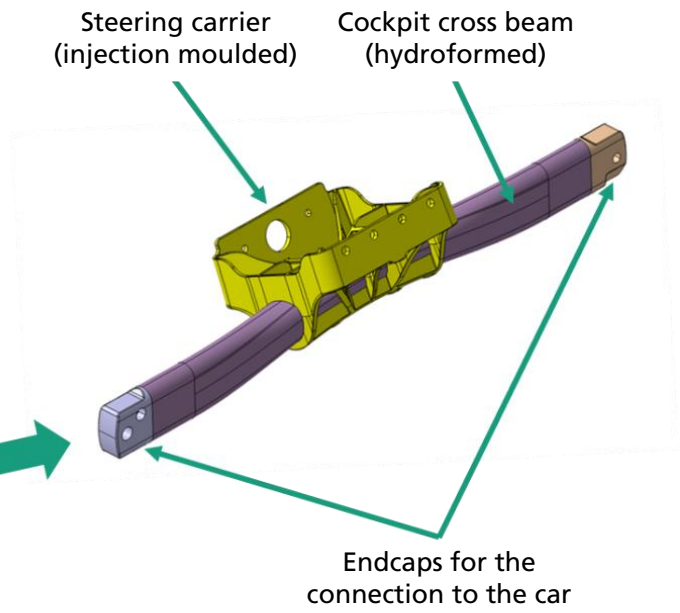
HYDROFORMING WITH INJECTION MOULDING BASED ON FIBRE REINFORCED PLASTIC TUBES

67th CIRP General Assembly, CWG on Composite Materials Parts Manufacturing

Welf-Guntram Drossel, André Albert, Markus Layer; 24th of August 2017, Lugano



- Introduction
- Media based forming with gaseous media
- Hydroforming with injection moulding based on fibre reinforced plastic tubes
  - With continuous fibre reinforcement
  - With short fibre reinforcement
- Conclusion and outlook

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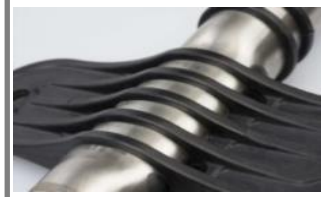
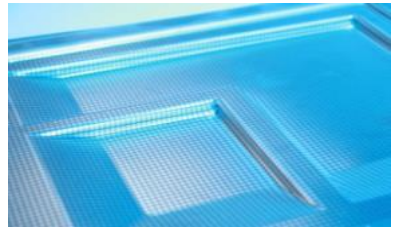
Media based Forming at the Fraunhofer IWU

in-situ-manufacturing processes for hybrid parts



Hydroforming with heated oil

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



Hydroforming at room temperature

More than 20 years hydroforming experience at the Fraunhofer IWU

1995 2001 2006 2011 2017

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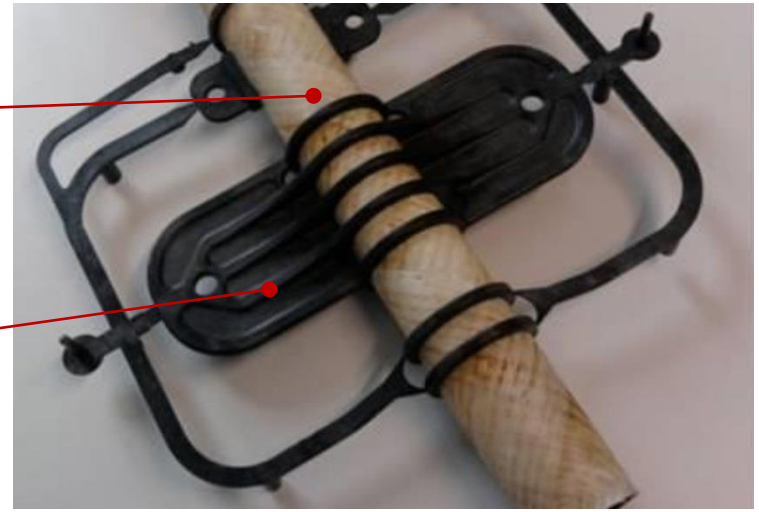
In-situ-manufacturing processes for hybrid parts

Process combination of hydroforming with injection moulding

Hybrid process

I. Media based forming of a tube / realisation of the support pressure

II. Injection moulding of the plastic elements



- Research fields of the Fraunhofer IWU
  - Usage of gas (nitrogen) as working media
  - Substitution of the chemical bonding agents through a structuring of the metal surface for metal/plastic hybrid parts
  - Development and usage of fibre reinforced plastic tubes

Industrial applications

Source:
www.elringklinger.de/de/unternehmen/einblicke/kunststoff-leichtbauteile-fuer-die-karosserie

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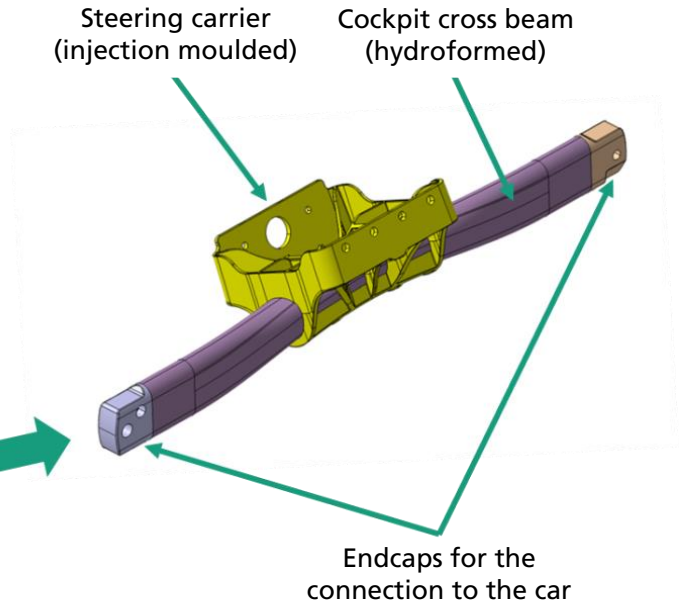

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Media based forming with gaseous active media

