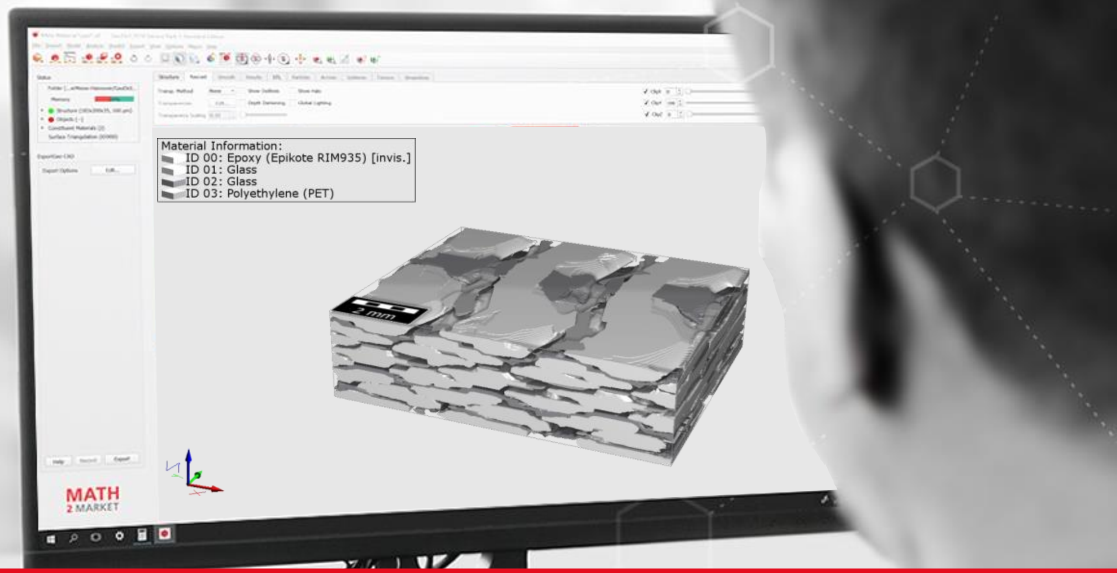
GeoDict



Development of a multiscale simulation workflow to predict the permeability of textiles

ECCM19, June 23rd 2020

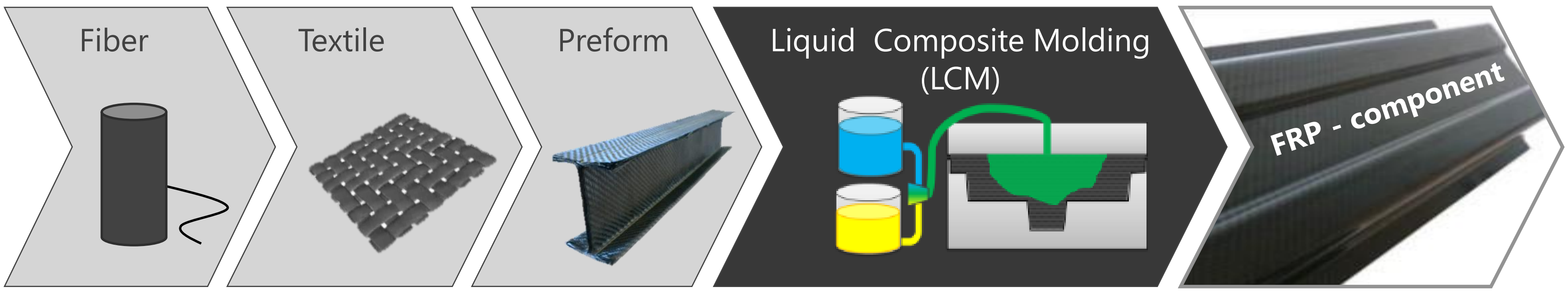
Math2Market GmbH: **A. Widera**, M. Hümbert

