DFG

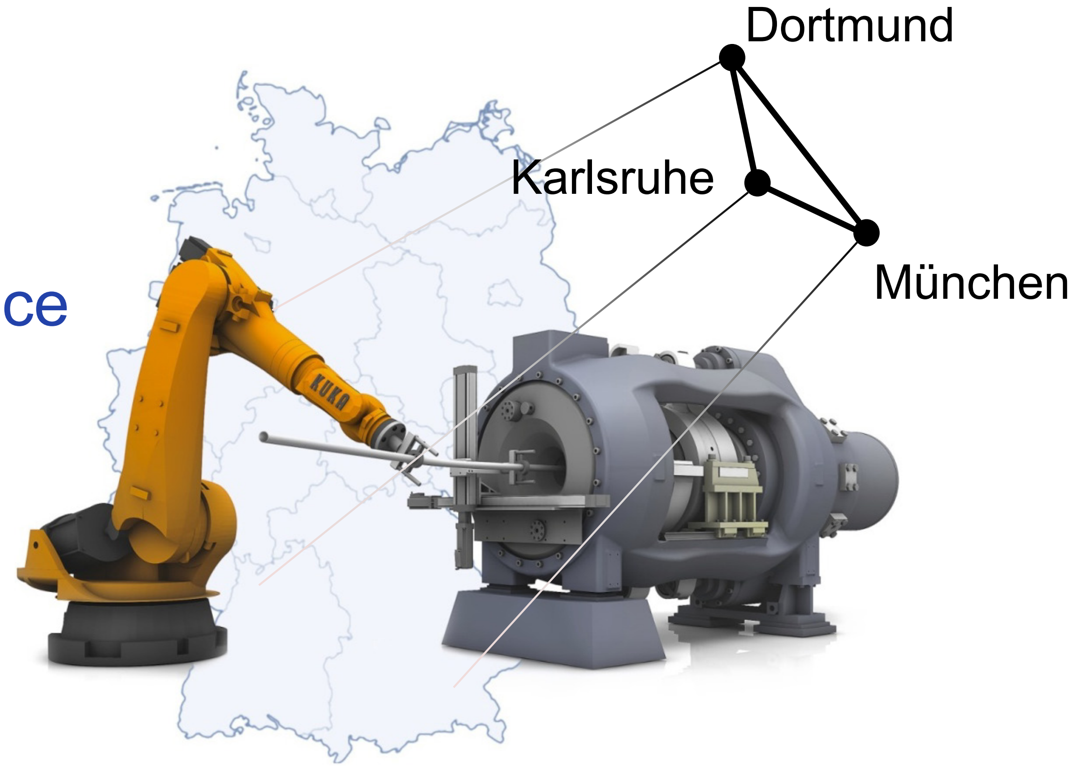
Sonderforschungsbereich Transregio10

Influencing Factors on the Strength of Electromagnetically Produced Form-Fit Joints using Knurled Surfaces

ICHSF2012

5th International Conference on High Speed Forming

April 24th – April 26th, 2012
Dortmund, Germany



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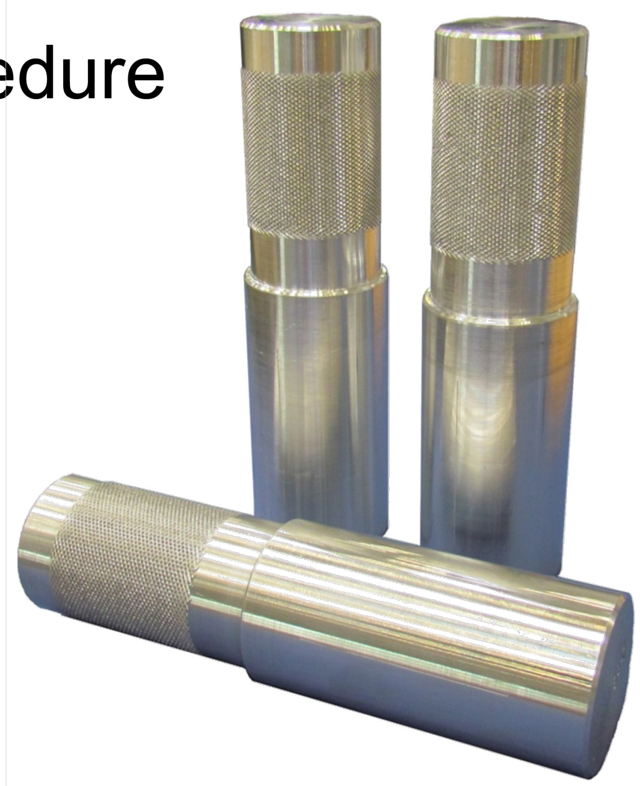
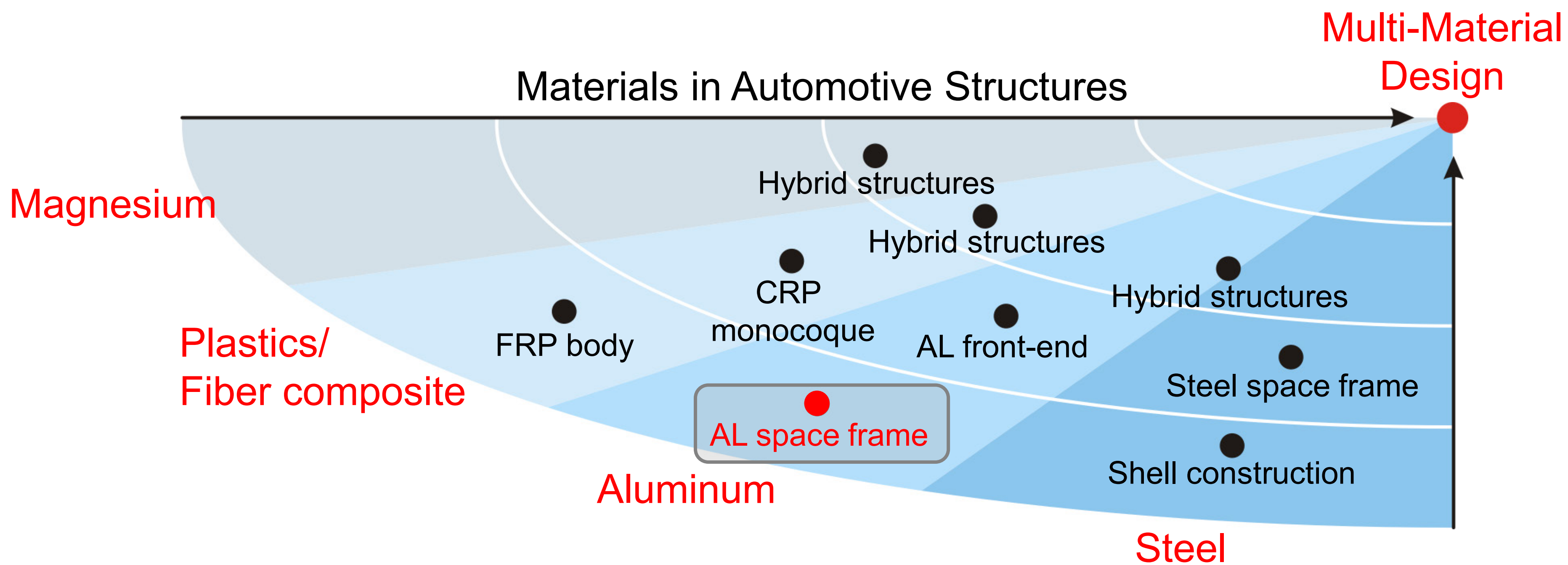
TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

Outline

- Introduction
- Joining by Electromagnetic Forming
- Experimental Setup and Procedure
- Results and Discussion
- Summary and Outlook