- 2006 installation of a 70 MPa gas pressure unit by Maximator (upgraded to 120 MPa in 2014)
- Realized processes
  - Isothermal forming
  - Hot forming with tools at room temperature
  - Superplastic forming
  - Hot metal gas forming with press hardening HMGF-PH
  - Hydroforming with injection moulding
- Advantages
  - Clean and dry: No cleaning operations necessary
  - Tempered forming possible up to more than 1000 ° C
- Disadvantages
  - Gaseous medium is compressible
  - Additional safety effort

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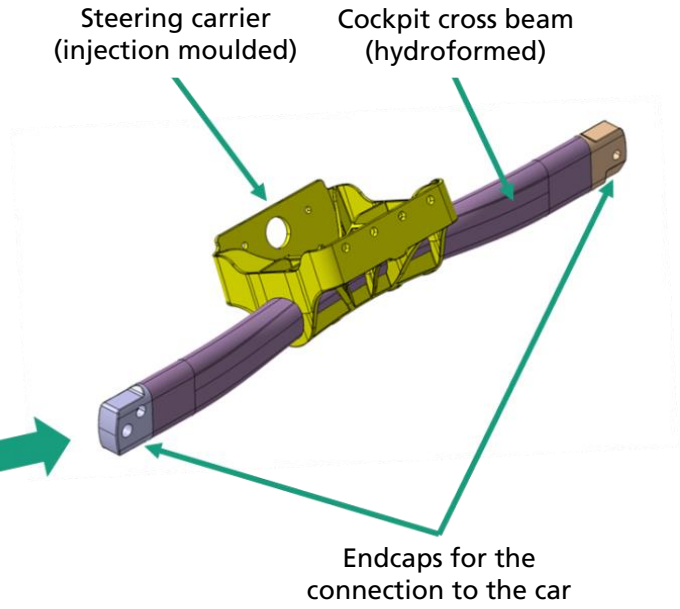

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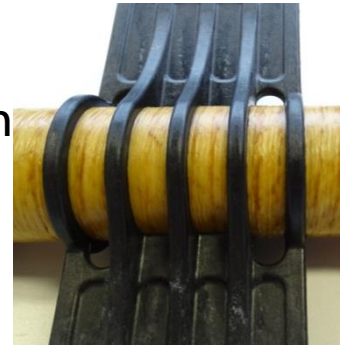
Hydroforming with injection moulding based on fibre reinforced plastic tubes

semi finished parts: short fibre reinforced tubes vs. continuous fibre reinforced tubes

- Short fibre reinforced tubes
  - Advantages
    - Cost-effective production by extrusion
    - High degree of formability

  - Disadvantages
    - Lower strength
    - Combined hydroforming and injection moulding process is difficult to control (lower burst pressures in the area of the injection moulding geometries)

- Continuous fibre reinforced tubes
  - Advantages
    - Component properties can specifically influenced by fibre position
    - Simpler process control at the combined hydroforming and injection moulding process



  - Disadvantages
    - High costs due to winding process
    - No forming of the tube possible, only calibration due to low formability of the fibers

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Hydroforming with injection moulding based on continuous fibre reinforced plastic tubes
tube development

Tube requirements

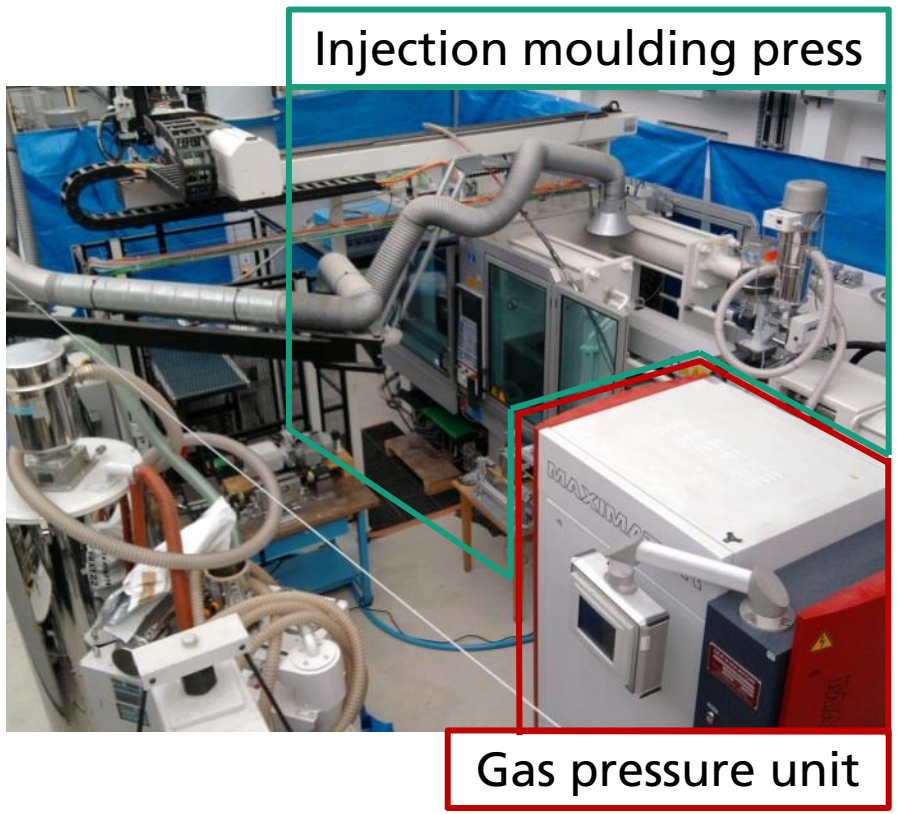
- Gastight for the hydroforming with injection moulding process
  - 2-component tubes
    - Extrusion tube (PA6.6/GF or PPA/GF) as a gas-tight inner layer
    - Reinforced outer layer (PA6/GF-tapes)
- No material strains possible due to the continuous-fibre-reinforcement
- Sufficient self-stability for handling at forming temperature
  - Forming just below melting temperature

Tube manufacturing

- Extrusion of the gastight inner layer
- Winding process of the reinforced outer layer direct on the extruded inner layer