Institut für Verbundwerkstoffe: T. Schmidt, D. May

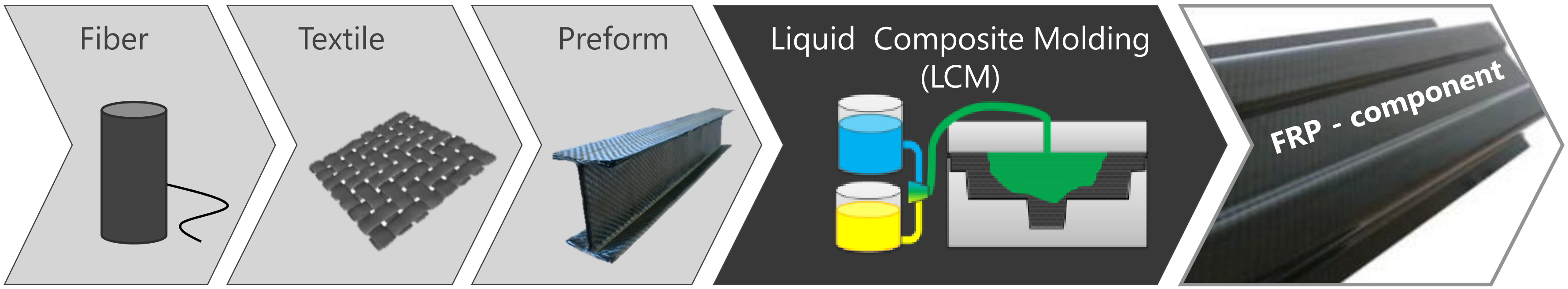
MATH
2 MARKET

Outline

Liquid Composite Molding – Process Chain



Liquid Composite Molding – Process Chain



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

Automotive

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Aerospace

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

Ship Building

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Energy Industry

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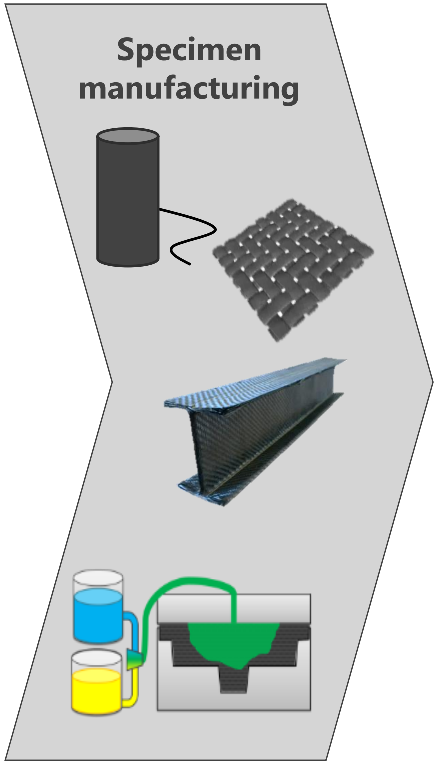
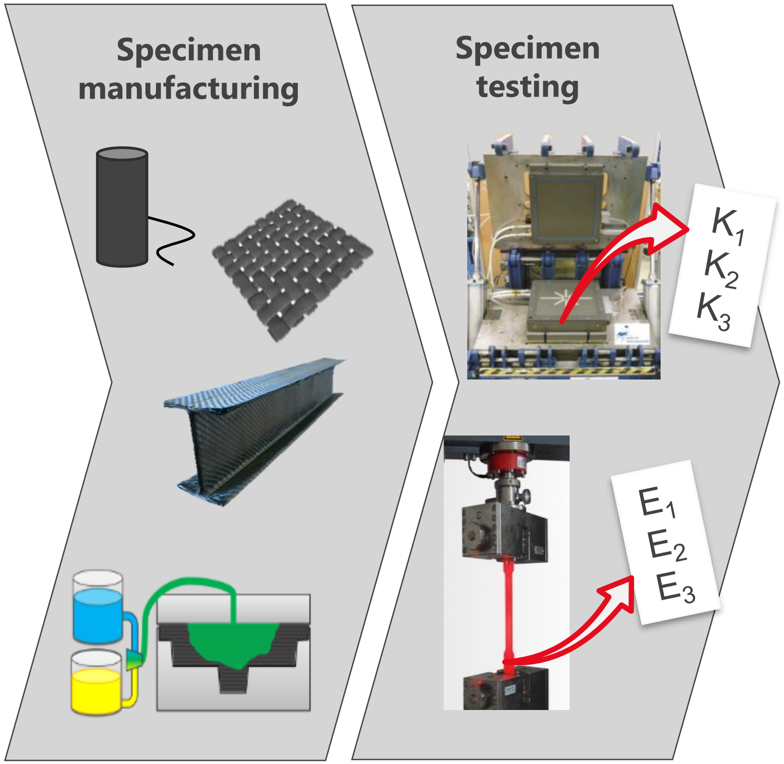
Liquid Composite Molding
Component development



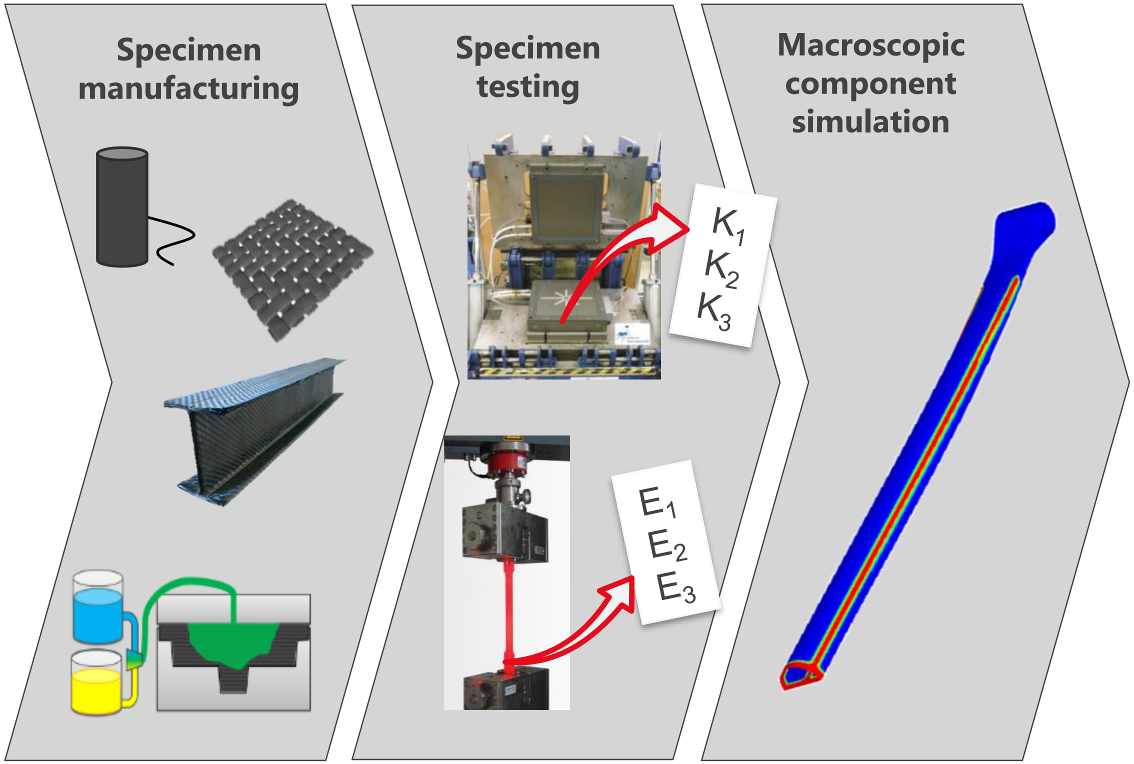
- Start with manufacturing a set of specimen
  - In general, about 5 specimen for statistical variance
- Manufactured in research and development labs

