Automated Production of Large Preforms Based on Robot-Robot Cooperation

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Outline

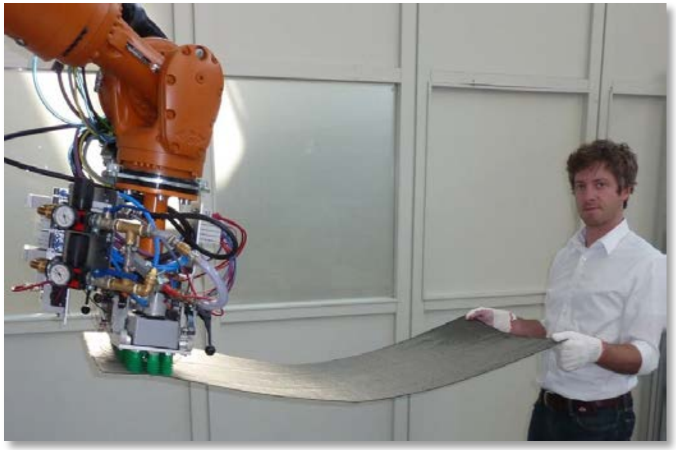
- Introduction: the Challenge
- Preforming with Cooperating Robots
- Video
- Experimental Validation
- Summary and Outlook

Introduction: the Challenge

- Large preforms
- High layup rates
- Many manual processes
- Potential issues
  - Material damages
  - Repeatability
  - Quality assurance
- Material attachment
- Robotic gripper weight for large cut pieces

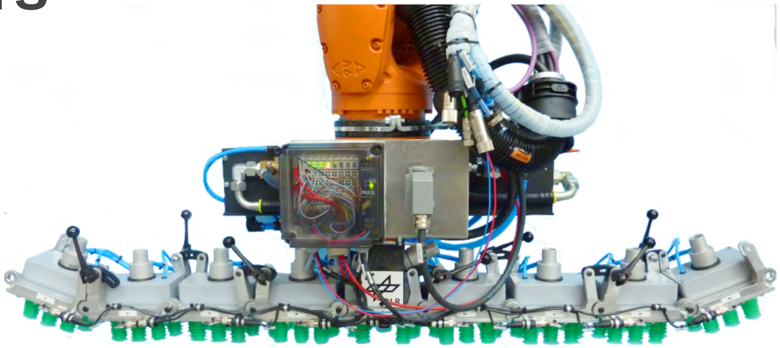
Preforming Approach: Concept

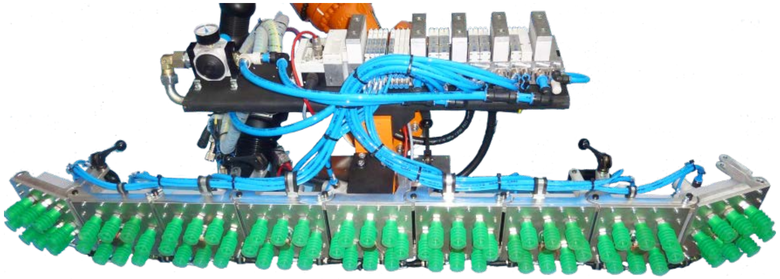
- Large cut pieces up to 1.4 x 6 m
- Manual handling of cut pieces by 2 workers, i.e. 4 hands
- General idea: cooperating robots with 2 grippers
- Process:
  - Pick up without damage
  - Transfer
  - Exact, repeatable positioning
  - Attachment

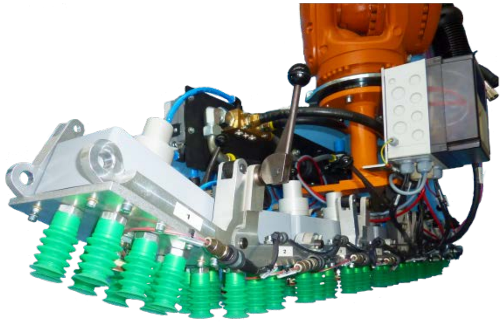


Preforming Approach: Grippers

- Gripper principles
  - Modularity
  - Vacuum (low pressure), high volume flow
  - Supply: 6 bar, 24 V, EtherCat
  - Flexible adjustment of deformation
- Gripper details
  - Components:
    - Valve cluster by Festo
    - Bus module by Beckhoff
    - Gripper mechanics by Kuka Systems
  - Bellows suction pads (optimized for choice of material)
  - Activation of thermoplastic binder by heating device on linear actuator

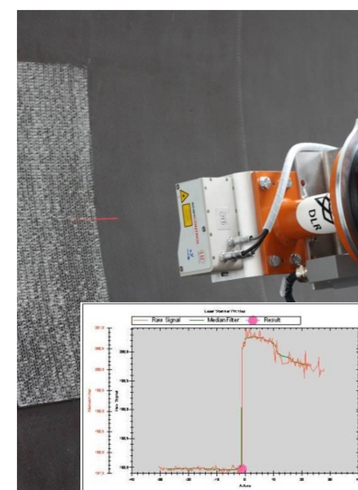






Preforming Approach: Preliminary Testing

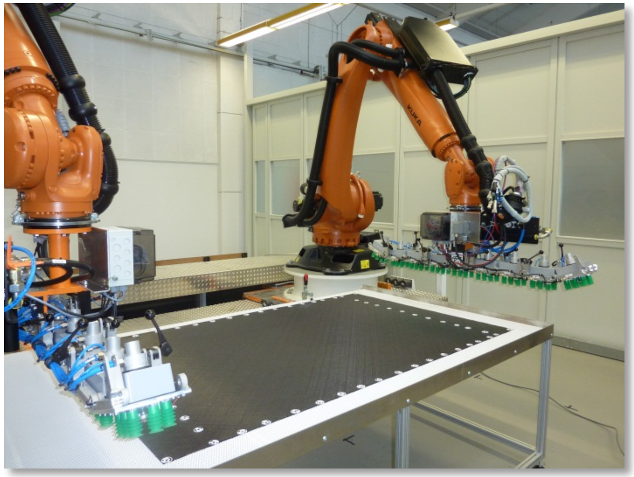
- Initial steps
  - Gripper integration and controls
  - Validation of gripper principle
  - Optimization
- Preliminary test setup
  - Validation of positioning accuracy
  - Small sample cut piece
    225 x 555 mm
  - Laser scanner for
    high accuracy measurements