Hydroforming with injection moulding based on continuous fibre reinforced plastic tubes

Experimental setup and realized parts



Process parameter	value
Injection moulding plastic	PA6 / GF60
Forming pressure	35 MPa
Tube temperature	220 °C
Tool temperature	80 °C
Injection temperature	280 °C

Cycle times	
hydroforming	3-5 sec
Injection	2 sec
total cycle (with cooling and handling)	59 sec

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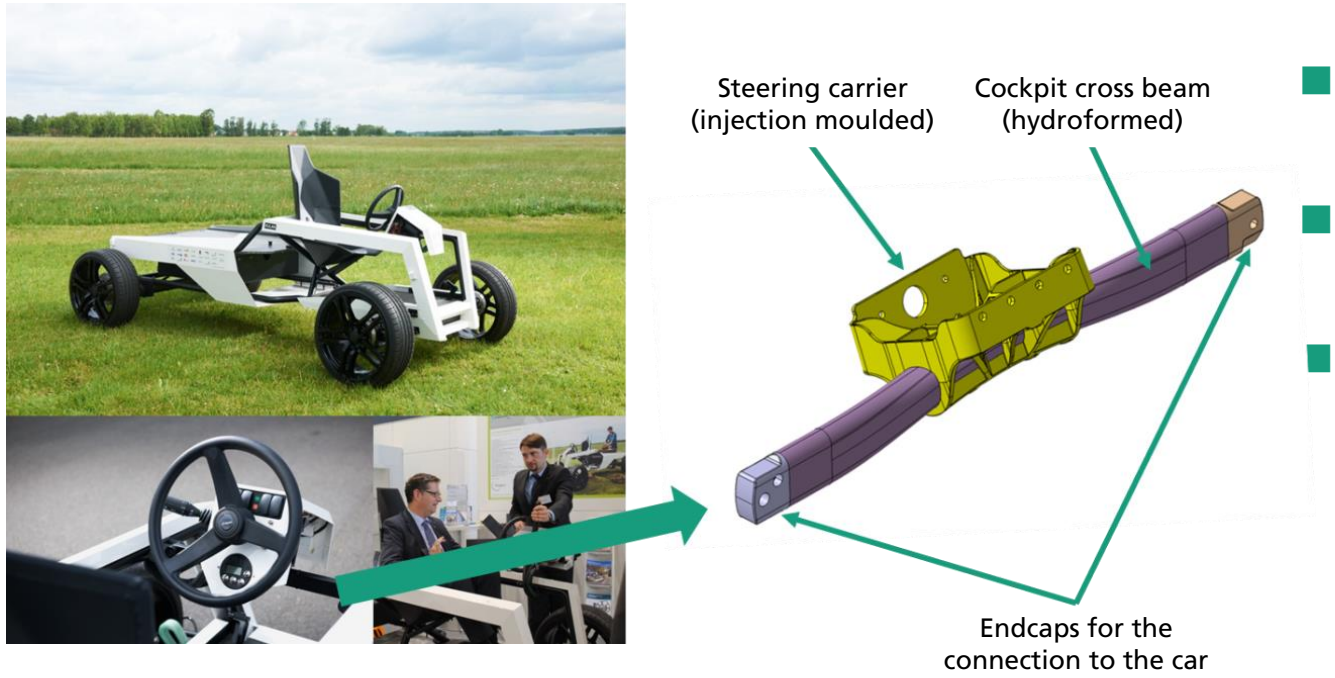
Hydroforming with injection moulding based on short fibre reinforced plastic tubes

ZIM-Project FVK-IHU: „Development of fibre-reinforced plastic tubes for further manufacturing of highly integrated lightweight parts using a combination of hydroforming and injection moulding"

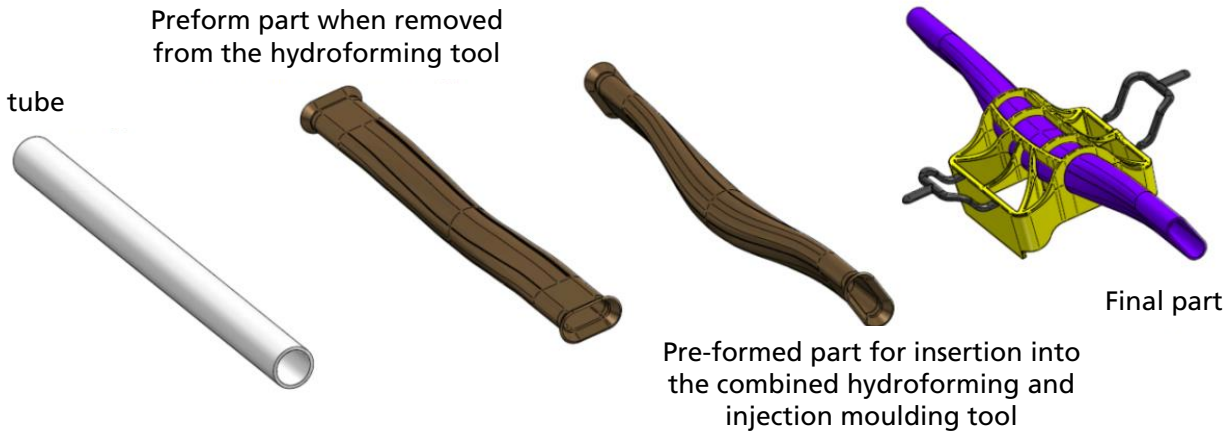


- Part A: development of **fibre-reinforced plastic tubes** for hydroforming
- Part B: **heating and handling** of the tubes
- Part C: tool and process development for **hydroforming**
- Part D: tool and process development for the combination of **hydroforming and injection moulding**

Hydroforming with injection moulding based on short fibre reinforced plastic tubes

Method plan – demonstrator part cockpit cross beam Kulan

- Process chain (start with tube)
  - Preform:
    1. Heating up the tube (Ø38mm, 500mm long)
    2. Part handling into the tool
    3. Hydroforming of the preform
  - Combination of hydroforming and injection moulding
    1. Heating up the preformed part
    2. Part handling into the tool
    3. Hydroforming and injection moulding process