- **Lightweight design by hybrid structures**
  - New challenges for joining technologies

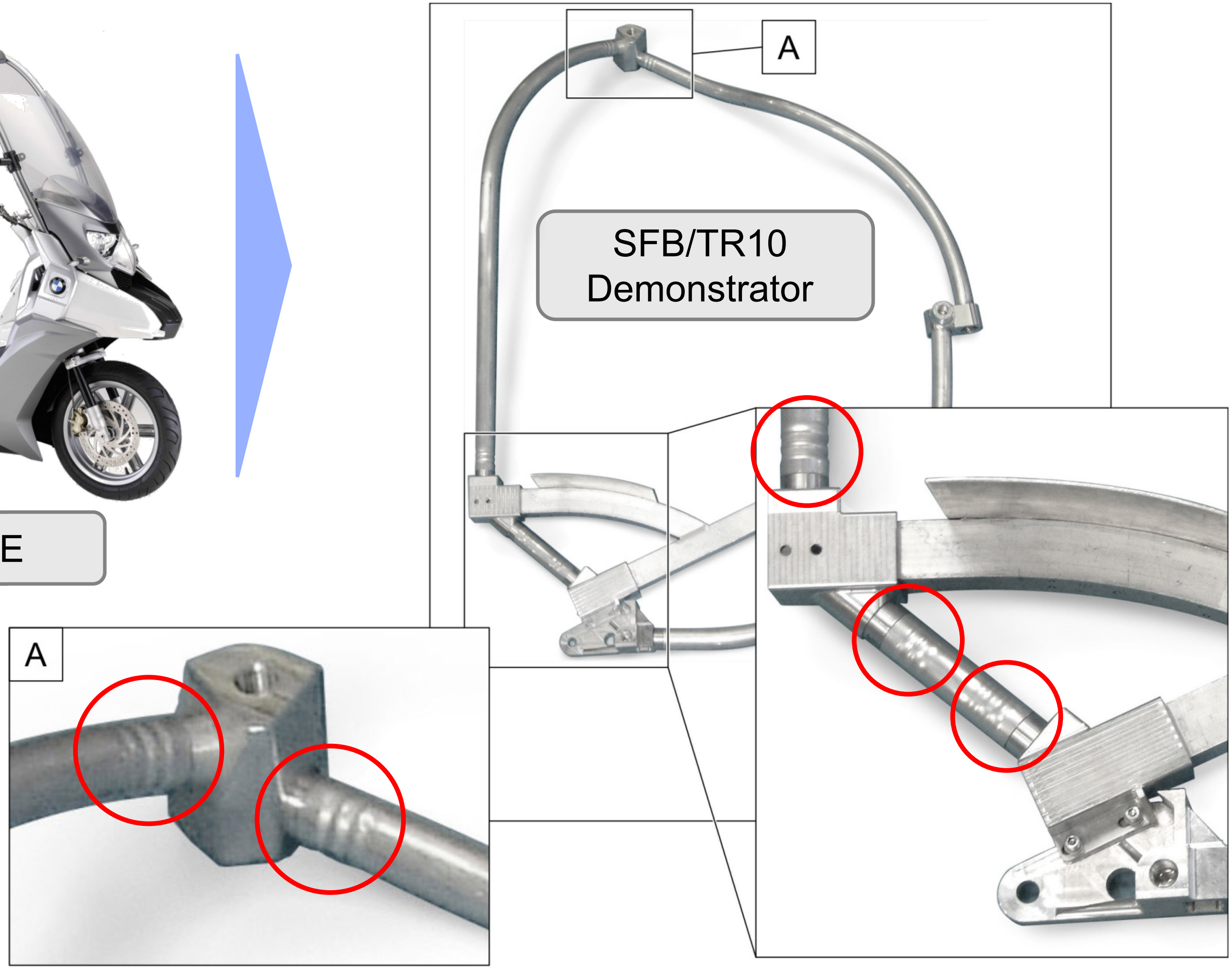


AL	Aluminum
FRP	Fiber-reinforced plastics
CRP	Carbon fiber reinforced plastics

Source: *Zweiter Bericht der Nationalen Plattform Elektromobilität*

Introduction

BMW-C1E



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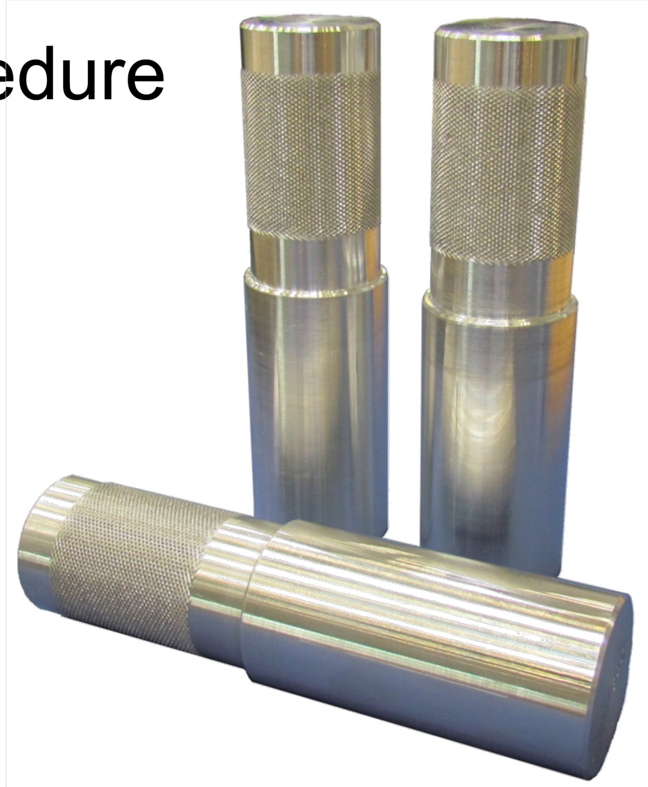
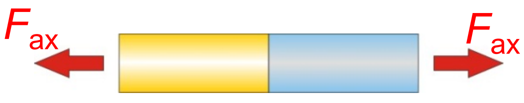
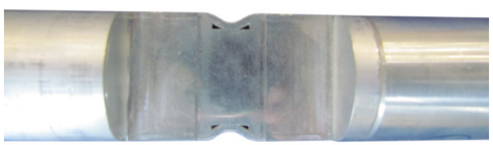


Classification of form-fit concepts

axial



circumferential grooves

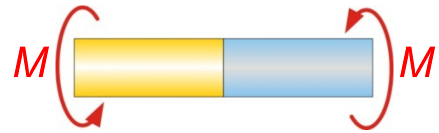


- Bühler / Finckenstein 1968
- Golovashchenko 2001
- Park et al. 2005
- Weddeling et al. 2011

screw thread

- Eguia et al. 2004

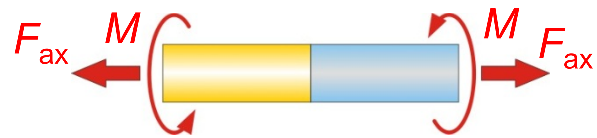
torsional



grooves in axial direction

longitudinally knurled surfaces

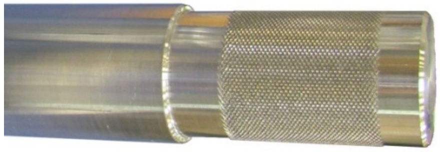
axial + torsional



discontinuous circumferential grooves

pockets

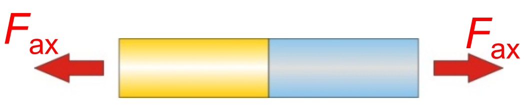
cross-knurled surfaces



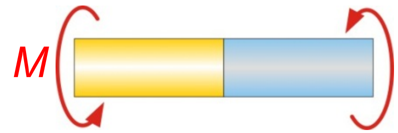
- Eguia et al. 2004
- Psyk et al. 2009

Classification of form-fit concepts

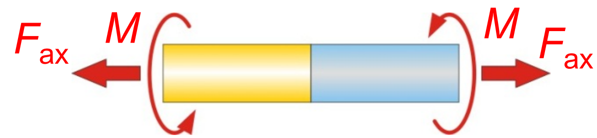
axial



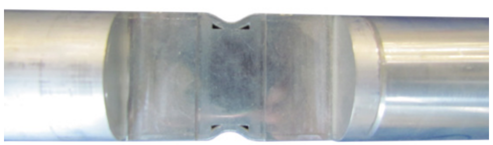
torsional



axial + torsional



circumferential grooves



- Bühler / Finckenstein 1968
- Golovashchenko 2001
- Park et al. 2005
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screw thread