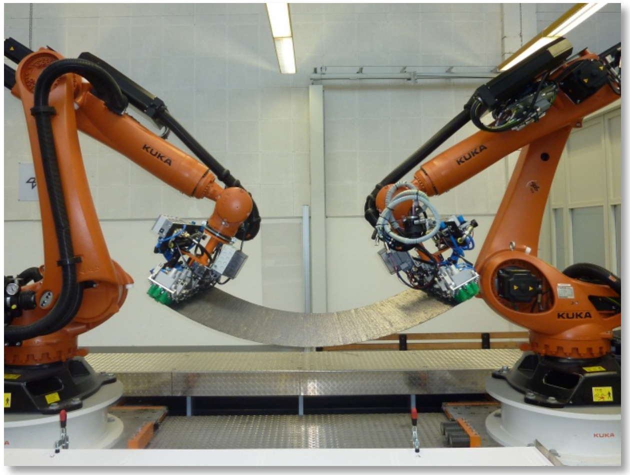


Preforming Approach: Setup

- Setup
  - Permeable surface for pick-up
  - Rectangular cut pieces
    - Dry NCF
    - 2.0 x 1.22 m
    - Thermoplastic binder
  - Two grippers, each 7 active modules

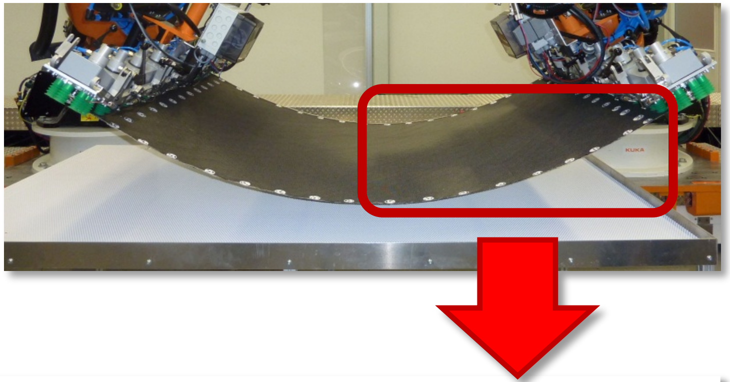
- Geometric conditions
  - Material forms catenary curve
  - Gripper position and orientation adjusted to catenary

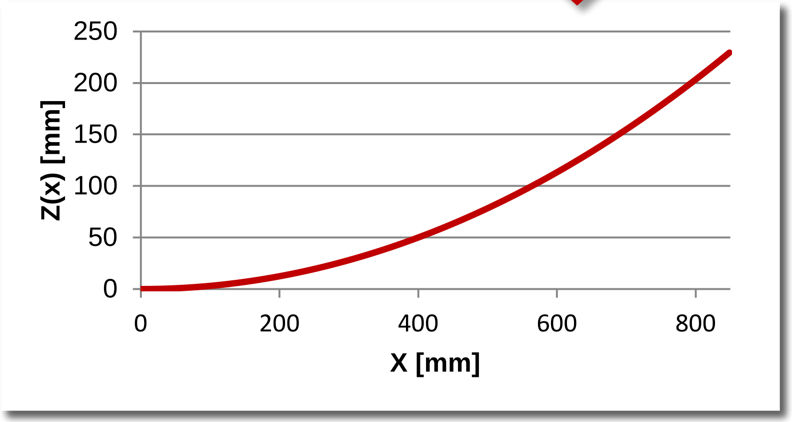




Preforming Approach: Catenary

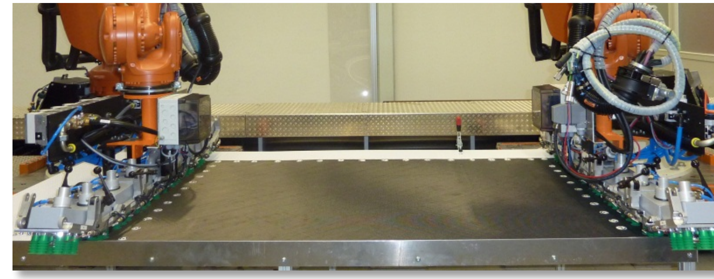
- Catenary can be computed for individual gripper-gripper positions
- Parameterised program: x, z, α
- Assuming constant length and width, then:
  - $z(x) = a\cosh\left(\frac{x - x_0}{a}\right) + z_0$
  - $l = 2a\sinh(\frac{w}{2a})$
  - $F = \frac{mg}{2}\coth(\frac{w}{2a})$





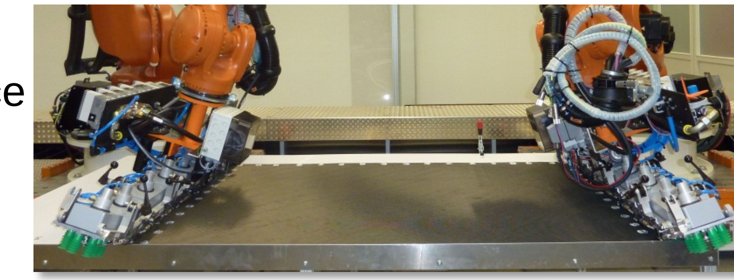
- Here: distance w = 1698 mm, length l = 1778 mm,
  hence: radius a = 1607 mm, angle α = 28.8°, m = 1.35 kg, F = 13.75 N