Hydroforming with injection moulding based on short fibre reinforced plastic tubes

Tube requirements / materials used

Tube requirements

- Gastight in hydroforming and hydro-forming with injection moulding process
  - 2-component tubes (gastight inner layer and reinforced base layer)
  - Thick-walled pipes with temperature profile over wall thickness in process
- Possible material strains up to approx. 20 percent ➔ short fibre reinforcement
- Self-stability for handling at forming temperature just below melting temperature
- Cost efficient tube manufacturing by extrusion / co-extrusion

Materials used

Mass plastic	**Technical plastics**	
Polypropylene (PP) Exxon mobile EXXTRAL CNK010	Polyamide 6.6 (PA6.6/GF25: Lanxess Durethan AKV 325 H2.0, PA 6.6/GF15: BASF Ultramid® Endure D5G3 BM)	Polyphthalamides (PPA) Sol[illegible]odel-PXM14261 [illegible]ches Polyamid)
• inexpensive • low density • most popular plastic in the automotive sector • with fibres usage for more heavily stressed components possible	• good mechanical properties • good heat resistance • high damping ca[illegible] • good chemical r[illegible] • barely fatigue p[illegible]a with dynamic[illegible]s • high water[illegible]ption	[illegible]d mechanical [illegible]s [illegible] heat [illegible]e [illegible]damping capacity [illegible]d chemical [illegible]sistance [illegible]arely fatigue phenomena under dynamic stress • low water absorption

Hydroforming with injection moulding based on short fibre reinforced plastic tubes

Automated preform process

Equipment:

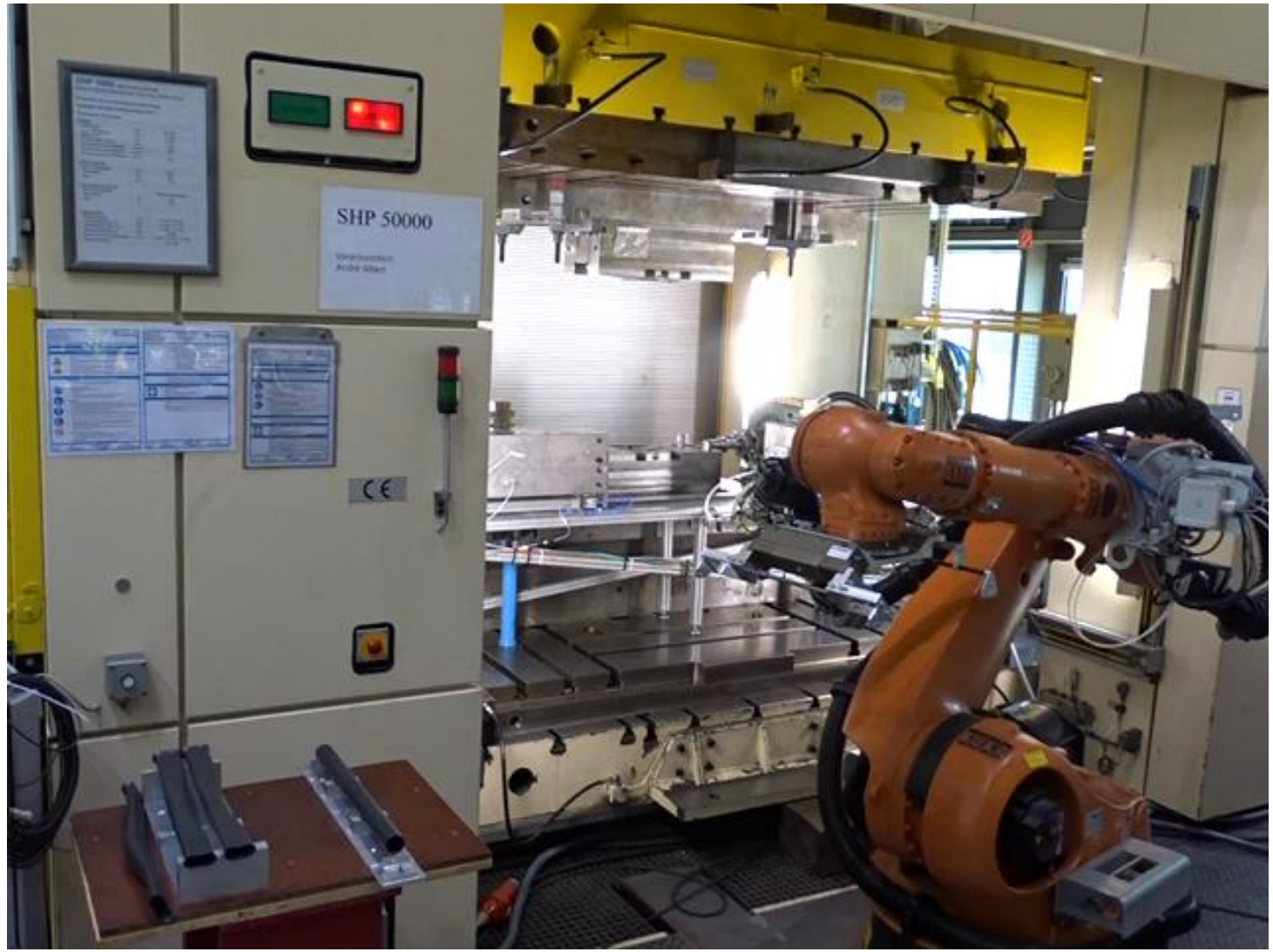
- Schuler hydroforming Press SHP 50.000
- Maximator gas pressure unit
- Kuka Robot KR 150

Process parameters:

- Tube heating (Furnace temperature: 390°C)

Material	Furnace time	Tube temperature
PP	100-140 sec	140 °C
PA 6.6	150 sec	195°C – 220 °C
PPA	180 sec	220 °C

- Hydroforming process
  - Max. pressure: 15 MPa
  - Pressure build up time: 5 sec
  - Pressure holding time: 15 sec



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Hydroforming with injection moulding based on short fibre reinforced plastic tubes