Liquid Composite Molding
Component Development



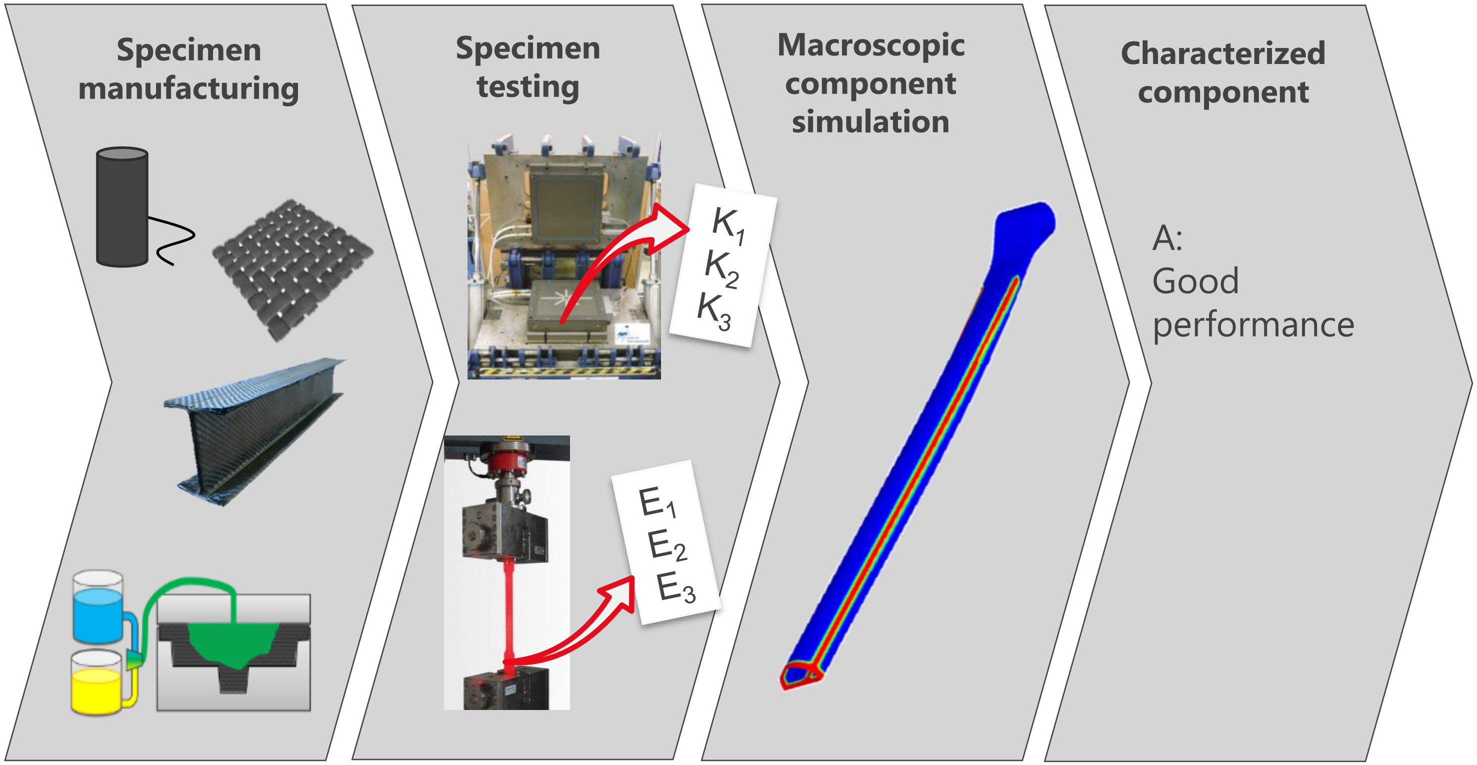
- Conduct laboratory experiments to characterize the specimen
- Determine permeability of the dry textile
  - Gives insight on the impregnability
- Determine mechanical properties

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

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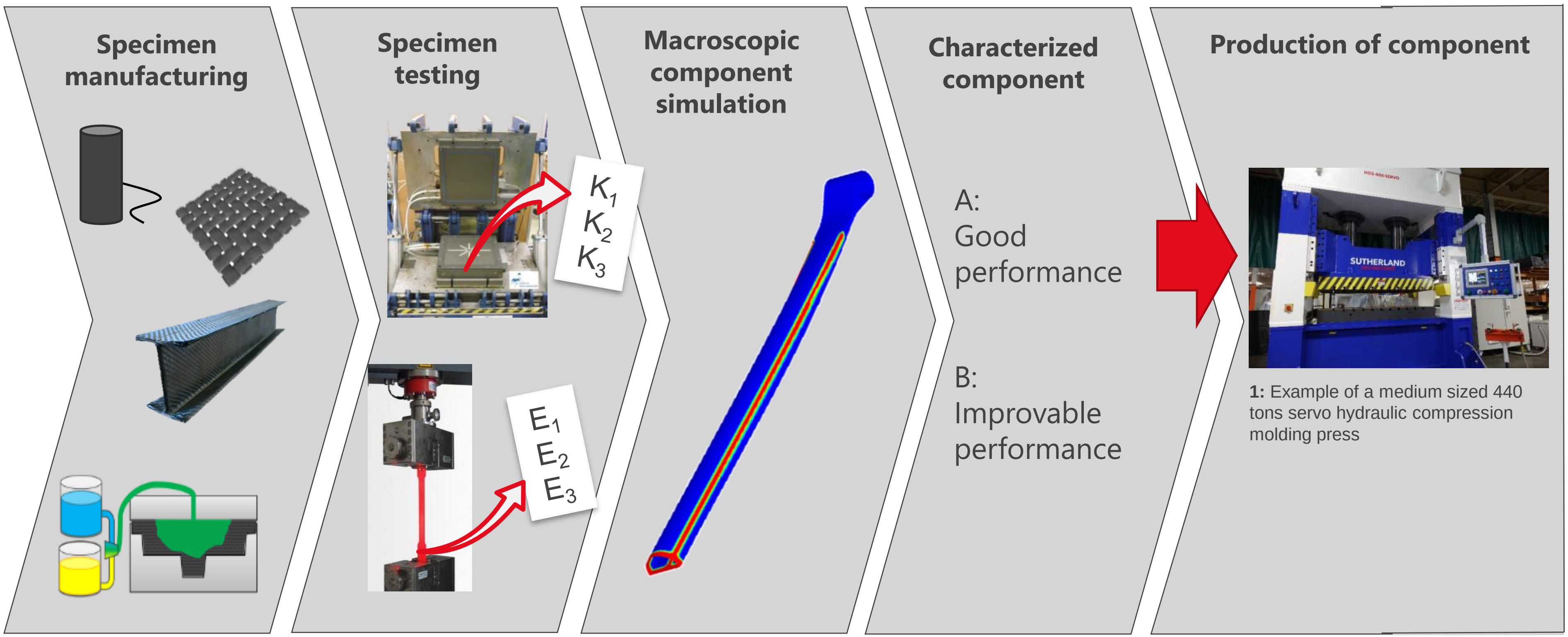

