DEVELOPMENT OF A MULTISCALE SIMULATION WORKFLOW TO PREDICT THE PERMEABILITY OF TEXTILES

ECCM19, June 23rd 2020

Math2Market GmbH:  A. Widera, M. Hümbert
Institut für Verbundwerkstoffe: T. Schmidt, D. May
1. Introduction

2. Research project Math2Composites

3. Generation of a digital twin and permeability simulation

4. Impact of Math2Composites
LIQUID COMPOSITE MOLDING – PROCESS CHAIN
LIQUID COMPOSITE MOLDING – PROCESS CHAIN

➢ LCM is an important process in the area of fiber-reinforced polymers

Automotive

Source: "Creative Commons, BMW i3" by TTNIS is licensed under CC BY 1.0

Aerospace

Source: "Creative Commons, Airbus A380" by "Ienac from the German Wikipedia"

Ship Building

Source: "Creative Commons, Yacht Arumaaz" by Arumaazu is licensed under CC BY 2.0

Energy Industry

Source: "Creative Commons, Blade for a Vestas wind turbine" by Lars Plougmann is licensed under CC BY 2.0

© Math2Market GmbH
Liquid Composite Molding Component Development

- Start with manufacturing a set of specimen
  - In general, about 5 specimen for statistical variance
- Manufactured in research and development labs
Conduct laboratory experiments to characterize the specimen

Determine permeability of the dry textile
  - Gives insight on the impregnability

Determine mechanical properties
Liquid Composite Molding Component Development

- Material properties are used for macroscopic simulation
LIQUID COMPOSITE MOLDING COMPONENT DEVELOPMENT

- Macroscopic simulation yields results for the performance
LIQUID COMPOSITE MOLDING COMPONENT DEVELOPMENT

- Specimen manufacturing
- Specimen testing
- Macroscopic component simulation
- Characterized component
- Production of component

- A: Good performance - the component goes into production
- B: Performance needs improvement

1: "Creative Commons, Example of a medium sized 440 tons servo hydraulic compression molding press" by Sam D. Wilbur is licensed under CC BY-SA 4.0
LIQUID COMPOSITE MOLDING COMPONENT DEVELOPMENT

Specimen manufacturing

Specimen testing

Macroscopic component simulation

Characterized component

Production of component

Adapt composition of specimen

1: "Creative Commons, Example of a medium sized 440 tons servo hydraulic compression molding press" by Sam D. Wilbur is licensed under CC BY-SA 4.0
1. Introduction

2. Research project Math2Composites

3. Generation of a digital twin and permeability simulation

4. Impact of Math2Composites
Start again with set of specimen which are characterized
Identification of parameters for modeling
- Selective calibration with experimental data
- Obtain a Digital Twin
Digital experiments for the characterization of the specimen
- Use digital characterizations for simulation on macroscopic level
- Use digital characterizations for simulation on macroscopic level
- If performance is acceptable go ahead with component production
RESEARCH PROJECT Math2Composites

Macroscopic component simulation

Characterized component

A: Good performance

Production of component

1: Example of a medium sized 440 tons servo hydraulic compression molding press

1: "Creative Commons, Example of a medium sized 440 tons servo hydraulic compression molding press" by Sam D. Wilbur is licensed under CC BY-SA 4.0
Macroscopic component simulation

Characterized component

A: Good performance

B: Improvable performance

Production of component

1: Example of a medium sized 440 tons servo hydraulic compression molding press

1: "Creative Commons, Example of a medium sized 440 tons servo hydraulic compression molding press" by Sam D. Wilbur is licensed under CC BY-SA 4.0
- Start parameter variation on the digitalized specimen

1: "Creative Commons, Example of a medium sized 440 tons servo hydraulic compression molding press" by Sam D. Wilbur is licensed under CC BY-SA 4.0
RESEARCH PROJECT MATH2COMPOSITES