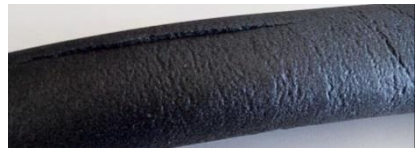
Automated preform process – forming results

Good parts

- Materials:
  - PPA-KM,
  - PA-KM,
  - Ultramid – TUC und
  - PP / GF15 -TUC

Failures

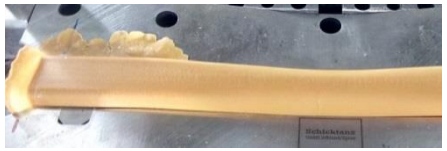
- Cracks



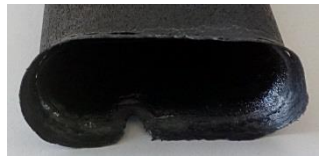
- Whitening fracture

- Wrinkles

- Material squeezed in the separating plane



- Deformed tube ends



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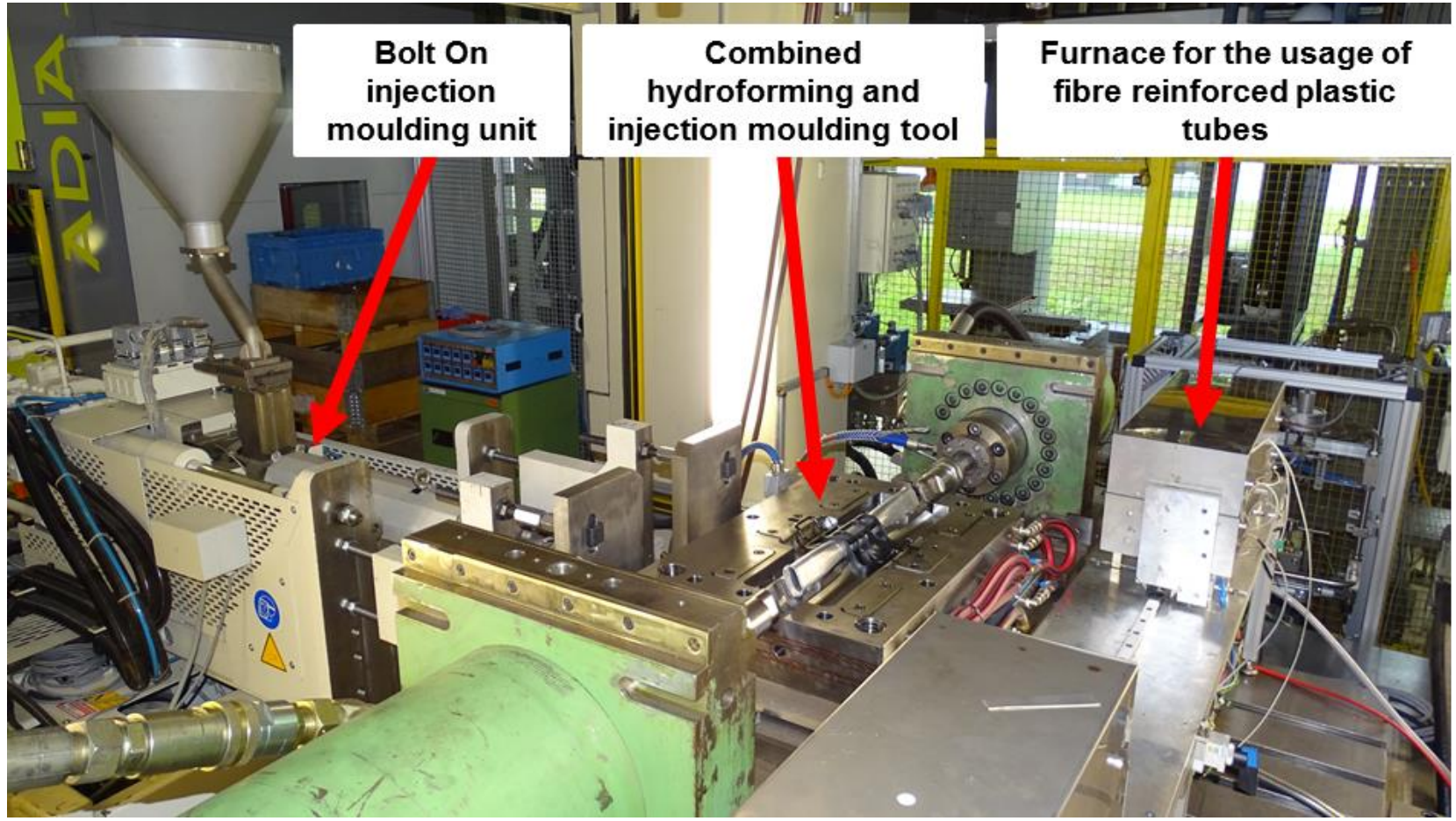
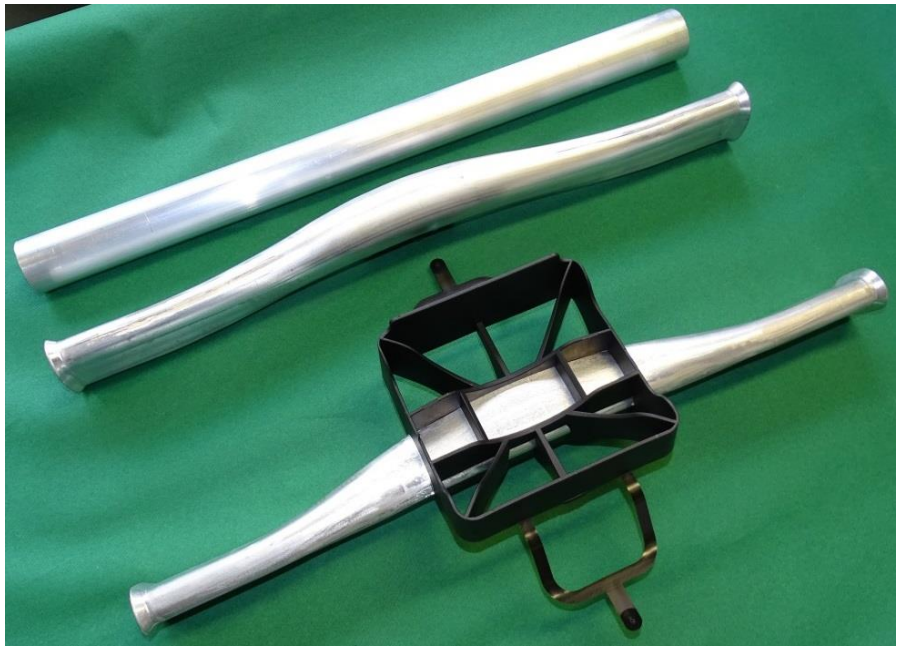
Hydroforming with injection moulding based on short fibre reinforced plastic tubes
Experimental setup