1: Example of a medium sized 440 tons servo hydraulic compression molding press

- 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

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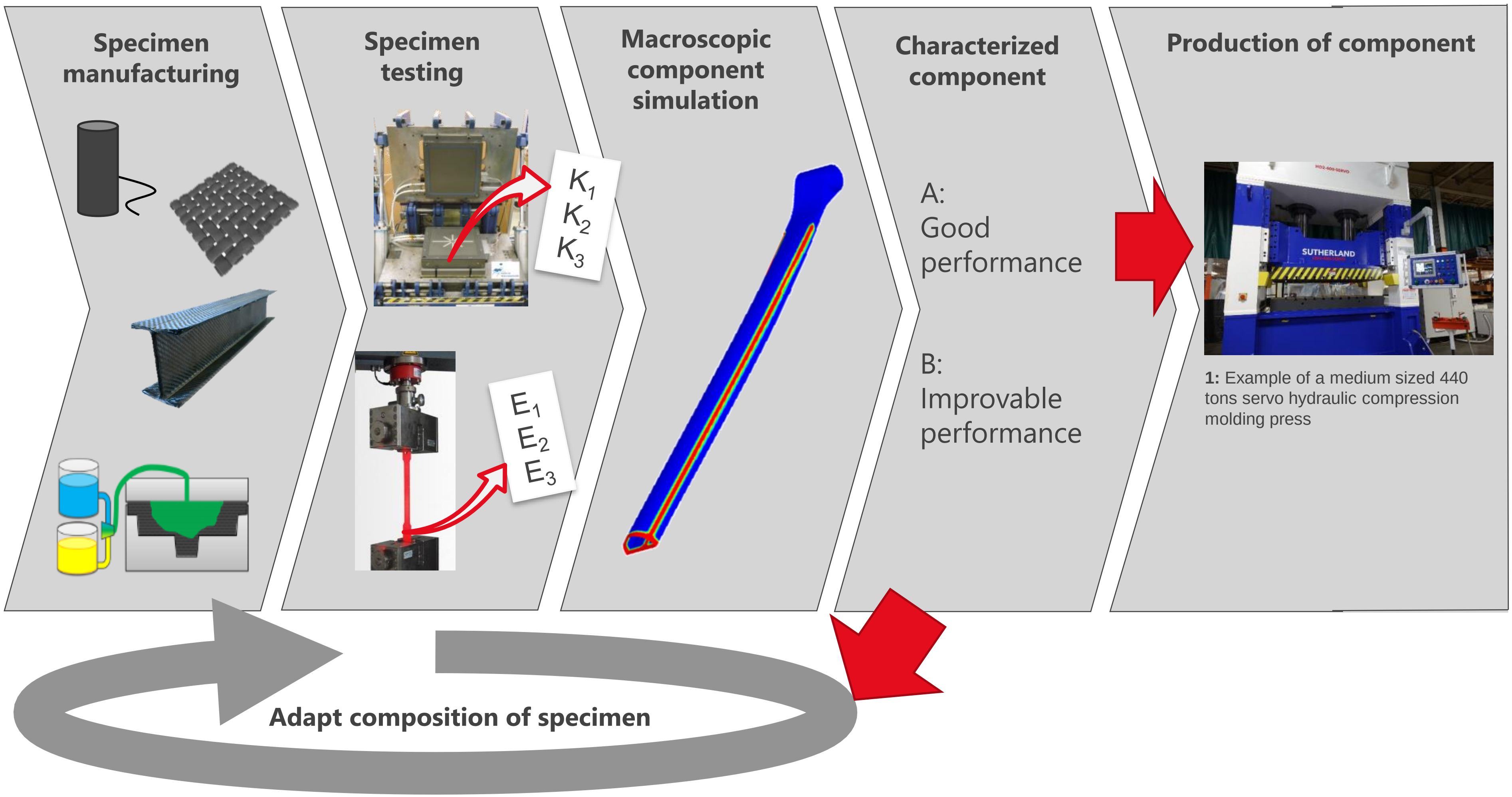
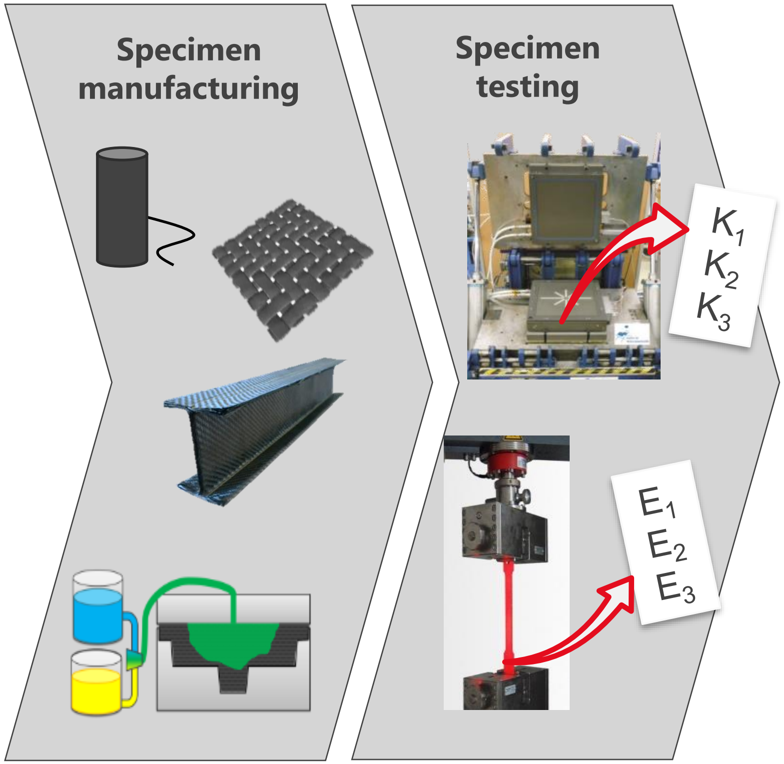
Liquid Composite Molding Component Development