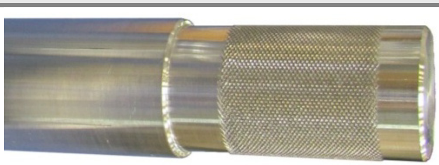
- Eguia et al. 2004

longitudinally knurled surfaces

Requirements

- ✓ simple machining

cross-knurled surfaces



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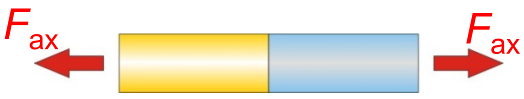
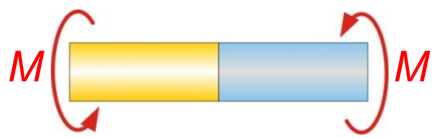
Classification of form-fit concepts

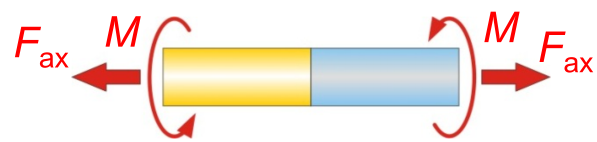
axial



torsional



axial + torsional



longitudinally knurled surfaces

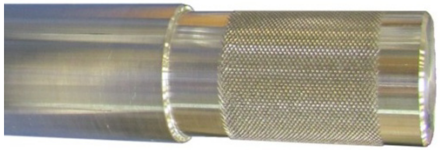
Requirements

- simple machining
- small amount of plastic deformation

screw thread

- Eguia et al. 2004

cross-knurled surfaces



- Eguia et al. 2004
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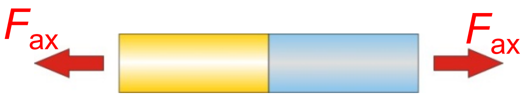
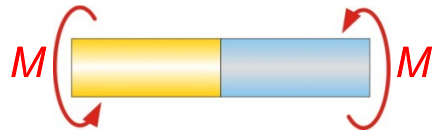
Classification of form-fit concepts

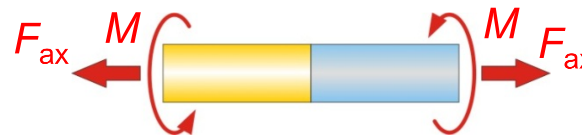
axial



torsional



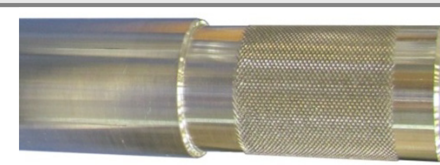
axial + torsional



Requirements

- ✓ simple machining
- ✓ small amount of plastic deformation
- ✓ increase of axial and torsional strength

cross-knurled surfaces

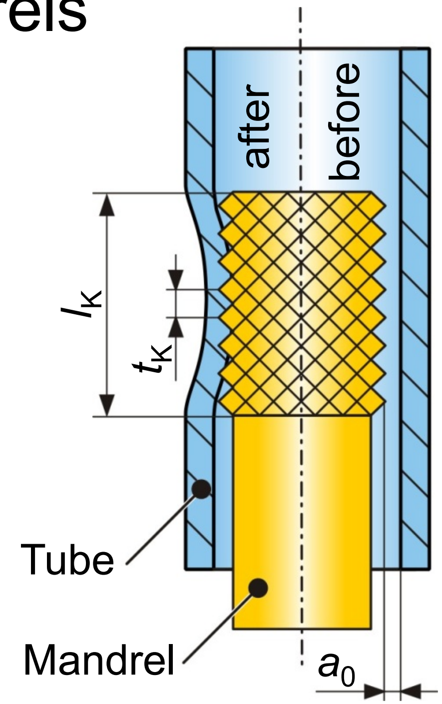


- EGUIA ET AL. 2004
- PSYK ET AL. 2009

Joining by Electromagnetic Forming

Form-fit joining using cross-knurled mandrels

- EGUIA ET AL. 2004
  - Parametric study (l_K, t_K, a_0, E_C)
  - Tube: EN AW-6061 / Mandrel: 9SMnPb36
  - Solid mandrels
- PSYK ET AL. 2009
  - Feasibility study
  - Tube: EN AW-6060 / Mandrel: EN AW-6060
  - Tube continuously reinforced with steel wires
  - Solid mandrels



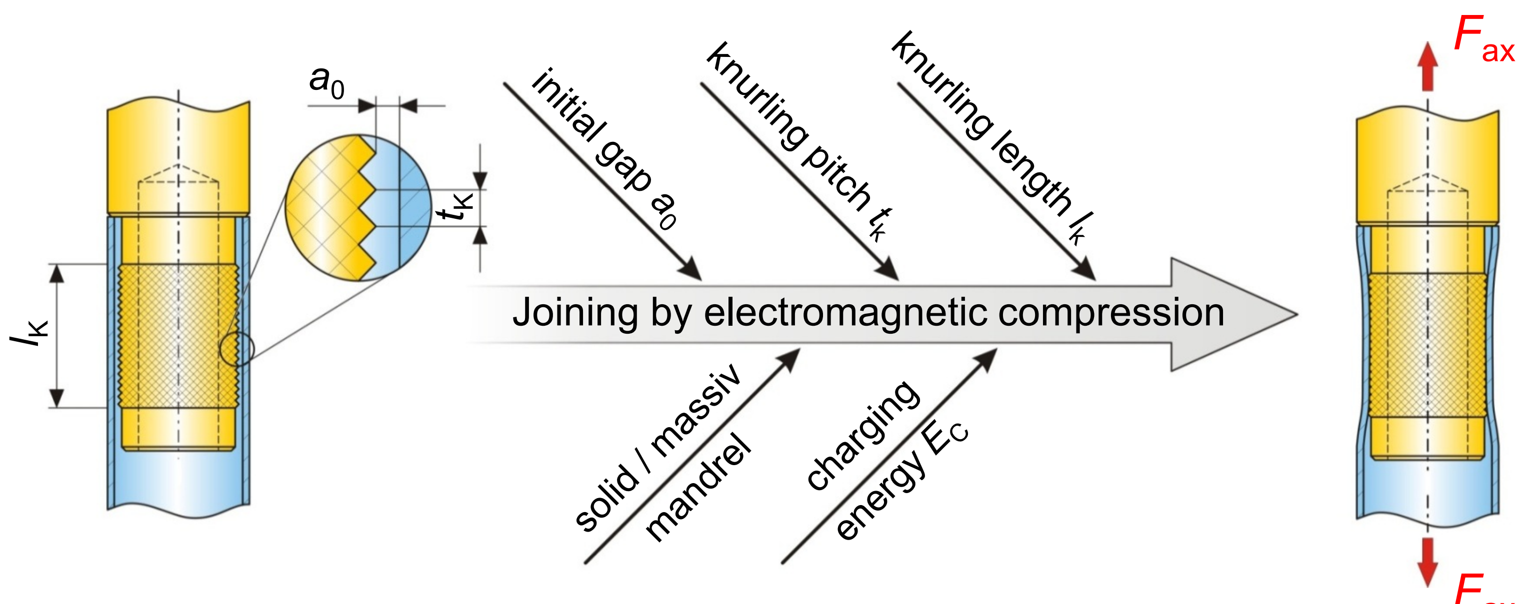
Remaining questions

- Influence of joint / process parameters in case of identical materials?
- Influence of hollow mandrels on the connection strength?