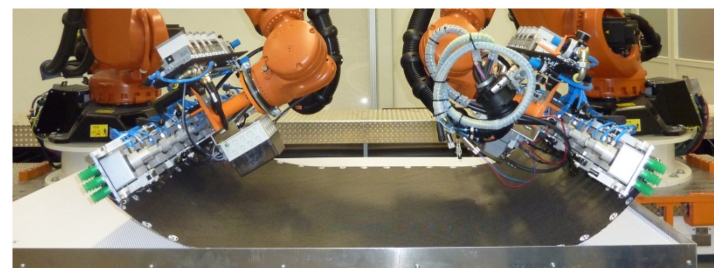
Preforming Approach: Process



Pick-up

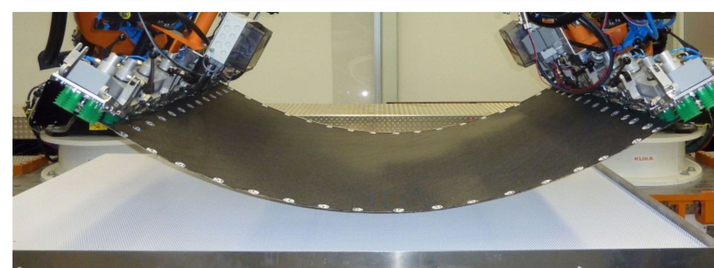
- Permeable table surface
- Resulting forces depending on gripper distance
- Gripper movements in 3 increments
- Cut piece forms catenary

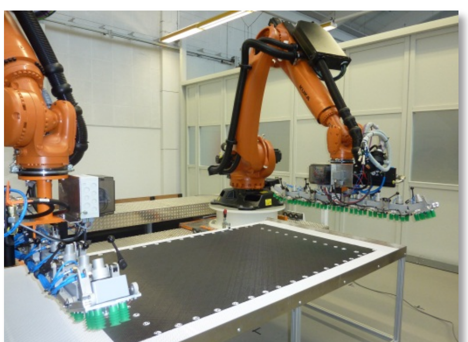




Transfer on linear track

- Grippers keep their relative position and orientation





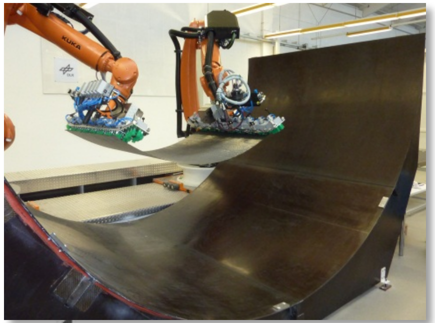
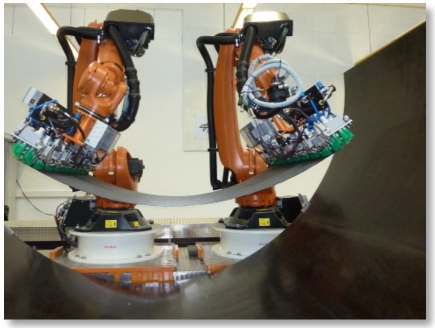
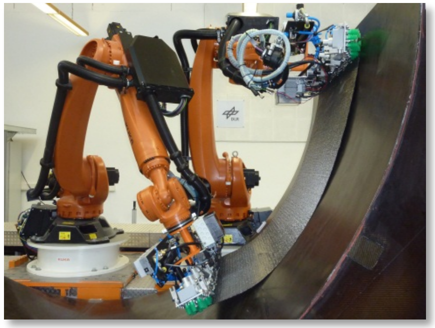
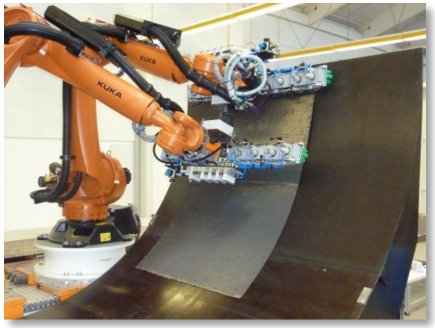
Preforming Approach: Process