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

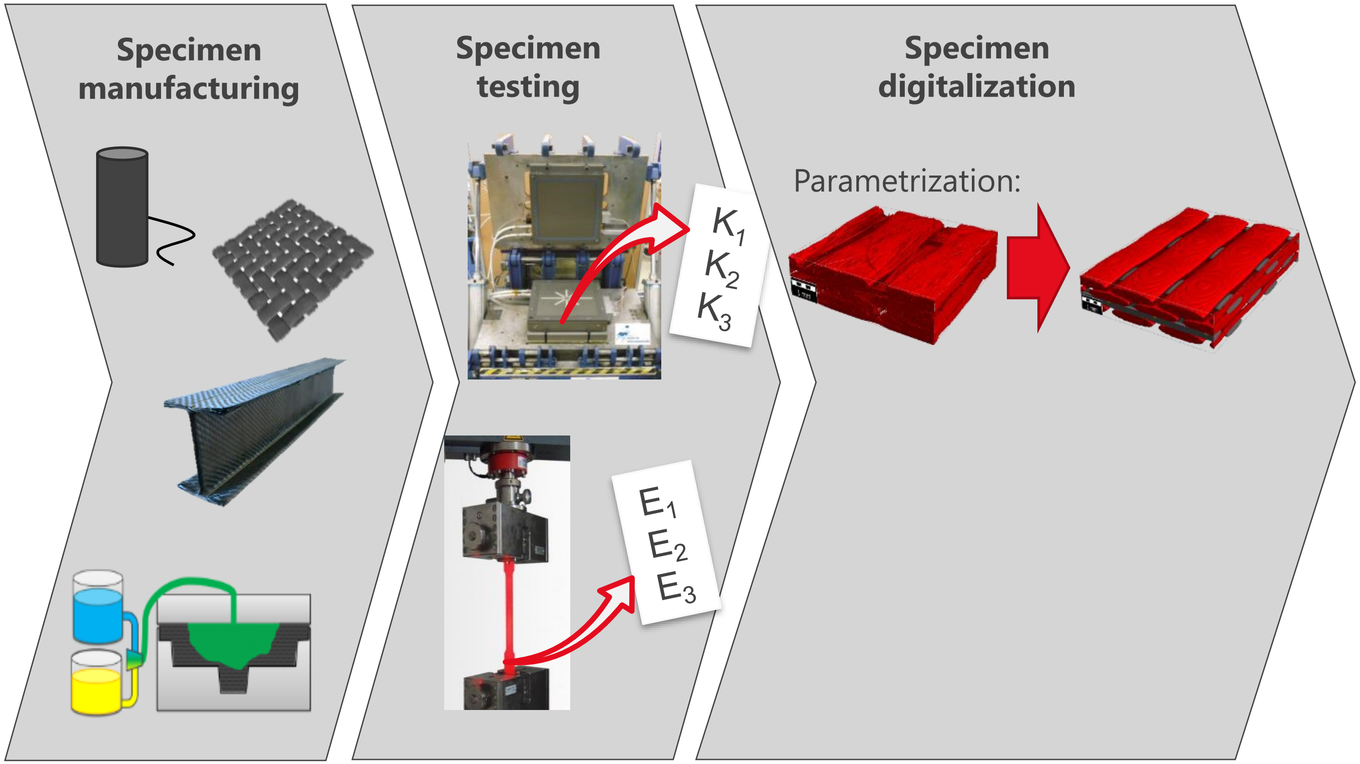
OUTLINE

Research project Math2Composites



- Start again with set of specimen which are characterized

Research project Math2Composites



- Identification of parameters for modeling

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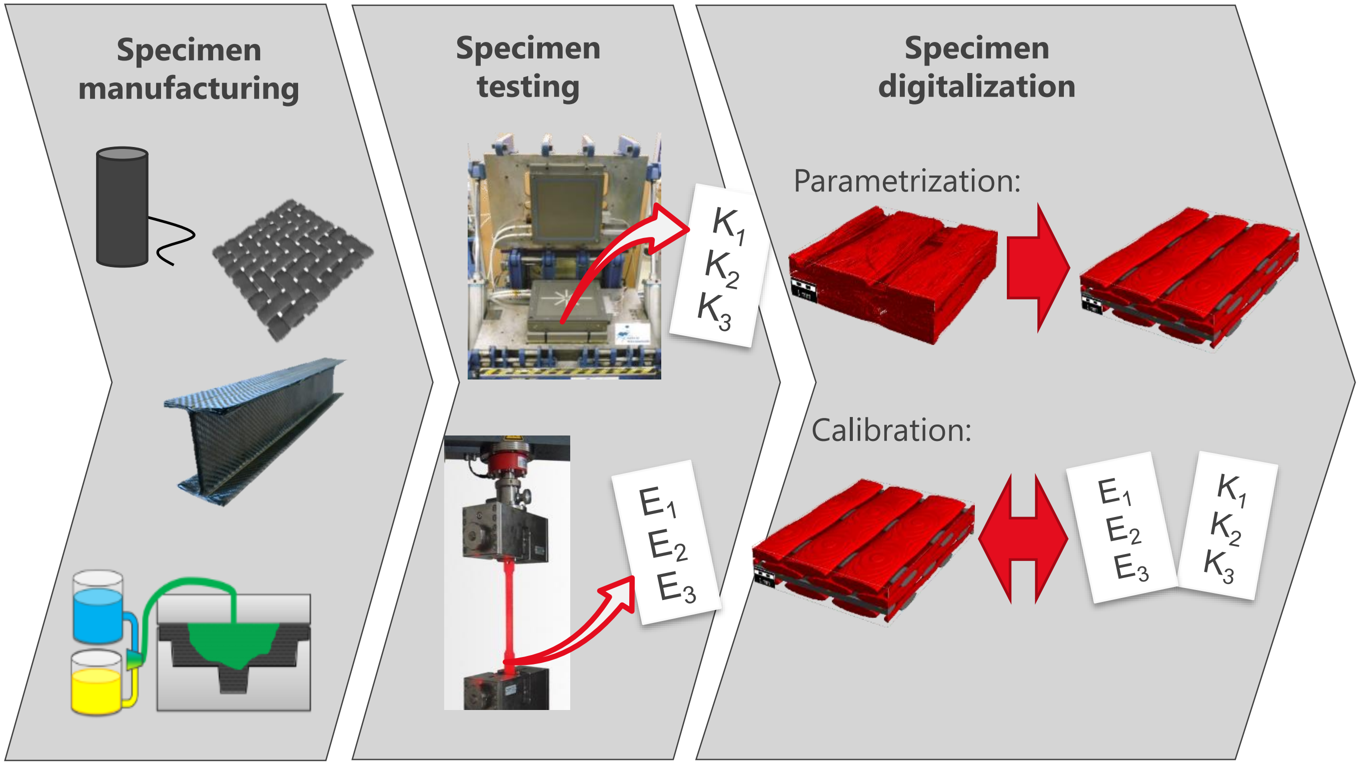