Macroscopic component simulation

Characterized component

A: Good performance

B: Improvable performance

Digital specimen adaptation

Production of component

Digital parameter variation

1: "Creative Commons, Example of a medium sized 440 tons servo hydraulic compression molding press" by Sam D. Wilbur is licensed under CC BY-SA 4.0
Resolution for single filament model:

- Highest realistic approach

but:

- High resolution needed to be RVE (representative volume element):
  - At least 5 longitudinal and 5 transversal rovings
  - At least 8 layers

CT-scan with 3 µm resolution
1760x1760x385 Voxel
3 longitudinal and transversal rovings and 4 layers

Results in very large structure (about 4000 x 4000 x 900 voxel), thus, meaning long simulation runtimes
Therefore, use multiscale approach:

- Simulate cell of single filaments
- Homogenize results
- Give homogenized properties to the “solid” roving

Domain size 1500 x 1500 x 600 voxel at 10 µm resolution

With 5 longitudinal and transversal rovings and 8 layers
1. Introduction
2. Research project Math2Composites
3. Generation of a digital twin and permeability simulation
4. Impact of Math2Composites
## Digitalization of the Specimen: Parametrization

### Description

<table>
<thead>
<tr>
<th>Description</th>
<th>Hacotech G300U – 1270 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texile</td>
<td>Biaxial non-crimp fabric (0°/90°), E-glass</td>
</tr>
<tr>
<td>Grammage</td>
<td>373 g/m²</td>
</tr>
<tr>
<td>Weft thread (0°)</td>
<td>600 tex, 10 µm filament, 300 g/m²</td>
</tr>
<tr>
<td>Warp thread (90°)</td>
<td>295 tex, 10 µm filament, 60 g/m²</td>
</tr>
<tr>
<td>Stitching yarn</td>
<td>PES-Garn, 11 tex, 13 g/m² grammage</td>
</tr>
</tbody>
</table>

### Sources for parameter selection

- Data sheet
DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION

Sources for parameter selection

Data sheet
DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION

- Ondulation of the roving
- Stitching of the rovings
- Irregularities in diameter and spacing of the rovings

Sources for parameter selection

- Data sheet
- Microscopy

5 mm

2 mm
DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION

Sources for parameter selection

- Data sheet
- Microscopy

5 mm
Sources for parameter selection

- Data sheet
- Microscopy
- CT scan

μCT scans provide insight into the actual appearance of the non-crimp fabric

2 mm

μCT scan
µCT scans provide insight into the actual appearance of the non-crimp fabric.

Sources for parameter selection:
- Data sheet
- Microscopy
- CT scan

DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION
**DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION**

**Sources for parameter selection**

- **Data sheet:**
  - Tex rovings
  - Dimension of the rovings
  - Dimension of stitching
  - Diameter

- **Microscopy:**
  - Spacing of the rovings
  - Ondulation of the Rovings

- **CT scan:**
  - Fibre volume content
  - Number of layers
  - Roving cross-sectional shape
  - Random stacking of the layers
  - Thickness of the sample

**Different complexities can be represented in the modeling**

- Rovings
- Rovings with stitching
- Virtual compaction with mechanics solver
DIGITALIZATION OF THE SPECIMEN: CALIBRATION

Measurement of 5 different specimens

K₁, K₂, K₃
K₁, K₂, K₃
K₁, K₂, K₃
K₁, K₂, K₃
K₁, K₂, K₃
DIGITALIZATION OF THE SPECIMEN: CALIBRATION

Measurement of 5 different specimens

Optimization routine for parameterization
Digitalization of the specimen: Calibration

Measurement of 5 different specimens

Optimization routine for parameterization

Digital twin for permeability
Digitalization of the Specimen: Calibration

- Measurement of 5 different specimens
- Optimization routine for parameterization
- Digital twin for permeability
  - Same statistical properties
  - Other random seeds
Digitalization of the specimen: Calibration