Positioning

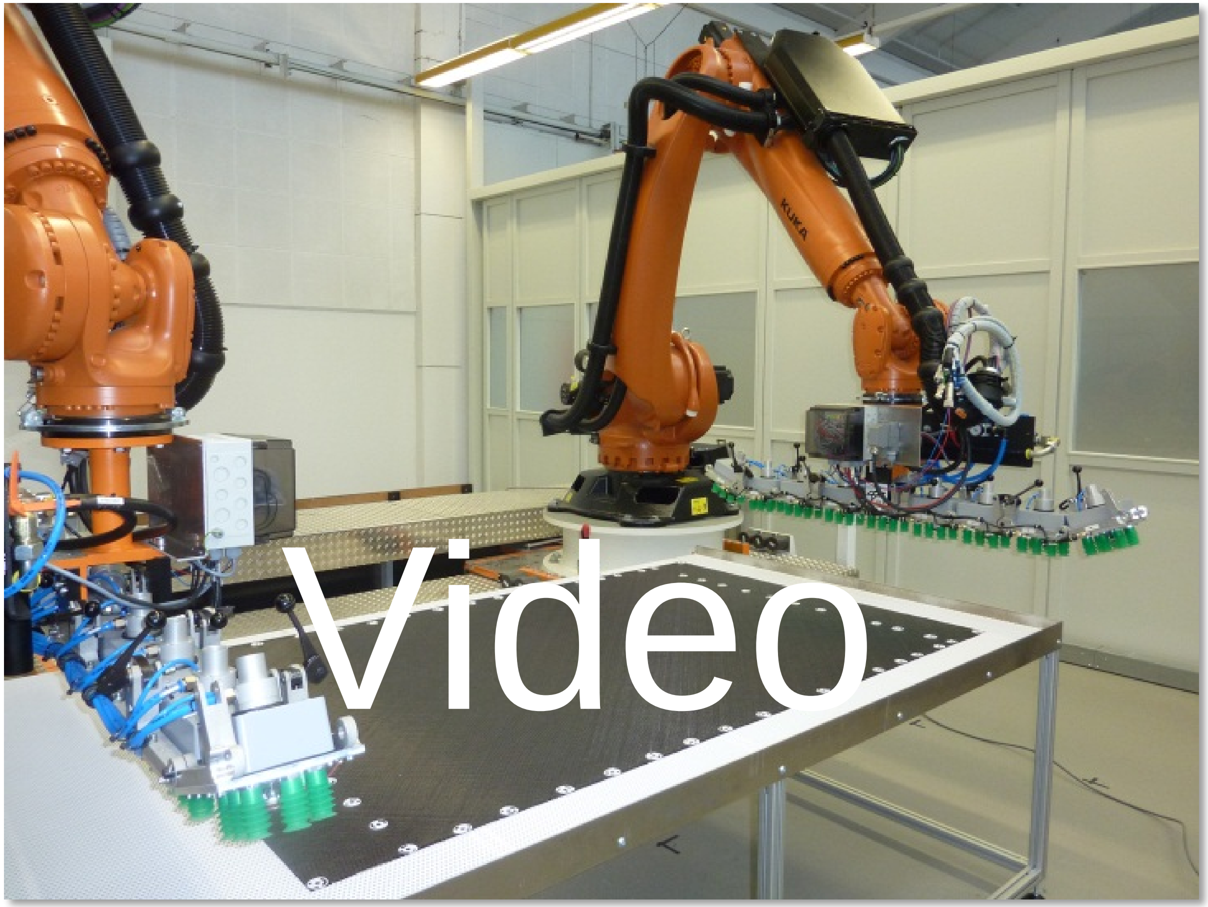
- Gripper no. 1: first cut piece edge held in position
- Activation of thermoplastic binder

Attachment

- Individual gripper movements
- Gripper no. 2 releases cut piece (now free for local cut piece attachment)

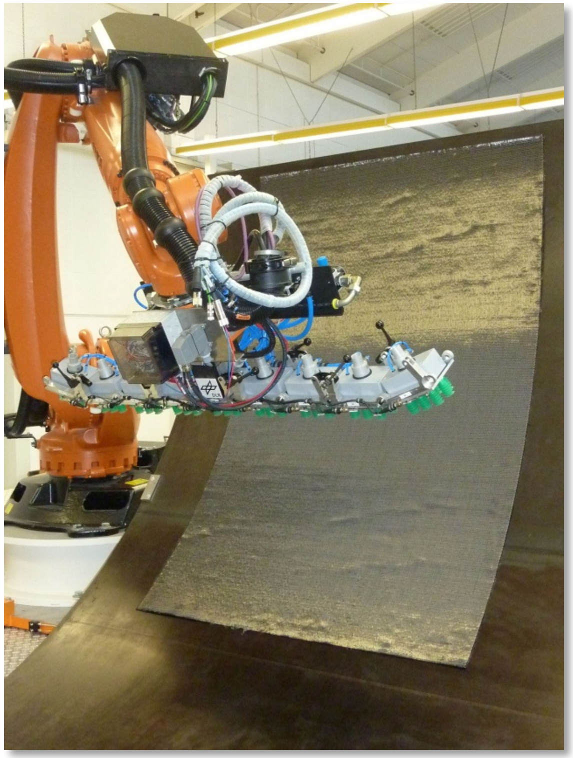





Preforming Approach: Video

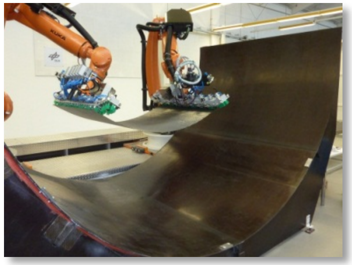


Preforming Result

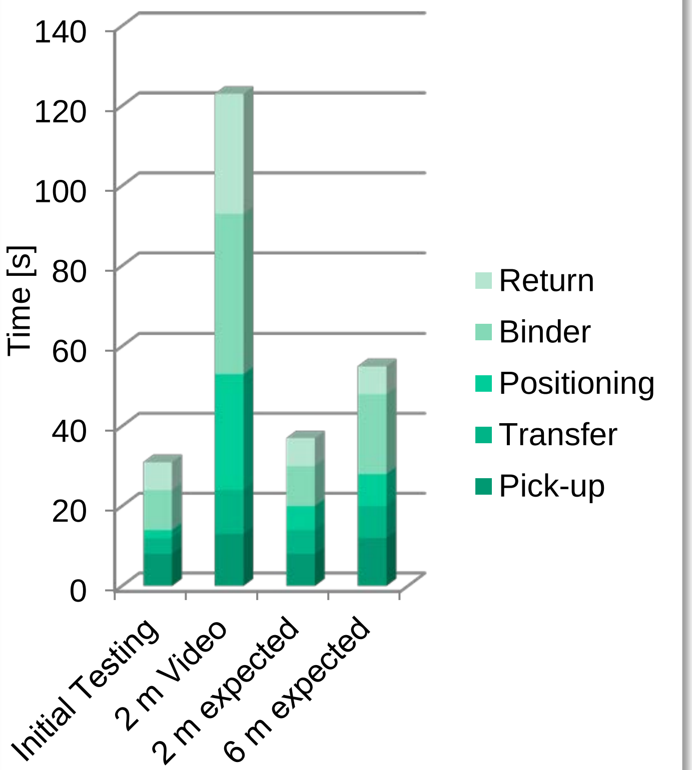
- Key aspects:
  - Positioning accuracy (absolute, relative)
  - Cut piece accuracy (boundary curve)
  - Cut piece deformation
  - Lay-up rate
- Pushing boundaries
  - Cut piece 1.22 x 6.0 m
  - NCF +/-45°
  - 4.06 kg