- Selective calibration with experimental data
- Obtain a Digital Twin

MATH 2 MARKET

Research project Math2Composites

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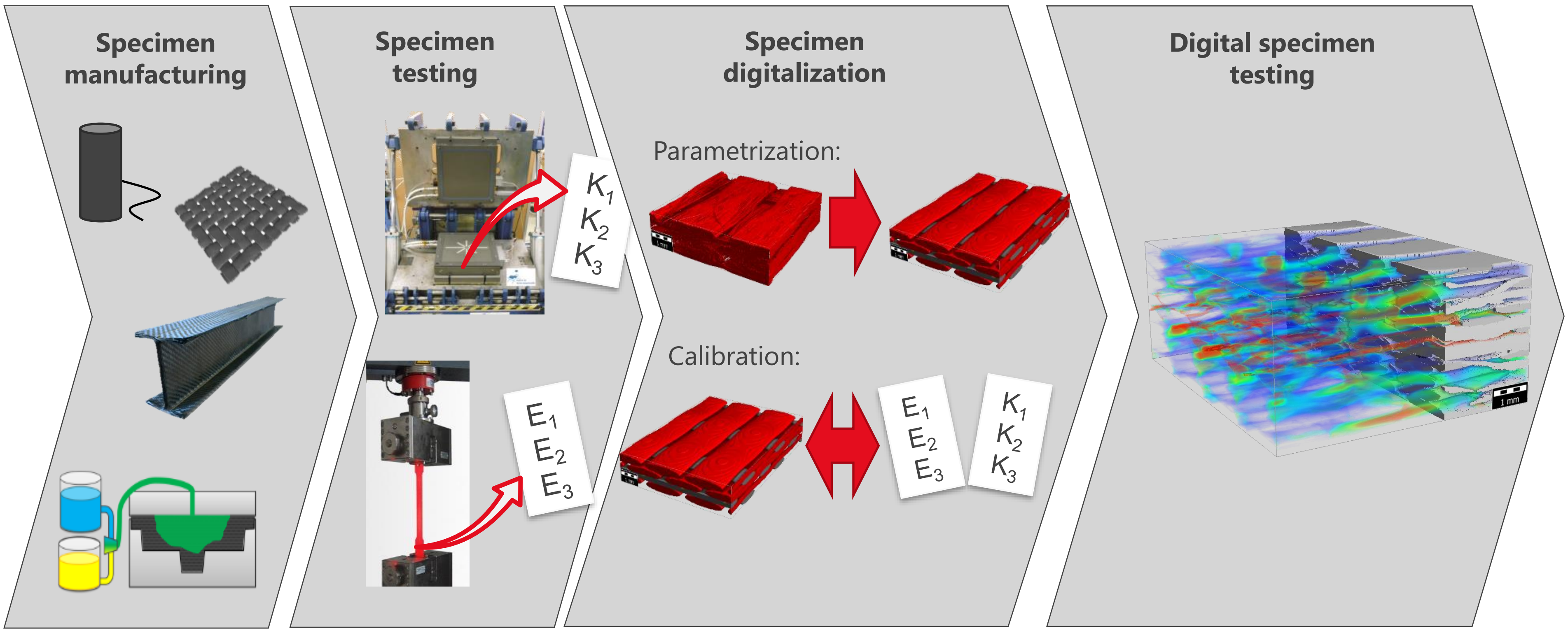
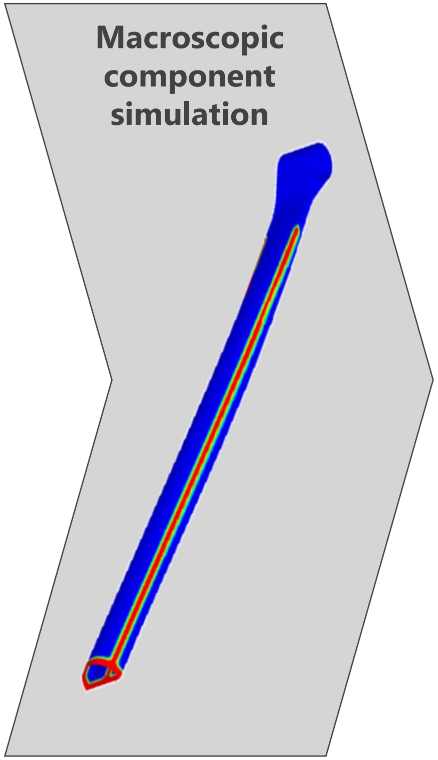
GeoDict



Digital experiments for the characterization of the specimen

MATH 2 MARKET

RESEARCH PROJECT MATH2COMPOSITES



- Use digital characterizations for simulation on macroscopic level

Research project Math2Composites

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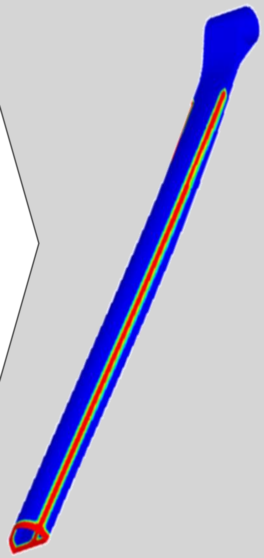
Macroscopic component simulation



Characterized component

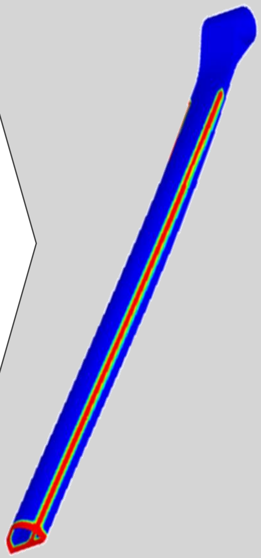
A:
Good performance

- Use digital characterizations for simulation on macroscopic level
- If performance is acceptable go ahead with component production

MATH 2 MARKET

RESEARCH PROJECT MATH2COMPOSITES

Macroscopic component simulation



Characterized component

A:
Good
performance

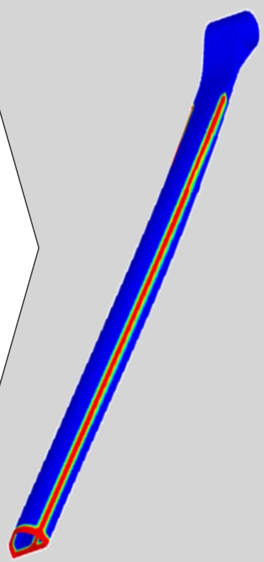
Production of component

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

Research project Math2Composites

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

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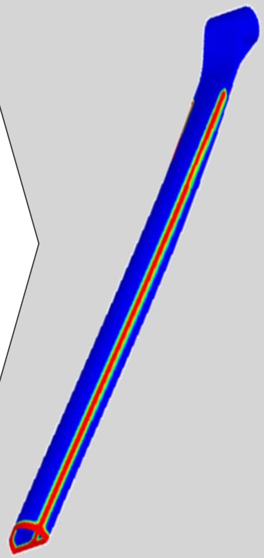
Macroscopic component simulation

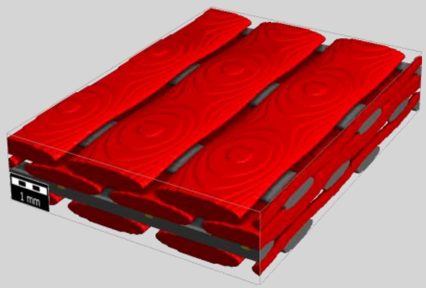


Characterized component

A: Good performance

B: Improvable performance

Digital specimen adaptation



Digital parameter variation

Production of component

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

- Start parameter variation on the digitalized specimen

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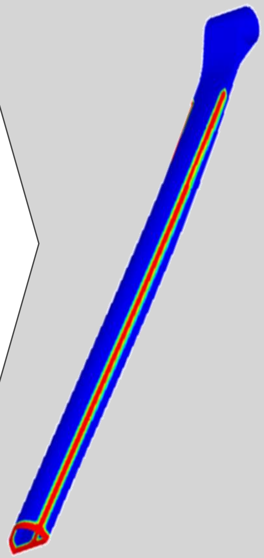
Macroscopic component simulation