Joining by Electromagnetic Forming

Research objective:

- **Parametric study** on the influence of:
  - knurling length l_K
  - initial gap a_0
  - knurling pitch t_K
  - charging energy E_C
- in case of **solid and hollow mandrels**
- both made of the **same material**



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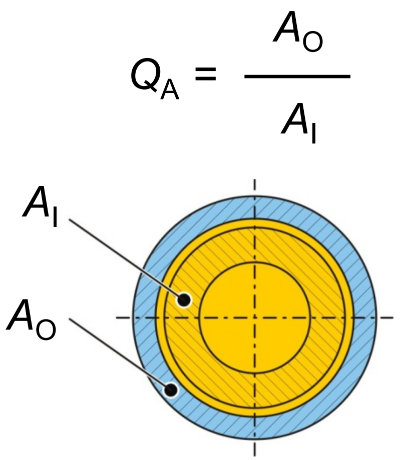
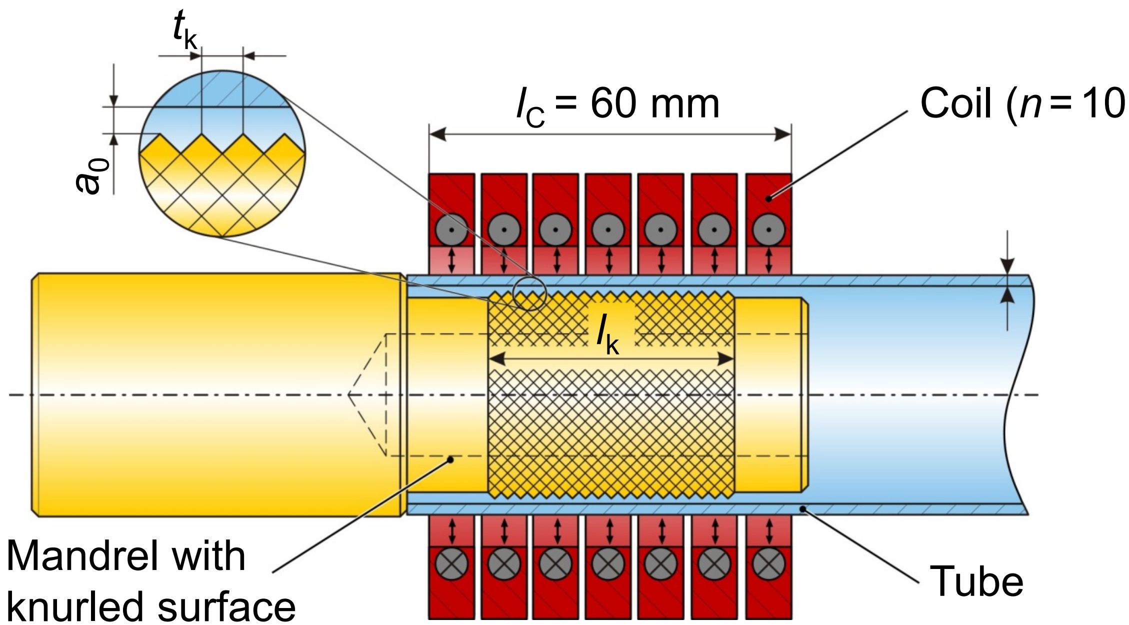
Experimental Setup





Mandrel	
Material:	EN AW-6060
Outer diameter:	36; 34; 32; 31 mm
Knurling* pitch t_K:	0.5; 1.0; 1.6 mm
Knurling* length l_K:	20; 40; 60 mm
Q_A (hollow mandrels)	1.07; 1.27; 1.46

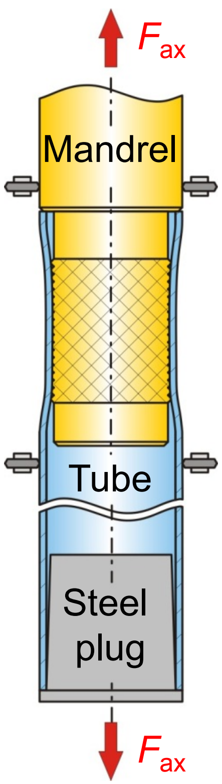
(*Cross knurl pattern according to DIN 82)

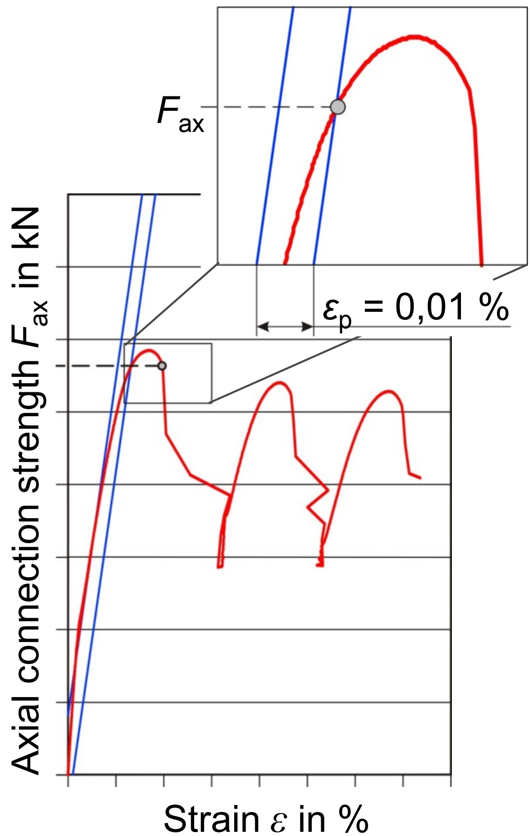
Tube	
Material:	EN AW-6060
Outer diameter:	40 mm
Wall thickness:	2 mm