Layup Rate

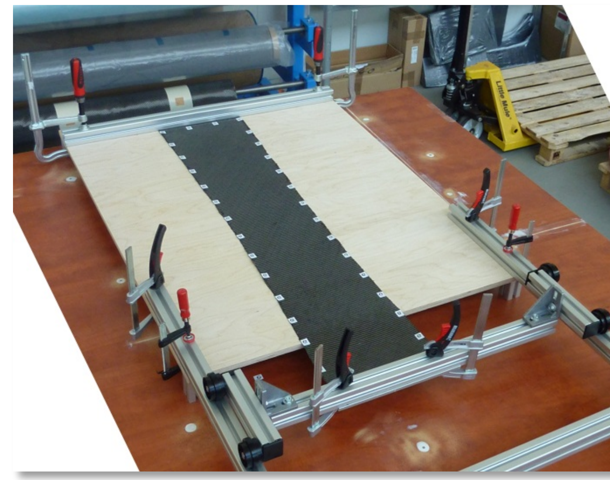


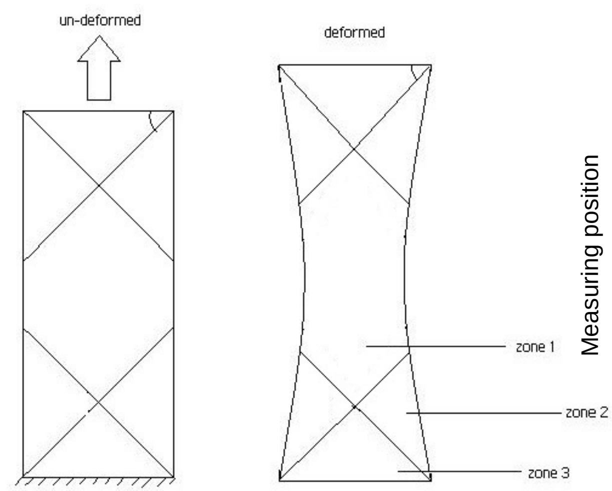
	Initial testing	2 m Video	*2 m expected*	*6 m expected*
Pick-up [s]	8	13	*8*	*12*
Transfer [s]	4	11	*6*	*8*
Positioning [s]	2	29	*6*	*8*
Binder [s]	10	40	*10*	*20*
Return [s]	7	30	*7*	*7*
Mass [g]	69	1354	*1354*	*4063*
Layup rate [kg/h]	**7.53**	**39.62**	***131.74***	***265.94***

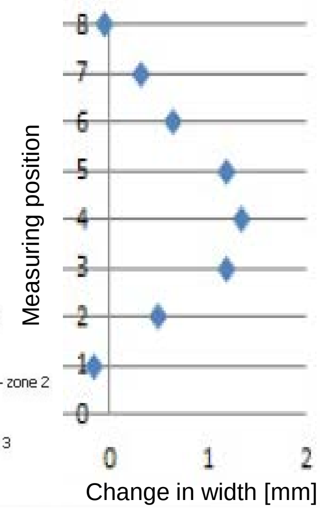


Cut Piece Deformation

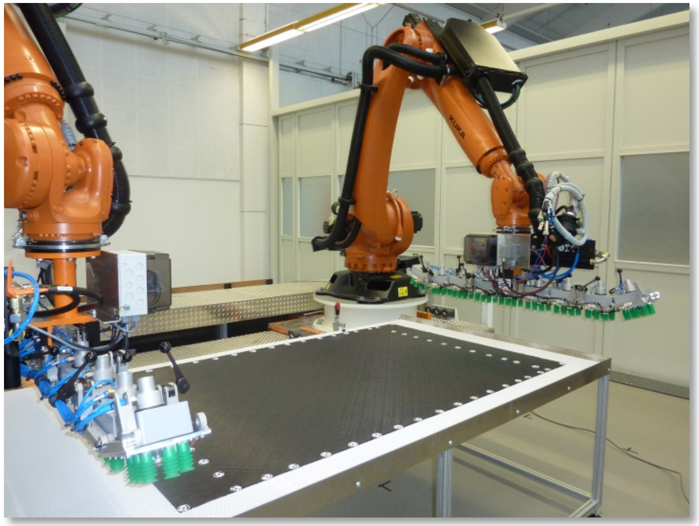
- Preliminary testing
  - Small test coupons
    max. 350 x 644 mm (W x L)
  - Unidirectional force applied
    max: 4.4 N
- Results for small test coupons
  - Elongation
    max: 2.1 mm
  - Lateral indentation
    max: -1.33 mm