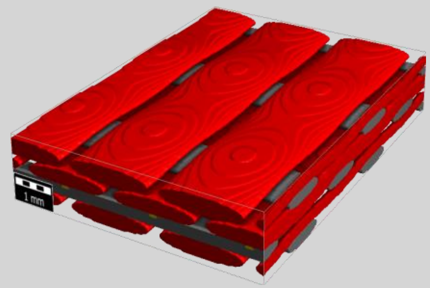


Characterized component

A: Good performance

B: Improvable performance

Digital specimen adaptation



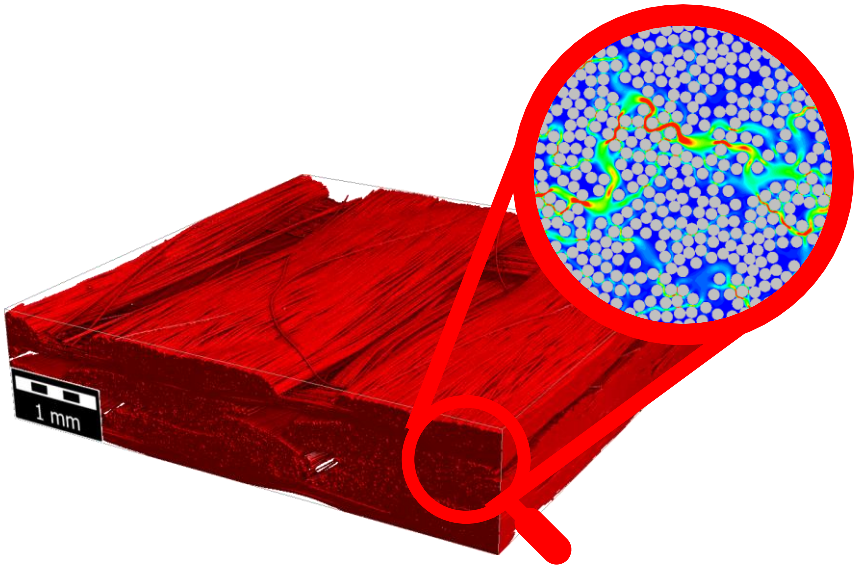
Digital parameter variation

Production of component

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

MATH 2 MARKET

SINGLE FILAMENT SIMULATION APPROACH



CT-scan with 3 µm resolution

1760x1760x385 Voxel

3 longitudinal and transversal rovings and 4 layers

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

Results in very large structure (about 4000 x 4000 x 900 voxel), thus, meaning long simulation runtimes

Math2Composites multiscale approach

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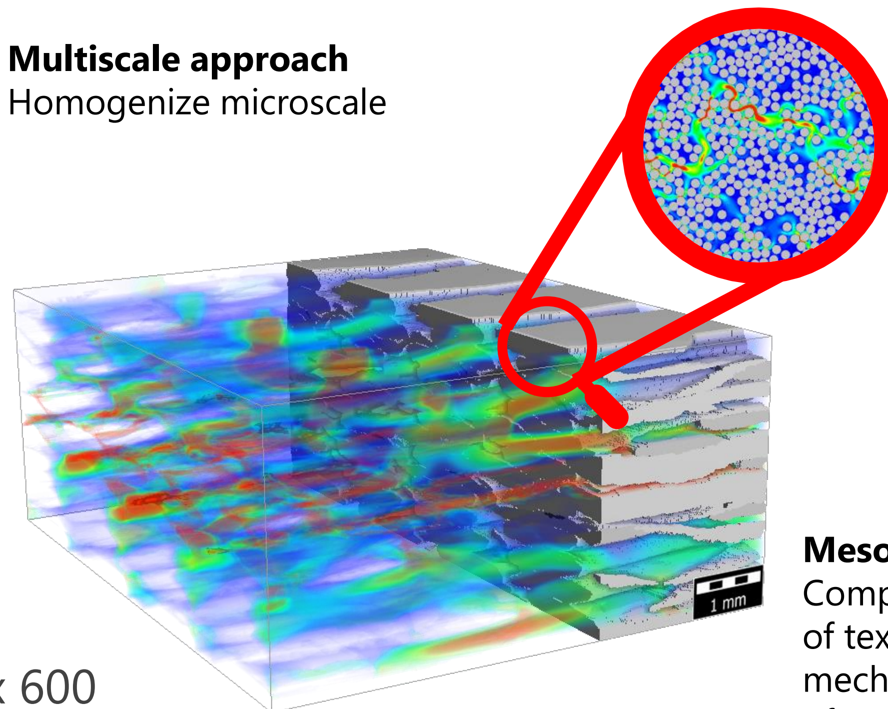
Therefore, use multiscale approach:

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

Multiscale approach
Homogenize microscale



Microscale:
Compute permeability and mechanical behavior

Mesoscale:
Compute permeability of textile and mechanical properties of cured component

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

With 5 longitudinal and transversal rovings and 8 layers

MATH 2 MARKET

OUTLINE

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MATH 2 MARKET

DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION

Sources for parameter selection

Data sheet

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

DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION

Sources for parameter selection

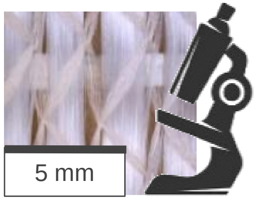
Data sheet

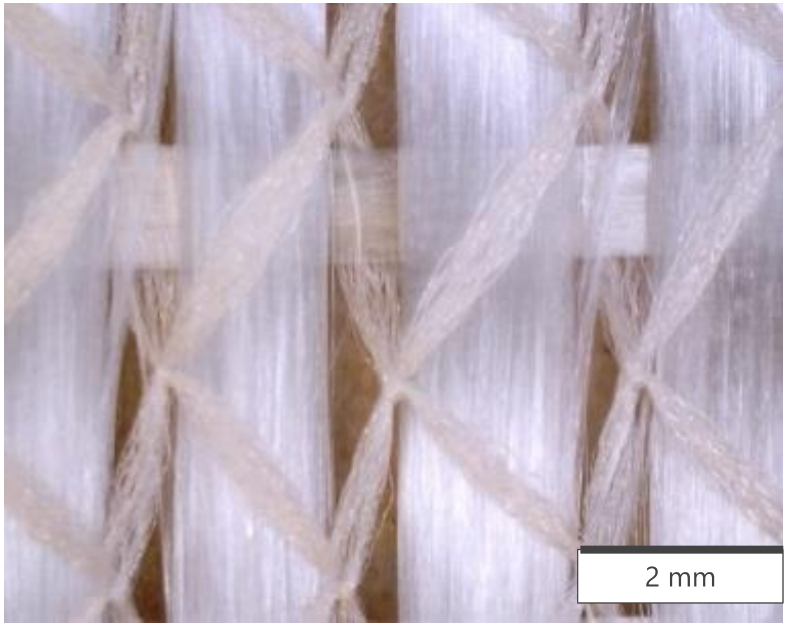
Digitalization of the specimen: Parametrization

