Investigation of novel preforming technologies for large-scale composite production

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RWTH Aachen University

Aachen - in the heart of Europe, close to
- Düsseldorf
- Cologne
- Belgium
- The Netherlands
- Paris

- founded in 1870 by industrial initiative
- 31,500 students in 106 courses of study
- 450 chairs
- 4400 assistant lecturers (mostly PhD positions)
- 2500 non-academic members of staff
- 650 apprentices
- 650 Mill. € total budget
- thereof 30 % third party funding
Institut für Textiltechnik at RWTH Aachen University

Departments
- Man made fibers
- Textile machinery
- Smart & medical textiles
- Fiber-reinforced composites

Numbers
- 85 scientists
- 55 members of service staff
- 150 graduate research assistants
- Budget 14,3 mio. €
Fiber-reinforced composites at ITA

Technologies and process chains for the production and quality assurance of preforms for fiber-reinforced composites

- Development of new processes, machines and textile reinforcement structures
  - Design
  - Simulation
  - Prototyping
  - Production

Reinforcement fibers:
- Carbon, glass, aramid, ceramics, high strength polymers

Matrices:
- Thermosets, thermoplastics, concrete, metals
Mass production technologies for textile reinforcement structures

Motivation

- Increasing fuel costs and electric vehicle concepts require lighter car body structures
- Fiber-reinforced plastics (FRP) have great potential for weight saving (excellent weight/strength ratio)

Problem

- High cycle times due to manual and semi-automated production
- High production costs due to the production of textile reinforcement structures

Automated production technologies for textile preforms are essential for cost reduction and for sufficient production rates!
Combination of single- and multi-step preforming

- **Single-step preforming**: production of „Tailored Textiles“ with locally adjusted properties
- **Multi-step preforming**: converting „Tailored NCF“ and „Tailored Braids“ into near-netshape preforms in a sequence of automated process steps
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Single-step preforming

Production of near-netshape semi-finished parts in one production process

- Non-crimp fabrics (NCF) with locally adjusted properties → Tailored NCF
  - Fiberorientation
  - Thickness
  - Drapability
  - Bending stiffness
- Benefits for preforming
  - Reduced cutting operations
  - Reduction of scrap
  - Reduced handling operations
  - Eased handling operations

Production of Tailored NCF requires enhanced production technologies
Single-step preforming

State of the art: NCF and production technology

- Non-crimp fabrics (NCF)
  - Adjustable fiber orientation
  - Adjustable number of layers
  - Constant drapability
  - Constant layer set-up

- Production technology
  - Warp-knitting machine with multiaxial weft-insertion
  - High productivity
  - Industrial established

Source: LIBA Maschinenfabrik
Production technology for Tailored NCF

Enhancement of multi-axial warp-knitting machinery

- Tailored NCF
  - Locally adjusted thickness
  - Locally adjusted fiberorientation
  - Locally adjusted drapability

- Production technologies
  - Feeding module
  - Adaptive pillar thread bar
  - Electro-mechanical driven guide-bar
  - Electro-mechanical driven beam drive
  - Cutting and stacking modul

Local reinforcements on NCF

Direction of production

adjusted stitch type
Production technology for *Tailored NCF*

Enhancement of multi-axial warp-knitting machinery
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Multi-step preforming

Automated preform assembly

- Efficient and quality-oriented production technologies for textile preforms via
  - Use of Tailored NCF
  - Increased production speed of single process steps
  - Parallelization of process steps
  - Transition from a sequentiel to a continuous production
Multi-step preforming: Cutting

Cutting of reinforcement textiles

- CNC-cutter-tables (2D)
  - Oscillating knife
  - Rotation cutting disc
  - Laser

- Three-dimensional edge-trimming
  - Robotically guided
  - Ultrasonic knife
  - Cutting of complex geometries
Multi-step preforming: handling

Handling device

- Robot guided needle gripper device
- Fast and reproducible pick & place operations
- Onboard charge coupled device (CCD) Camera for quality assurance (QA) and positioning
Multi-step preforming: joining

Binder application
- Thermoplastic binders
- Bisphenol-A based epoxies
- Permanent adhesive coating

Onesided sewing
- Tufting
- Onesided ITA-Stitching
- Blindstitch
- Onesided stiching (OSS)
Multi-step preforming: quality control

FALCON (fiber automatic life control)

- In-line-monitoring-system for
  - Textur (material, textile type)
  - Orientation and geometry of textiles
  - Defects in textiles (gaps, foreign objects)
  - Positioning-quality of cuts

Perspective

- Miniaturization of monitoring device
- Integration into various end-effectors
- Establishment of closed loop control for automated preforming processes
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Case study: Square shaped part with local reinforcement

**Shell:** 16 layers of glass fibers, quasi-isotropic

**Reinforcement:** 16 layers of glass fibers, quasi-isotropic

**Cut-out:** 80x40 mm

**Practical Relevance**
- Wall linings in airplanes
- Floor structures in cars / trains
## Case study: development of process chains

### 4-step methodology

<table>
<thead>
<tr>
<th>Step</th>
<th>Tools</th>
<th>Results</th>
</tr>
</thead>
</table>
| 1. **Creation of a decision basis** | Inquiry, Experiments | • Product data  
• Technology data  
• Economical data |
| 2. **Combination of process modules** | Free combination, Creativity methods | • Process chain alternatives |
| 3. **Development of technology chains** | Pictograms, Spider-diagrams, Technology matrices | • Choice of technologies  
• Technology chain alternatives  
• Choice of technology chains |
| 4. **Process chain development** | Efficiency analysis, Product web, EcoPreform | • Production facility  
• Operation chart  
• Quantitative and qualitative process chain evaluation |
Process chain 1