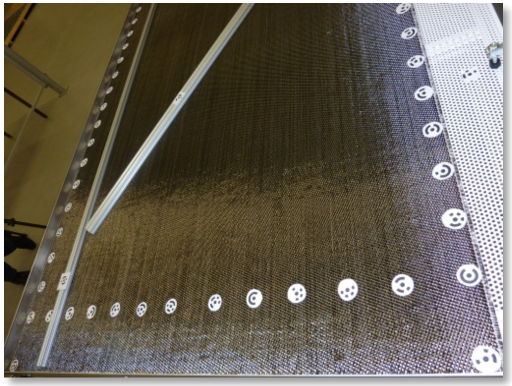
Experimental Setup

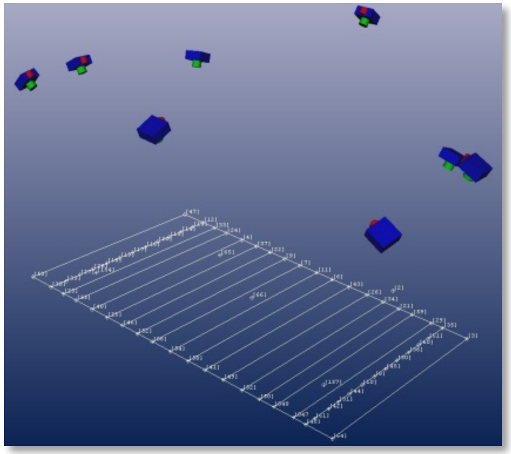


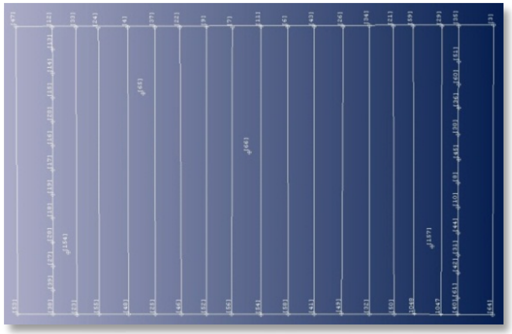
- Specimen (cut pieces)
  - NCF, +/-45°, 2.0 x 1.22 m
  - Weave, 0/90°, 2.0 x 1.30 m
- Experiment
  - Flat table surface
  - Pick-up, catenary, transfer, re-positioning on table
  - Measurement of cut piece deformation
- Measurement method: photogrammetry
  - Camera Panasonic Lumix DMC-TZ7
  - Software EOS Photomodeler 2011

Experimental Setup

- Cut piece preparation
  - Attachment of coded targets
  - Positioning on table with limit stop
- Measurement
  - Rigid bar for scaling
  - Reference set of 6-8 photos
  - Set of photos of „deformed“ cut piece
- Processing
  - 3D computation of target coordinates in Photomodeler
  - Assessment of change of distance between pairs of targets