Determination of Joint Quality

Pull-out tests

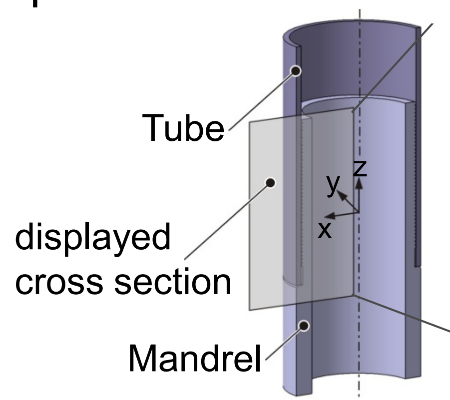
Determination of connection strength

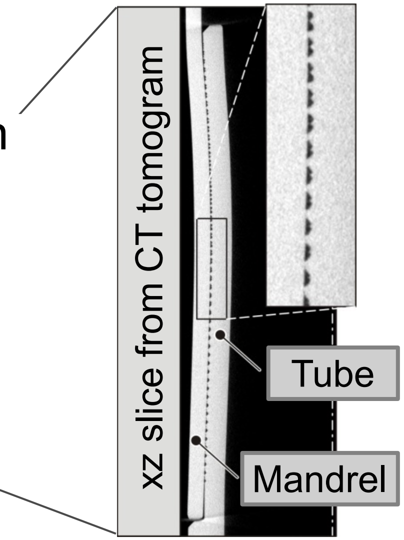




CT scans

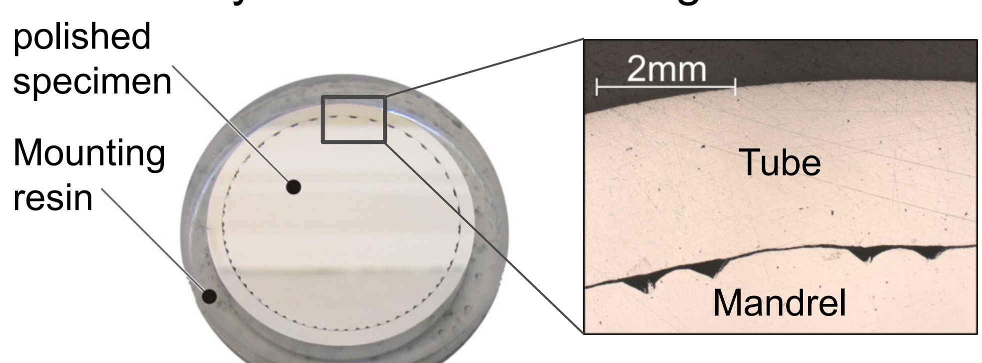
Specimen deformation





Micrographs

Analysis of the interlocking mechanism



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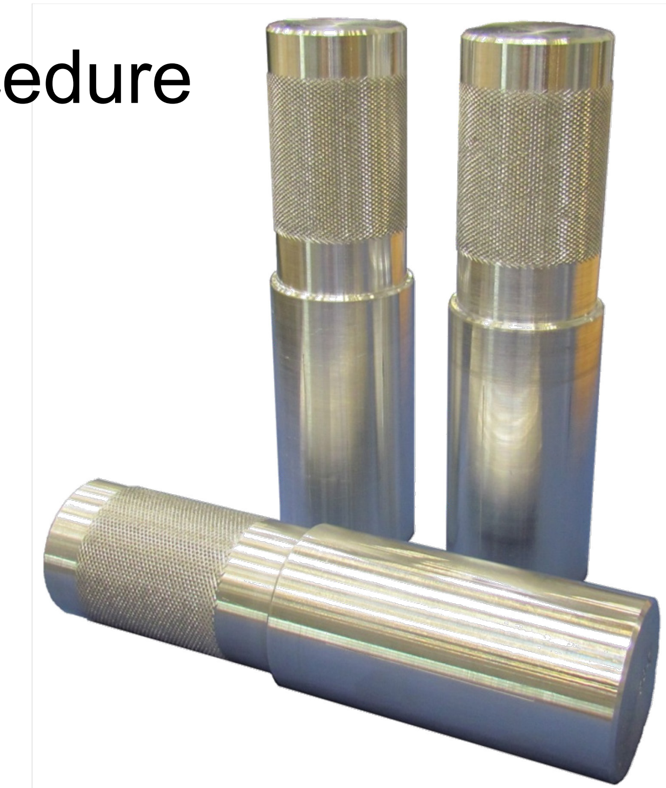
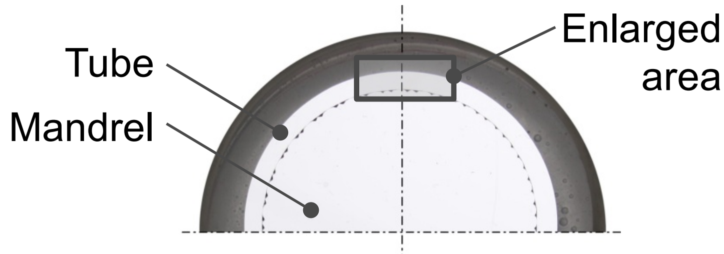
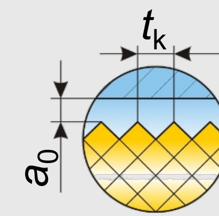
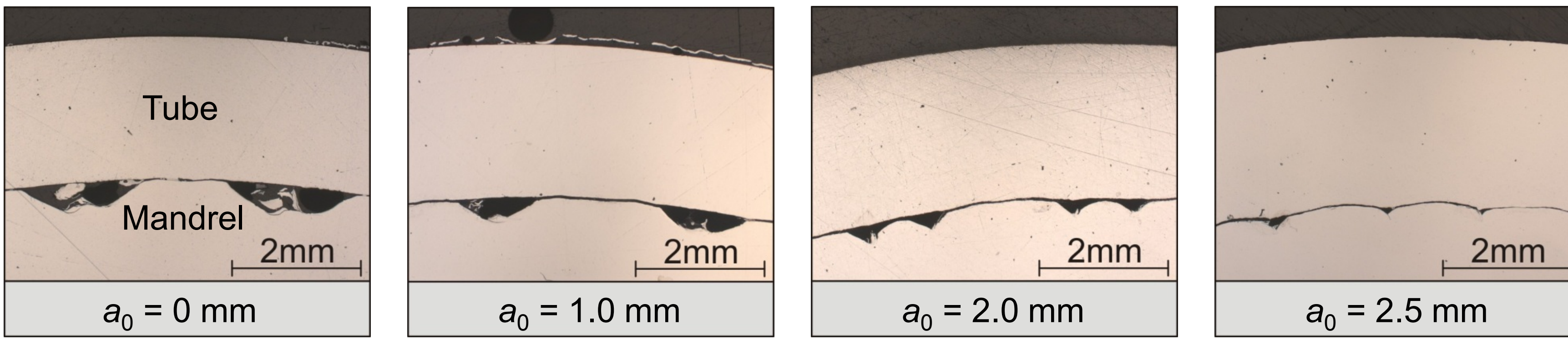