Automated processing of standard NCF

- Parallel work of preformcenter (automatic) and cutting table (controlled by a worker)
- Cutting table
  - Cutting both fabric types
  - Positioning
- Preformcenter
  - Handling and joining
  - Edge-trimming and insertion of disruption
  - Handling / Storage
Process chain 2

Automated processing of Tailored NCF

- Synchronous execution of process steps
  - Feeding of non-crimp fabric layers
  - Insertion of local reinforcement
  - Joining of all layers
  - Cutting
  - Insertion of disruption (stamping)
  - Handling / Storage
Economic evaluation

EcoPreform:

- xls.-tool developed at ITA
- Flexible, easy to use and able to analyze various process chains
- Cycle time and costs

Approach:

- Entering basic data into EcoPreform
  - Database (experimentally generated)
  - E.g. costs, speeds, materials, machines,...
- Modelling process modules
- Modelling the described process chains
- Calculating cycle time and costs for different lot sizes
Economic evaluation

- EcoPreform
## Economic evaluation: results

<table>
<thead>
<tr>
<th></th>
<th>Process chain 1</th>
<th>Process chain 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cycle time [min]</strong></td>
<td>13,4</td>
<td>2,3</td>
</tr>
<tr>
<td><strong>Cost per piece [€]</strong></td>
<td>28,6</td>
<td>11,9</td>
</tr>
<tr>
<td><strong>Share of material costs [%]</strong></td>
<td>25,7</td>
<td>57,0</td>
</tr>
<tr>
<td><strong>Share of wages [%]</strong></td>
<td>61,2</td>
<td>24,5</td>
</tr>
<tr>
<td><strong>Share of machine costs [%]</strong></td>
<td>13,1</td>
<td>18,4</td>
</tr>
<tr>
<td><strong>Purchasing cost [€]</strong></td>
<td>573.400</td>
<td>2.190.500</td>
</tr>
</tbody>
</table>
Economic evaluation: cost/unit over annual volume

![Graph showing cost per unit over annual production volume for Process Chains 1 and 2.](image-url)
Economic evaluation

Final evaluation of process chain 1 and 2:

- Process chain 2 (Tailored NCF) is more suitable for production of shaped part with local reinforcement
  - Lower unit costs
  - Reduced cycle time
  - Reduced processing time

- High potential of Tailored NCF for mass production
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Case study: BMW 3 series convertible roof segment

Shell: 8 layers of glass fibers, quasi-isotropic (0°, 90°, ±45°, ±45°, 90°, 0°), 210 g/m² each

Reinforcements: 4 layers of fibers

Stiffeners: Polymethacrylimid (PMI) foam core with 8 layers glass fiber draping

Inserts: CNC-machined aluminum
Process chain 1

Automated processing of standard NCF

- 36 process steps
- 2 parallel processes
  - Cutting
  - Preforming

Layout process chain 1

Technology chain for automated processing of standard NCF (process chain 1)
Process chain 2

Automated processing of *Tailored NCF*

- 17 process steps
- 2 parallel processes
  - **Single-Step Preforming**
  - **Multi-Step Preforming**

![Diagram of process chain 2](attachment:image.png)

Layout process chain 2

Technology chain for automated processing of *Tailored NCF* (process chain 2)
Economic evaluation

- EcoPreform
  - Production examined for one year periods
  - Linear deprecation of machinery within 10 years

EcoPreform (screenshots)
## Economic evaluation: results

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</thead>
<tbody>
<tr>
<td>Cycle time [min]</td>
<td>20,8</td>
<td>8,3</td>
</tr>
<tr>
<td>Cost per piece [$]</td>
<td>598,6</td>
<td>590,3</td>
</tr>
<tr>
<td>Share of material costs [%]</td>
<td>93,6</td>
<td>95,6</td>
</tr>
<tr>
<td>Share of wages [%]</td>
<td>5,1</td>
<td>2,8</td>
</tr>
<tr>
<td>Share of machine costs [%]</td>
<td>1,3</td>
<td>1,6</td>
</tr>
<tr>
<td>Purchasing cost [€]</td>
<td>589,400</td>
<td>2,240,500</td>
</tr>
</tbody>
</table>
Economic evaluation: cost/unit over annual volume
Validation

Process simulation
- Software *KukaSim Pro*

Praktikal validation
- Implementation of both process chains at ITA
Iteration / Optimization

Process analysis / optimization

- Process chains are dominated by material costs (~ 95%)
  - Expensive purchase parts (Stringer, Inserts (> 90%!))
  - No material-specific part design
- Cycle time can be reduced to 3.5 minutes
  - Parallelization of stiffener handling
  - Parallelization of Insert handling
Economic evaluation

Final evaluation of process chain 1 and 2:

- Process chain 2 (Tailored NCF) is more suitable for production of convertible roof segment
  - Lower unit costs
  - Reduced cycle time
  - Reduced processing time

- High potential of Tailored NCF for mass production
Extended economic evaluation

Extended evaluation

- Overhead costs (distribution structure)
- Dynamic economic evaluation
- Life cycle assessment (LCA)
  - Cradle to gate
  - Cradle to crave

Source: scienceinthebox.com
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Conclusion

Automated production technologies for textile preforms are the key to a cost-efficient production of fiber reinforced plastics

- Continous production of Tailored NCF with locally adjusted properties
- Automated preform assembly for the production of complex, near net-shape textile reinforcement structures

- Both cycle time and costs can be reduced significantly
- Developed technologies have high potential for mass production

We would like to thank the Deutsche Forschungsgemeinschaft (DFG) for supporting and funding the FOR860 working group of researchers (“The development of new process chains for fibre-reinforced plastic components and the integration of preforming, forming and crosslinking processes”).
Thank you for your Attention!

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