Measurement of 5 different specimens

Optimization routine for parameterization

Digital twin for permeability
SUCCESSIVE ADAPTATION OF GEOMETRICAL PARAMETERS OF WOVEN FABRIC PRIOR TO COMPACTION

DIGITALIZATION OF THE SPECIMEN: CALIBRATION AT 50% FVC

Permeability in m²

- Calibration (50% FVC)
- Validation (55% FVC)
- Validation (60% FVC)
Digitalization of the specimen: Validation at 55% FVC

Extrapolation to 55% FVC and comparison with experimental results

- Successful transfer and validation of the calibrated model to 55% FVC
**DIGITALIZATION OF THE SPECIMEN: VALIDATION AT 60% FVC**

Extrapolation to 60% FVC and comparison with experimental results

SUCCESSFUL TRANSFER AND VALIDATION OF THE CALIBRATED MODEL TO 60% FVC
Outline

1. Introduction

2. Research project Math2Composites

3. Generation of a digital twin and permeability simulation

4. Impact of Math2Composites
EFFICIENCY OF EXPERIMENTAL COMPONENT DEVELOPMENT

Specimen manufacturing

Manufacturing of 5 specimen to ensure statistical variance
EFFICIENCY OF EXPERIMENTAL COMPONENT DEVELOPMENT

Specimen manufacturing

Specimen testing

Macroscopic component simulation

Characterized component

A: Good performance

B: Improvable performance

About 5 iterations until A occurs

Adapt composition of specimen
EFFICIENCY OF EXPERIMENTAL COMPONENT DEVELOPMENT

Specimen manufacturing

Specimen testing

Macroscopic component simulation

Characterized component

A: Good performance

B: Improvable performance

About 5 iterations until A occurs

Adapt composition of specimen

Total number of specimen 25

Number of evaluated parameter sets 5
EFFICIENCY OF SIMULATION-AIDED COMPONENT DEVELOPMENT

Manufacturing of 5 specimen to ensure statistical variance
EFFICIENCY OF SIMULATION-AIDED COMPONENT DEVELOPMENT

Specimen manufacturing

Specimen testing

Specimen digitalization

Digital specimen testing

5 specimen needed for digitalization
EFFICIENCY OF SIMULATION-AIDED COMPONENT DEVELOPMENT

Macroscopic component simulation

Characterized component

A: Good performance

B: Improvable performance

Digital specimen adaptation

About 15 parameter variations. Validation of each 3\textsuperscript{rd}

Digital parameter variation
Efficiency of Simulation-Aided Component Development

Macroscopic component simulation

Characterized component

A: Good performance

B: Improvable performance

Digital specimen adaptation

Digital parameter variation

About 15 iterations until A (best design) is found

About 15 parameter variations. Validation of each 3rd
EFFICIENCY OF SIMULATION-AIDED COMPONENT DEVELOPMENT

Macroscopic component simulation

Characterized component

Digital specimen adaptation

Digital parameter variation

A: Good performance
B: Improvable performance

About 15 parameter variations. Validation of each 3rd

About 15 iterations until A (best design) is found

Total number of specimen 10
Number of evaluated parameter sets 15
COMPARISON: EXPERIMENTAL VS. SIMULATION-AIDED DEVELOPMENT

Solely experimental development

Total number of specimen
25

Number of evaluated parameter sets
5

Simulation-aided development

Total number of specimen
10

Number of evaluated parameter sets
15

Reduce number of manufactured specimen by 50% and less

Increase number of evaluated parameter sets by factor 3
The project “Math2Composites” is funded by the ZIM program of the Federal Ministry for Economic Affairs and Energy (BMWi), funding reference: ZF40523110EB6

Many thanks to the “Institut für Verbundwerkstoffe” for the great and pleasant cooperation.
THANK YOU FOR YOUR ATTENTION!

Aaron, Widera
Application Specialist, Digital Material R&D

Aaron.widera@math2market.de
www.math2market.de