Results - Interlocking Mechanism



Mandrel type	solid
Charging energy E_c	6.0 kJ
Knurling pitch t_K	1.6 mm



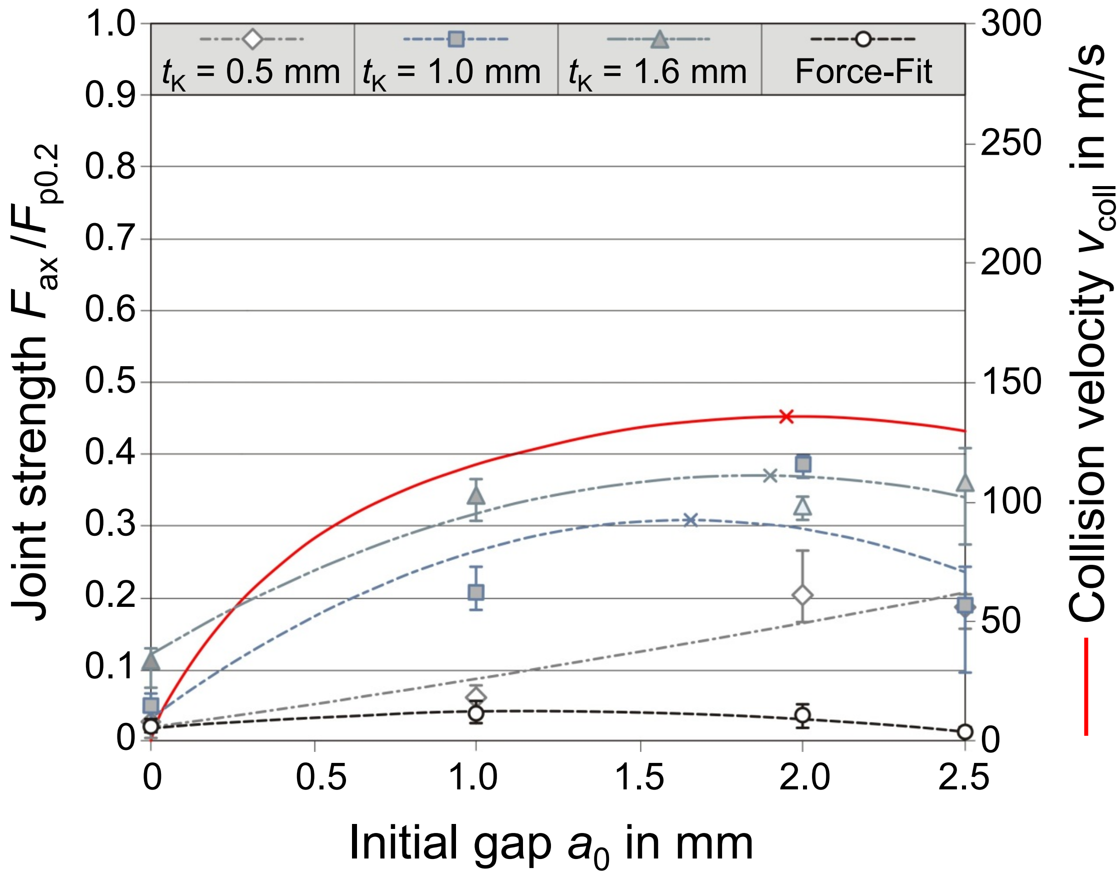


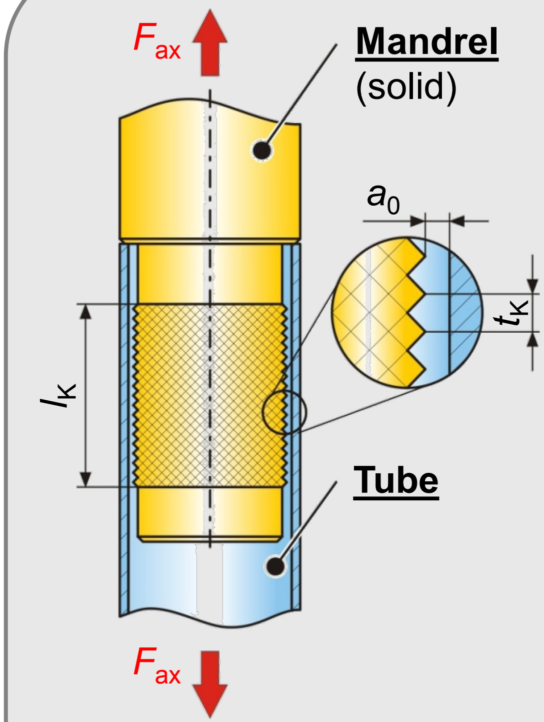
v_{coll} = 0 m/s — v_{coll} = 133 m/s — v_{coll} = 163 m/s — v_{coll} = 167 m/s

Collision velocity v_{coll}

- No indentation of the knurling teeth into tube
- Beneficial in case of dynamic loading

Results - Knurling Pitch

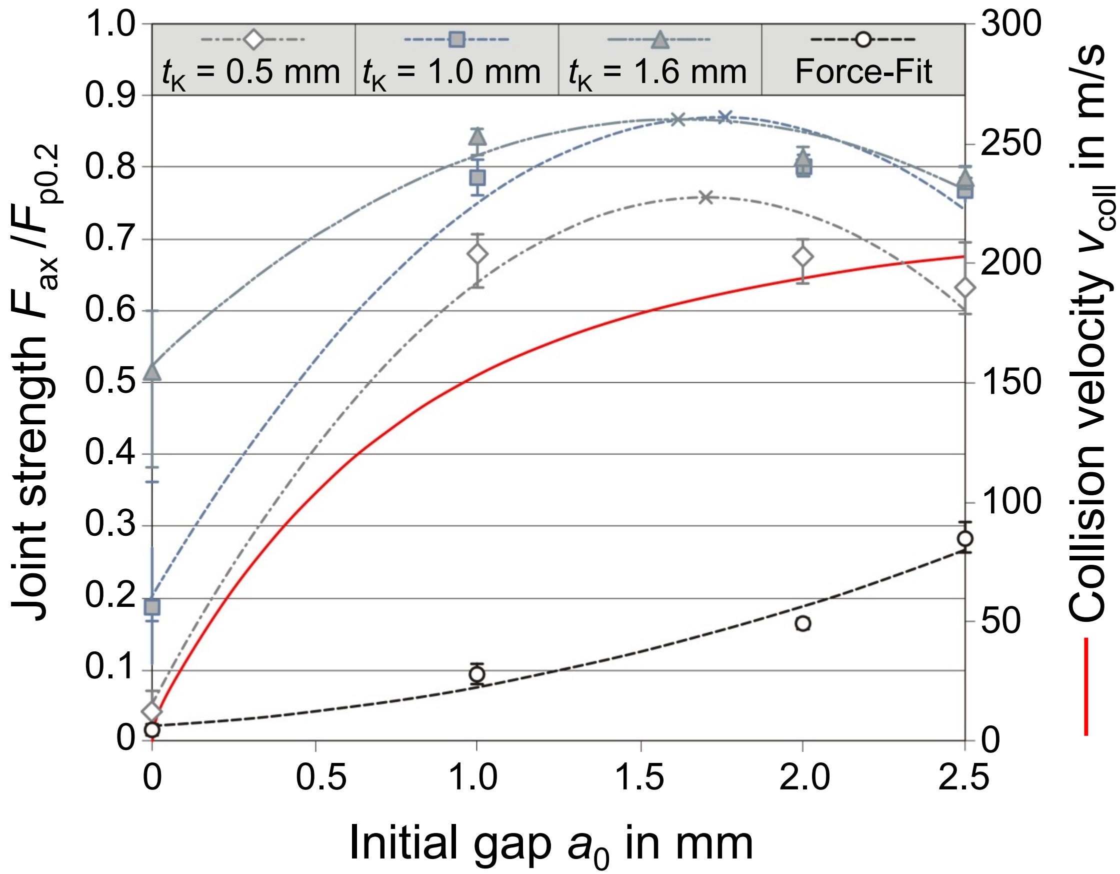




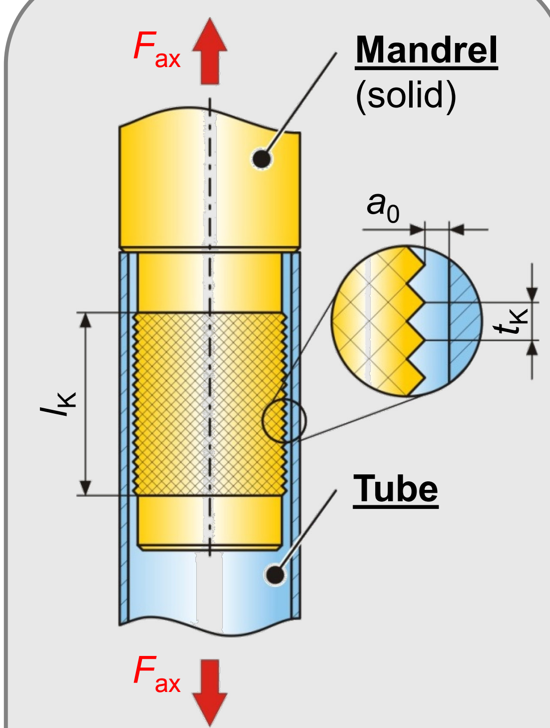
Charging energy: E_c = 4.8 kJ
Knurling pitch: t_K = varied
Knurling length: l_K = 60 mm
Initial gap: a_0 = varied

- coarse knurling → increased joint strength
- highest collision speed → highest joint strength