- Same process chain as hydroforming, but with an integrated injection moulding process
- Extended tool design based on hydroforming process
  - New tool with **integrated injection moulding hot channel**
  - Integration of a **Bolt On injection moulding unit** from the TU Chemnitz



Hydroforming with injection moulding based on short fibre reinforced plastic tubes
First results

- Tests with aluminum tubes were successful

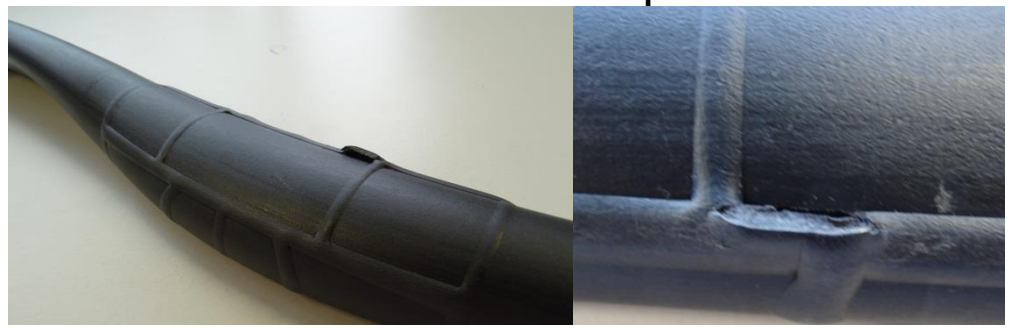


Production steps cockpit cross beam Kulan

  - Above: Semi - finished tube (Ø38mm, EN AW 6060)
  - Middle: hydroformed preform
  - Below: final part produced by the combination of hydroforming and injection moulding

- First experiments with FRP-tubes (hydroforming process without injection moulding):
  - Good process with 10 MPa inner pressure

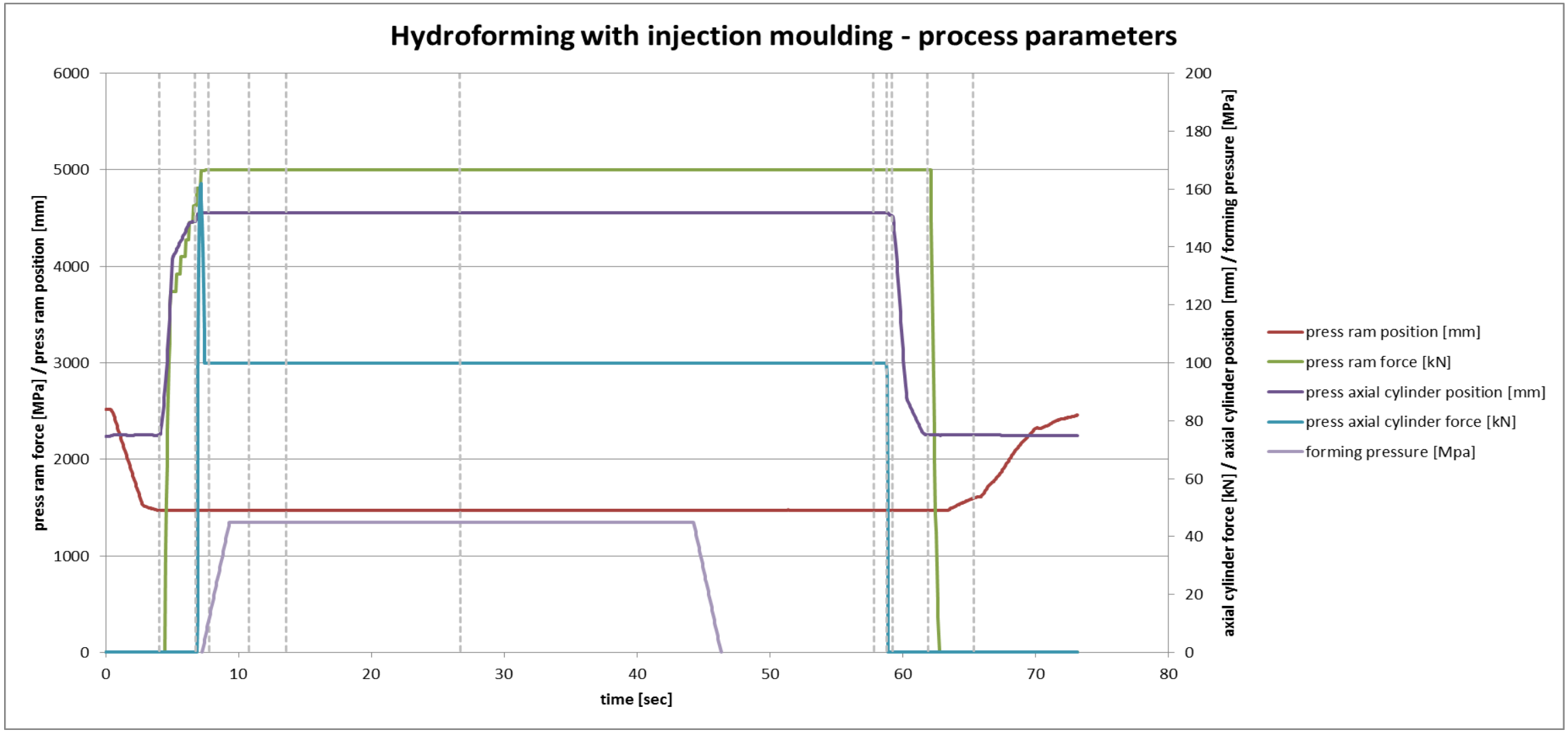
  - Crack with 13 MPa inner pressure



- Min. 20 MPa inner pressure are necessary!

