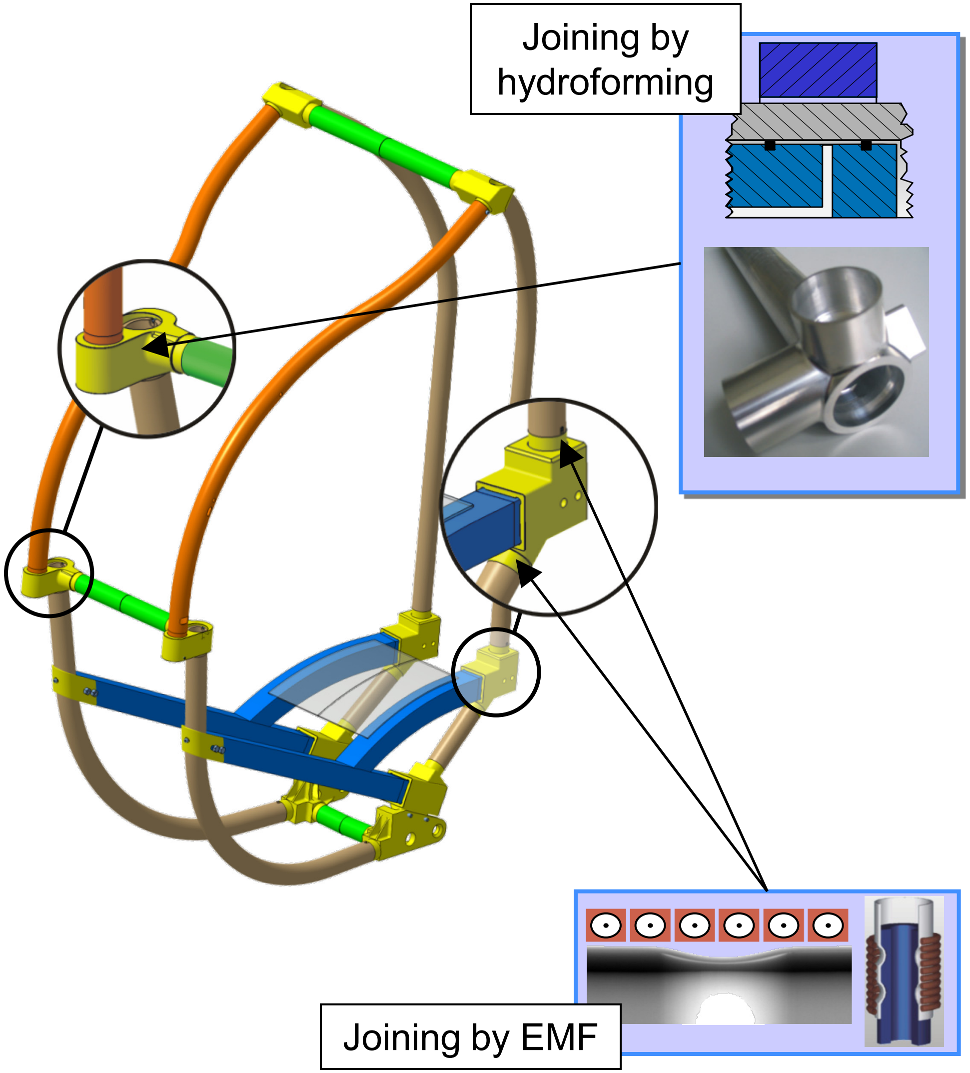
- ⇨ Summary and outlook



Summary

- Form-fit joining by EMF is suitable for manufacturing lightweight frame structures
- The joint strength can be increased with
  - **deeper** and
  - **narrower** grooves.
- The groove **geometry** has a significant influence on the joint strength.

- For the design of hollow inner joining elements the stiffness of the part has to be considered to avoid its **deformation**

  → decrease of joint strength
- Such deformations can be avoided by using a **support mandrel** for the joining process

Outlook

- Development of an analytical model to determine
  - the **required forming pressure** and
  - the **joint strength** concerning groove dimensions and geometry
- Upper limit of joint strength
  - regarding **quasi-static** loads
  - regarding **dynamic** loads
- Investigation of joint failure under
  - bending
  - cycling loads and
  - impact loads.