Results - Knurling Pitch

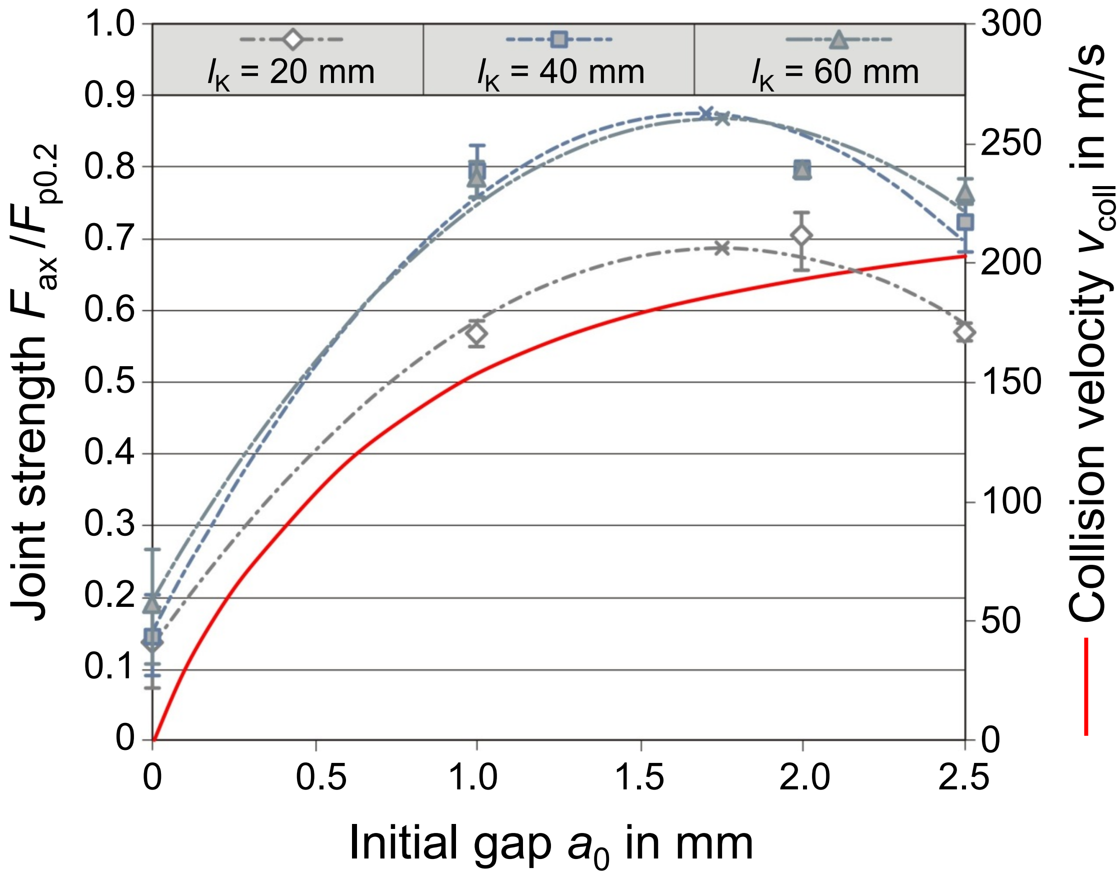


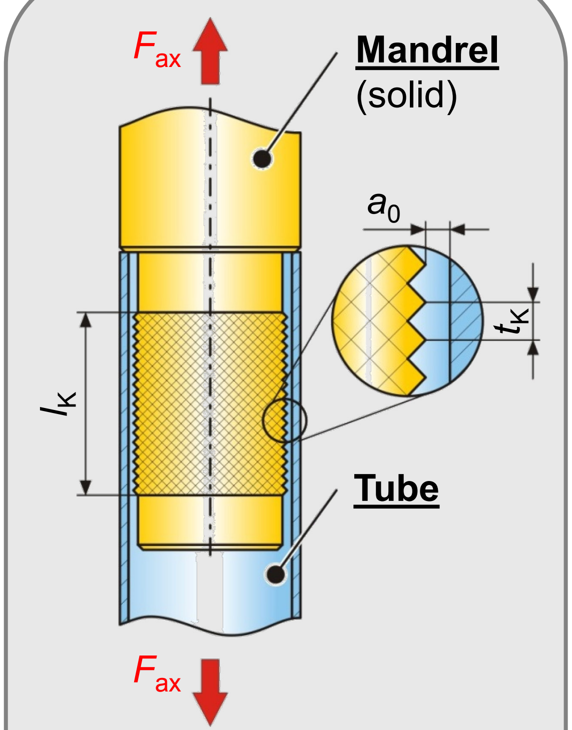
tube's yield strength is reached



Charging energy: E_c = 6.0 kJ
Knurling pitch: t_K = varied
Knurling length: l_K = 60 mm
Initial gap: a_0 = varied