Hydroforming with injection moulding based on short fibre reinforced plastic tubes

First results – process diagramm (based on aluminum tube)



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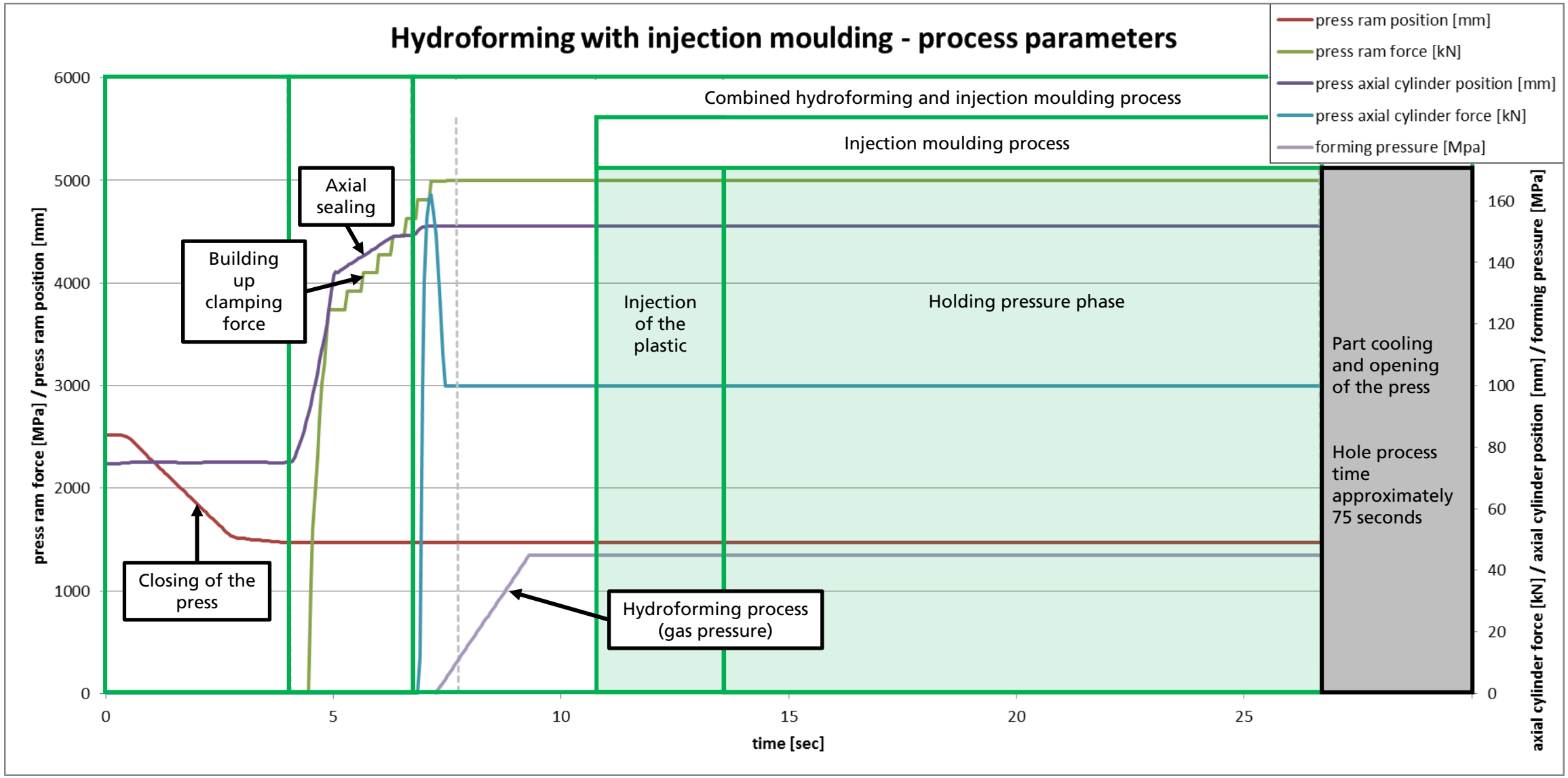
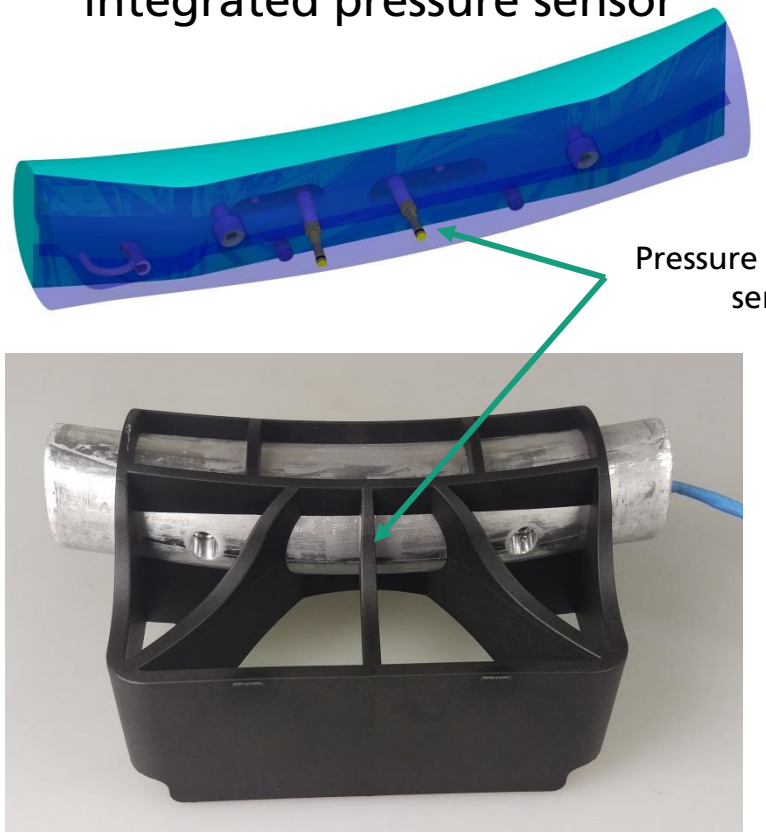