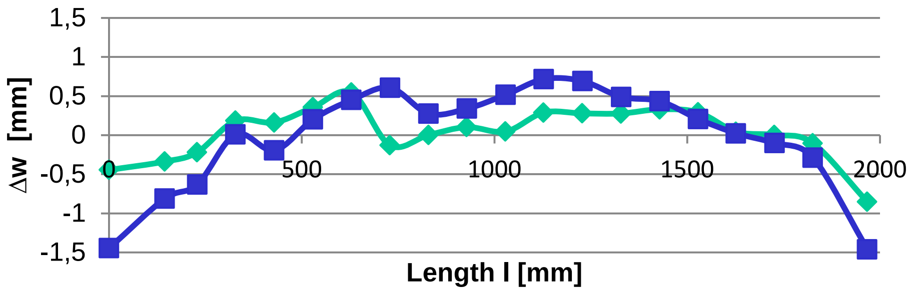


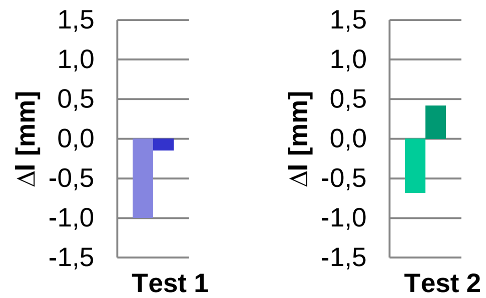


Experimental Results

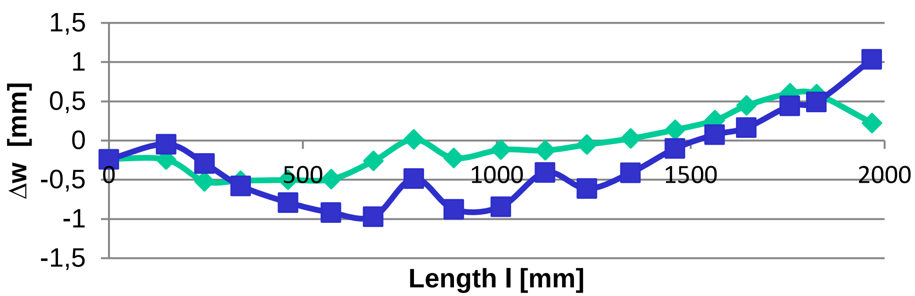
Change in width | **Elongation**

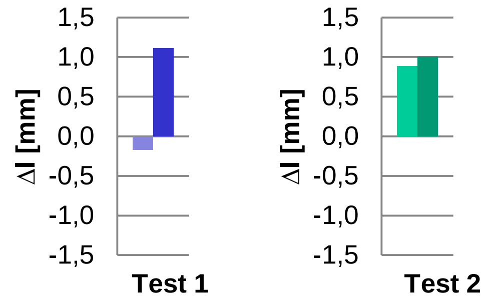
Weave





NCF +/-45°



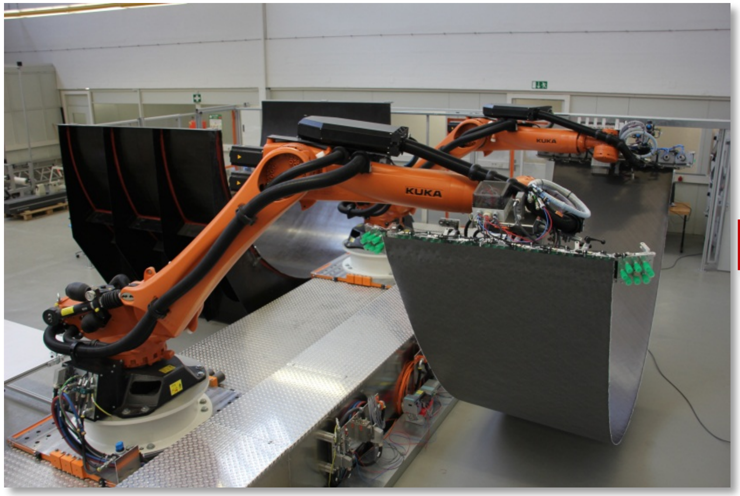


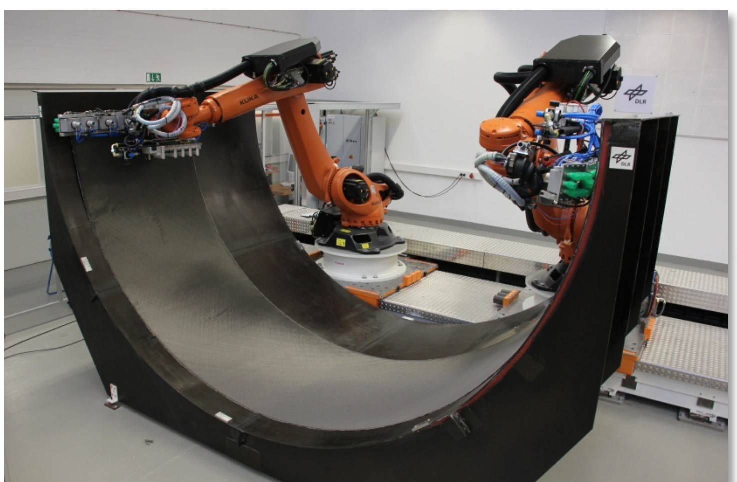
Precision of a single target position: 0.25 - 0.45 mm

Summary

- **Preforming approach with cooperating grippers does work**
  - Preliminary tests on positioning accuracy show good results
  - Grippers extended to full length
  - Implementation with KUKA RoboTeam
  - Cut pieces up to 2 m length have been handled
  - Process demonstrated: Pick-up, transfer, positioning and attachment
- **Measurement of cut piece deformation**
  - First assessment of influence on cut pieces
  - Preliminary results show little deformation
  - More testing required
  - No other cut piece damages observed
- **Fast process; high lay-up rates possible**
- **This is work in progress…**