Results – Knurling Length

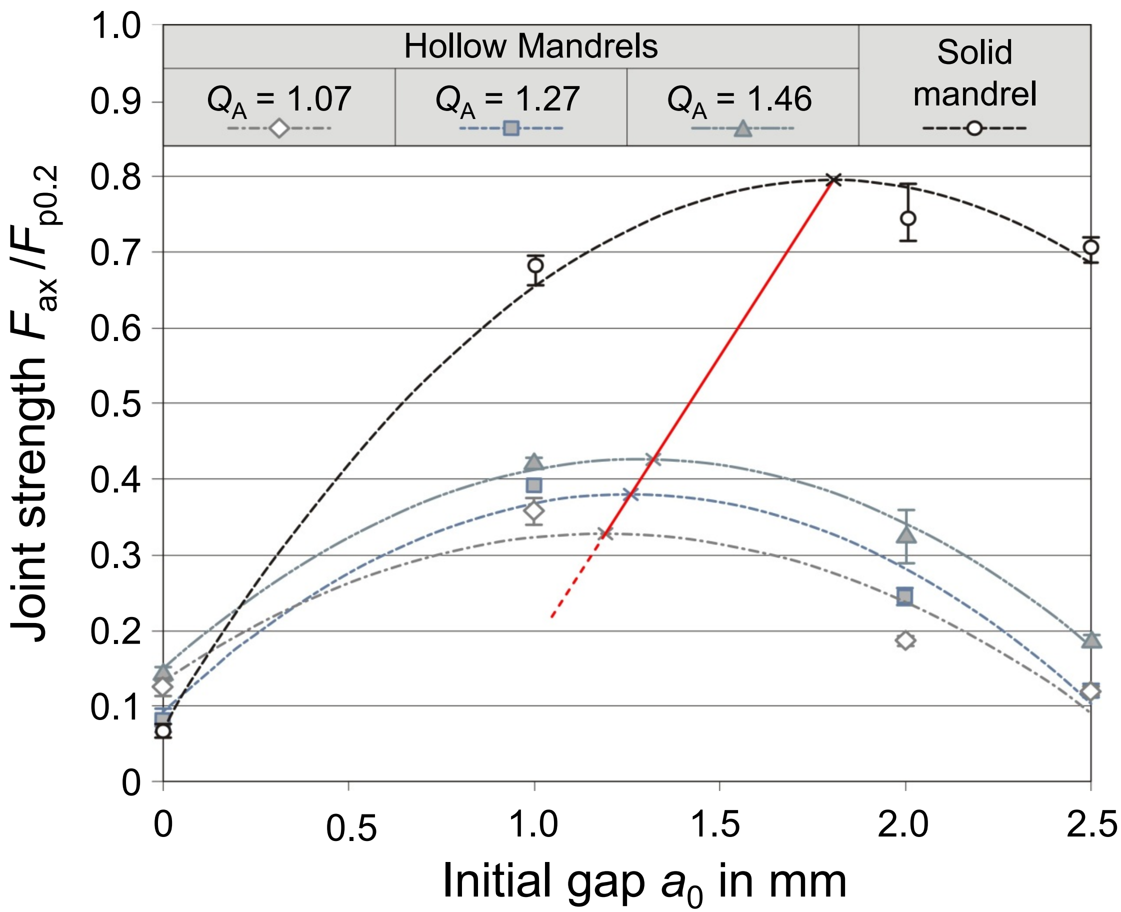


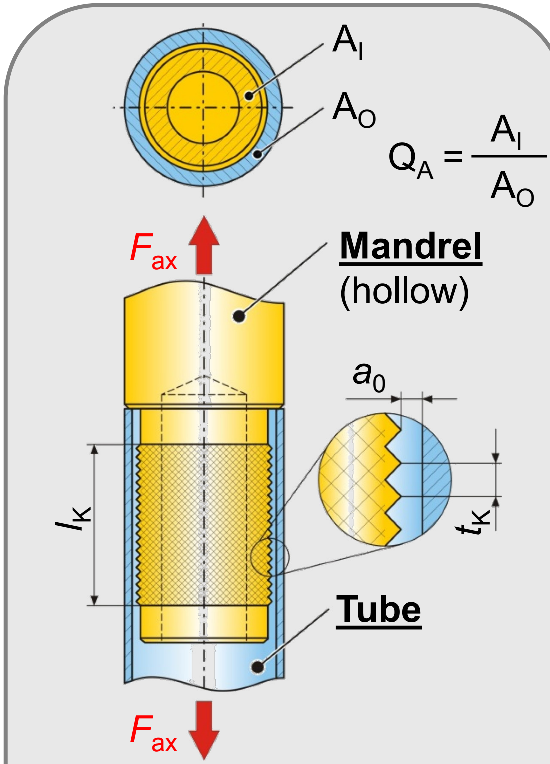


Charging energy: E_c = 7.2 kJ
Knurling pitch: t_K = 1.0 mm
Knurling length: l_K = varied
Initial gap: a_0 = varied

- Non-linear correlation between F_{ax} and l_K
- Reason: non-uniform pressure distribution

Results – Hollow mandrels

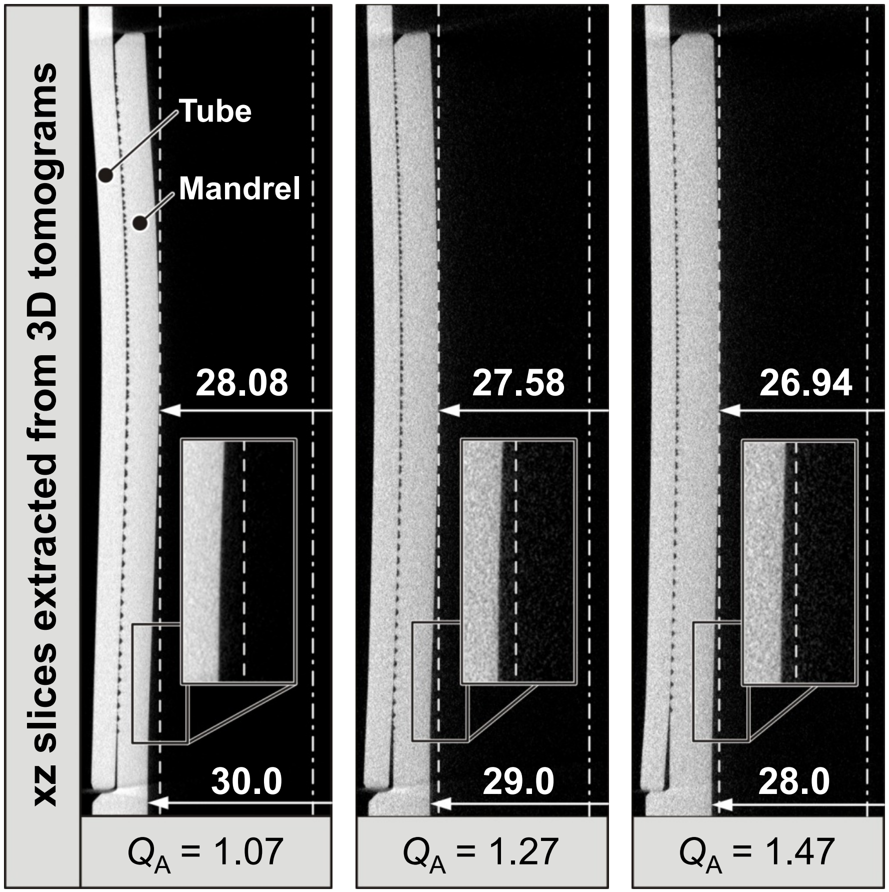




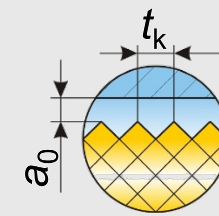
Charging energy:	E_c	= 6.0 kJ
Knurling pitch:	t_K	= 1.0 mm
Knurling length:	l_K	= 60 mm
Initial gap:	a_0	= varied

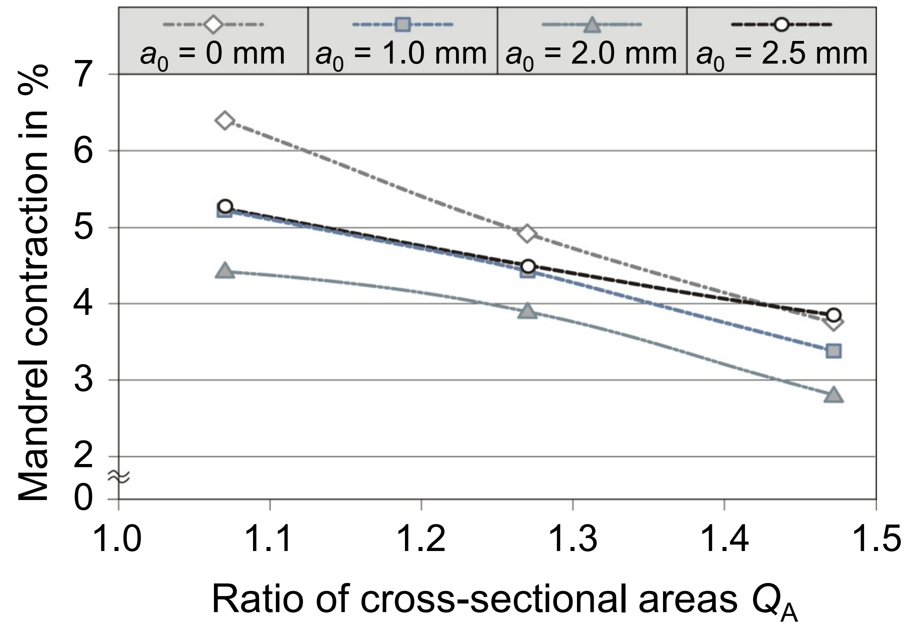
- Hollow mandrels → Decreasing joint strength
- Assumed reason: Deformation of the mandrel

Results – Hollow mandrels



Mandrel type	hollow
Charging energy E_c	6.0 kJ
Knurling pitch t_K	1.0 mm
Initial gap a_0	0 mm





- Increasing Q_A → Decreasing mandrel contraction
- Max. strength → Solid mandrel / Lightweight → Hollow mandrel

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Summary and Outlook

- **Knurled surfaces:** Effective form-fit concept for lightweight frame structures
- Joint strength exceeded strength of the weakest joining partner
- Additional investigations on
  - strength under dynamic loading
  - torsional joint strength

Thank you for your attention

This presentation is based on investigations of the Collaborative Research Center SFB/TR10 subproject A10 which is kindly supported by the German Research Foundation (DFG).