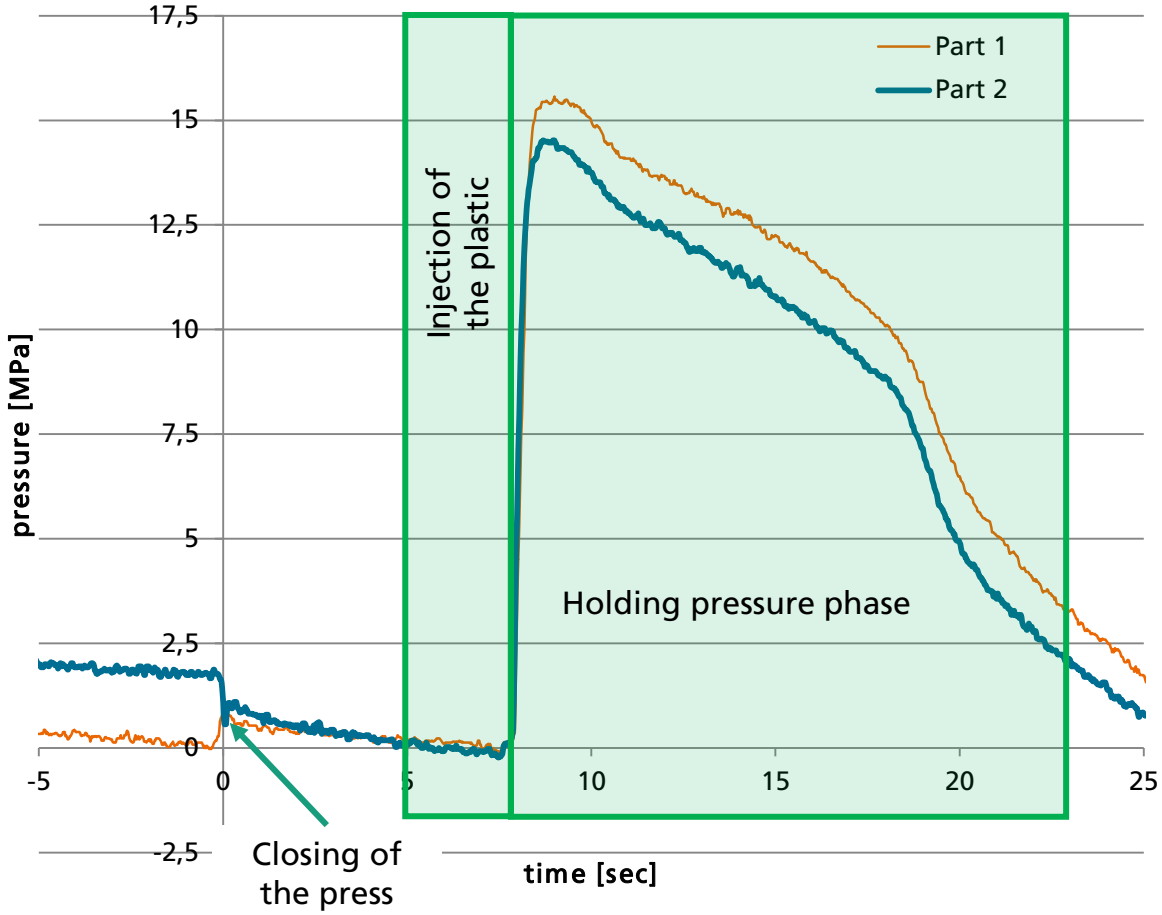
Hydroforming with injection moulding based on short fibre reinforced plastic tubes

First results – measuring of the injection moulding pressure at the surface of the tube

- Injection moulding on a dummy with integrated pressure sensor



injection moulding pressure at the tube surface



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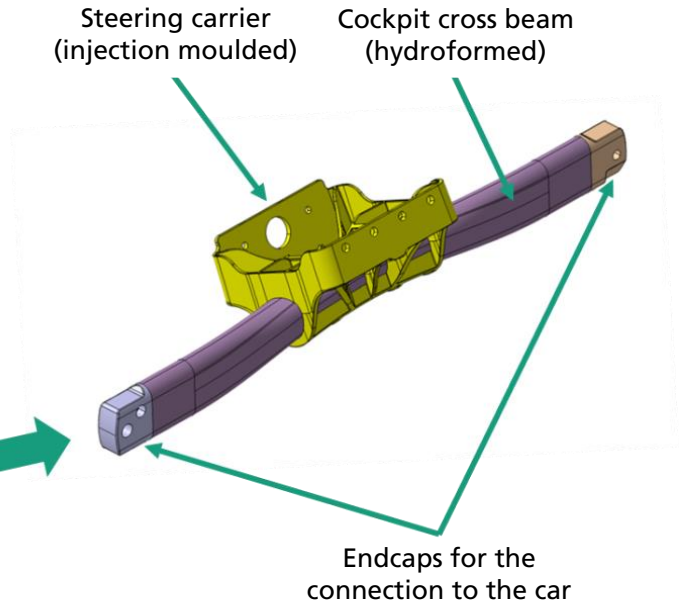

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Hydroforming with injection moulding based on short fibre reinforced plastic tubes

Conclusion and outlook:

- Hydroforming and hydroforming with injection moulding processes were realized based on fibre reinforced plastic tubes
- Short fibre reinforced plastic tubes and continuous fibre reinforced plastic tubes were developed, manufactured and tested

- **Next steps:** Optimization of the process control for hydroforming with injection moulding process based on short fibre reinforced plastic tubes
  - Use of tubes with higher wall thickness
  - Simultaneous build-up of the forming pressure / support pressure in the tube and of the injection pressure in particular when switching to the holding pressure phase

Thank you for your attention

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