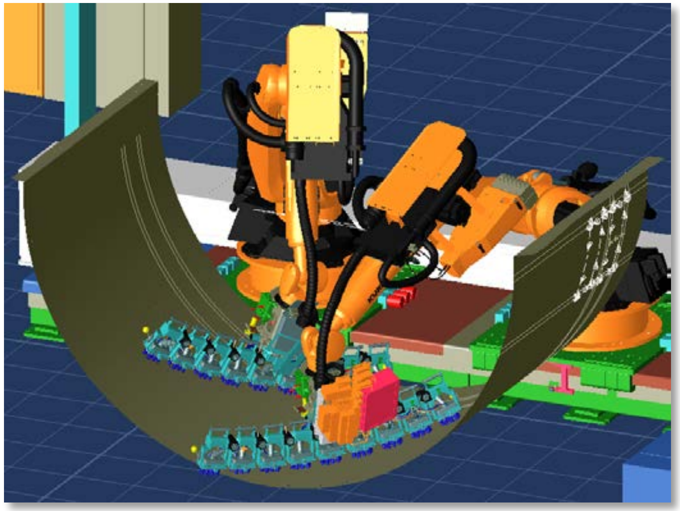
Pushing boundaries





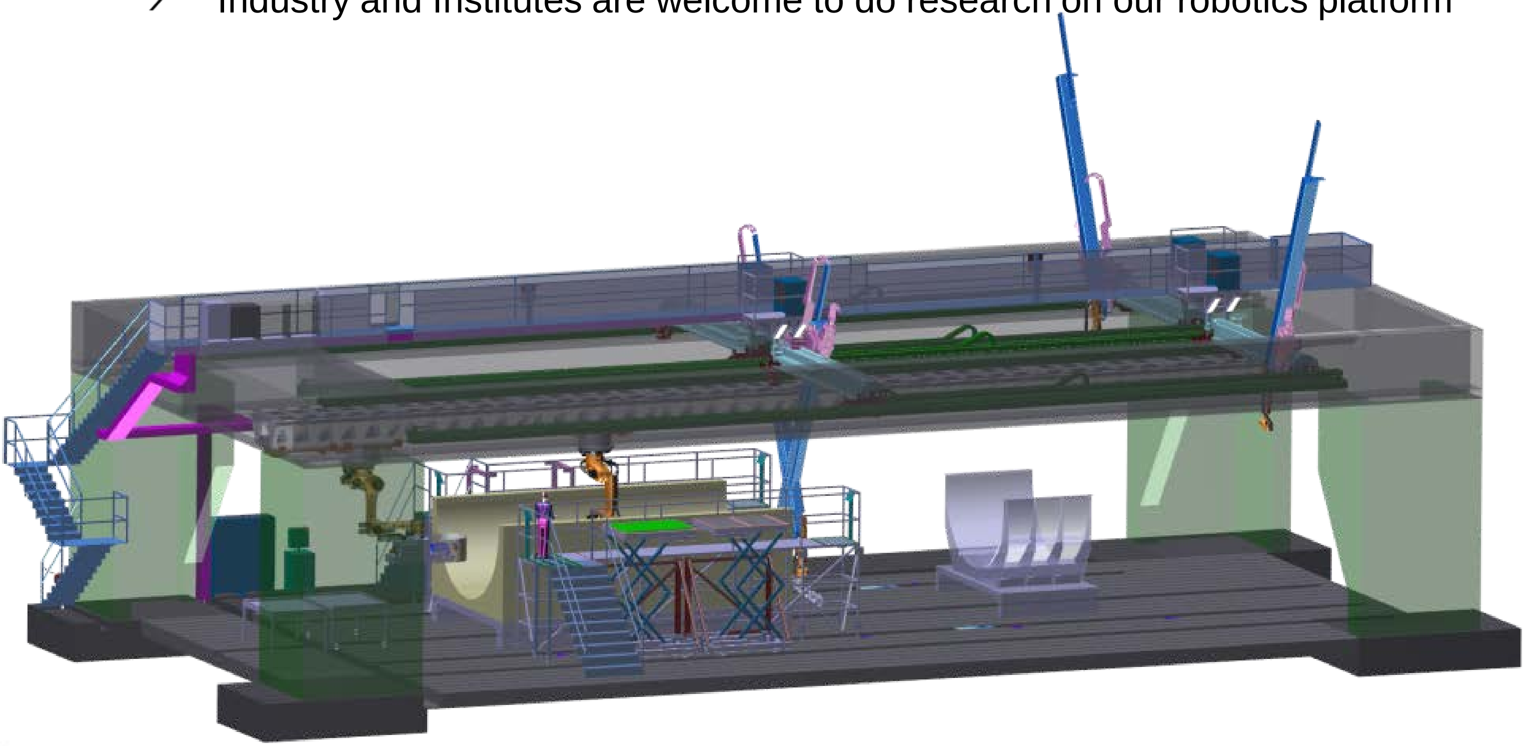
Outlook

- **Medium term development goals**
  - Short cycle time → increase of layup rate
  - High process stability → possible process qualification
- **Possible improvements**
  - Improved heating system for faster binder activation
  - Flexibility of gripper kinematics
  - Live consideration of catenary
  - Integration of quality control system
- **Next Steps**
  - Current gripper allows single curvature: Next generation gripper (for double curvature) in development with KUKA Systems
  - Further testing of cut piece accuracy
  - Optimization of process parameters



Outlook

- **Robotics scenario**
  - Gripper application in newly built
    multifunctional robotic cell at the DLR Augsburg
  - Industry and Institutes are welcome to do research on our robotics platform



Acknowledgements

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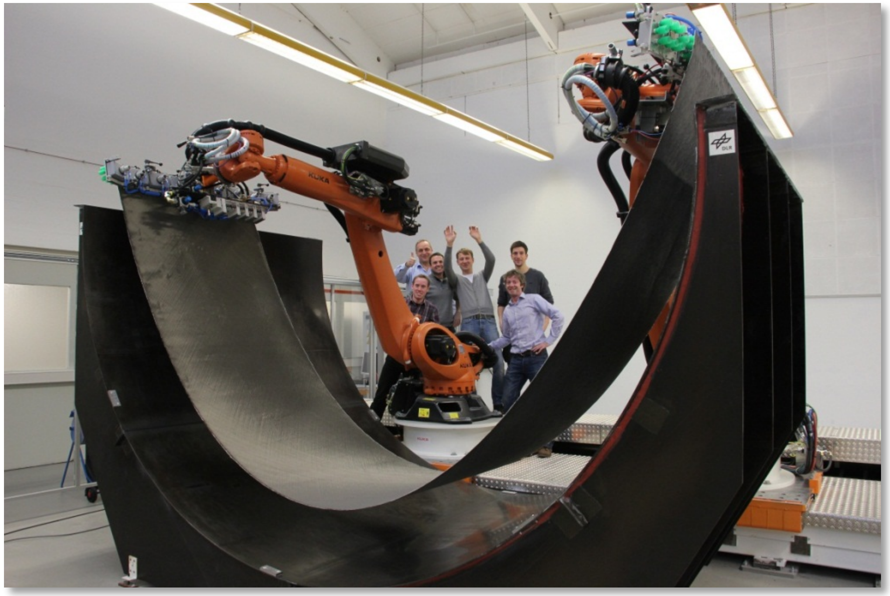
Stadt Augsburg

AUGSBURG INNOVATIONS PARK

Bundesministerium für Wirtschaft und Technologie



A special thanks goes to my colleagues at the DLR-ZLP in Augsburg. This work has been a team effort and their enduring help has made it possible.

Preforming Approach: Cooperating Robots

- Kuka RoboTeam features:
  - **Geolink:**
    Geometrically linked TCPs (pseudo-closed kinematic chain)
    Slave robot follows master‘s TCP
  - **ProgSync:**
    Simultaneous start of instructions
  - **Sync Movements:**
    Synchronized movements (start and end of movement)
  - **RemoteCommand:**
    Issuing commands to other team members

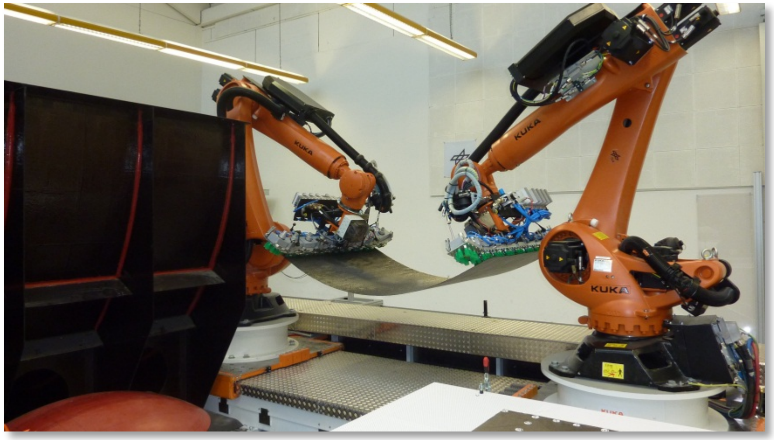
Preforming Approach: Cooperating Robots

- Cooperation of (industrial) manipulators (especially synchronized movements)

- Possible approaches:
  - No synchronization (calculation & teaching of required movements)
  - Single controller manages all participating joints (Single master)
  - Synchronization of multiple controllers (Master - Slave)

- **Here: Application of KUKA RoboTeam technology package**
  - **Master/Slave approach**

Preforming Approach: Cooperating Robots



- Chosen configuration:
  - **Pick-Up from table**:
    ProgSync (at start of program and incremental pickup stages) and GeoLink (after final pickup position)
  - **Transfer on linear track**:
    Sync movements (no GeoLink for linear tracks because of 7-axis redundancy)
  - **Positioning in mould**:
    combination of GeoLink (for positioning) and ProcSync (for attachment) statements
  - Slave gripper control through remote commands