Sources for parameter selection

Data sheet

Microscopy





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

Digitalization of the specimen: Parametrization

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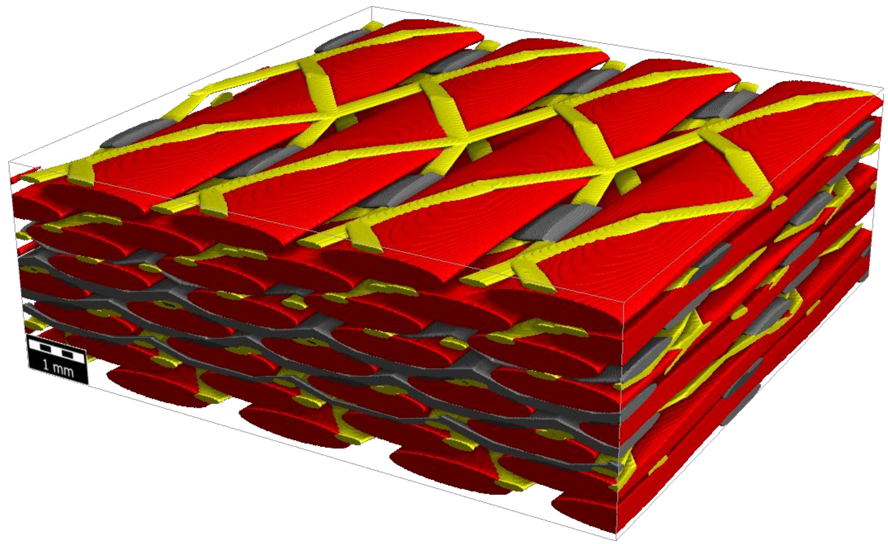
GeoDict

Sources for parameter selection



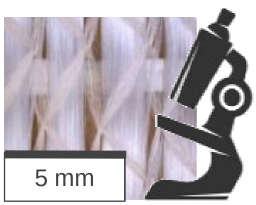
MATH 2 MARKET

DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION

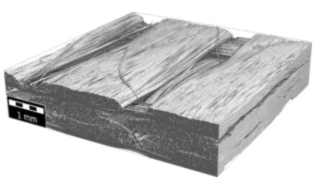
Sources for parameter selection

Data sheet

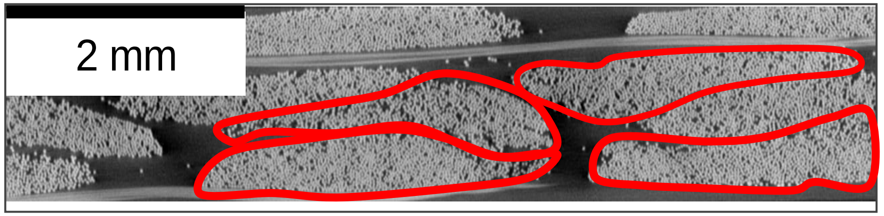
Microscopy



CT scan



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



µCT scan

DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION

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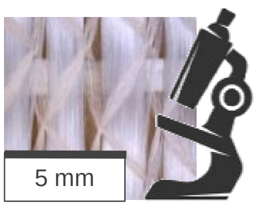
GEODICT

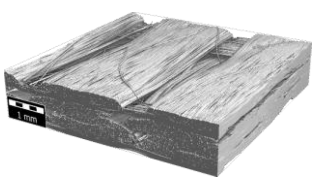
Sources for parameter selection

Data sheet

Microscopy



CT scan



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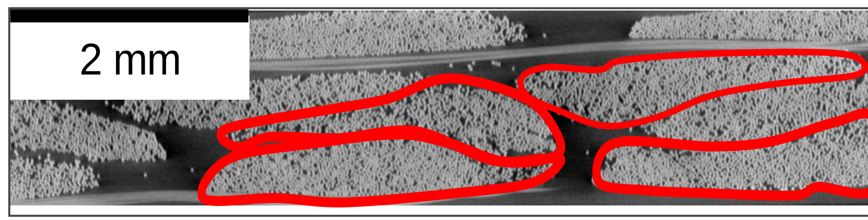

µCT scan

Digital model

MATH 2 MARKET

DIGITALIZATION OF THE SPECIMEN: PARAMETRIZATION

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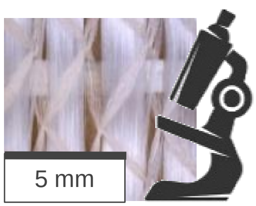
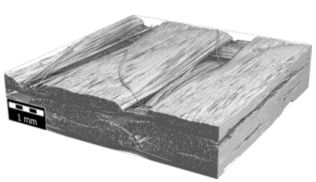
GEODICT

Sources for parameter selection

Microscopy



CT scan



Identified parameters

Data sheet:

- Tex rovings
- Dimension of the rovings
- Dimension of stitching
- Diameter

Microscopy:

- Spacing of the rovings
- Ondulation of the Rovings

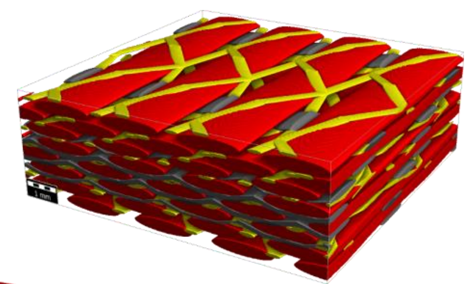
CT scan:

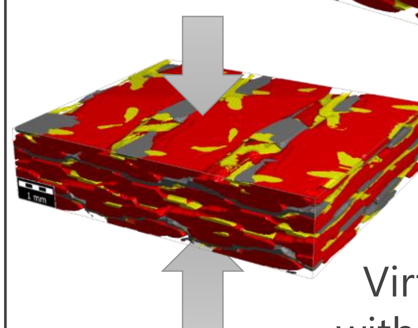
- Fibre volume content
- Number of layers
- Roving cross-sectional shape
- Random stacking of the layers
- Thickness of the sample

Different complexities can be represented in the modeling

Rovings

Rovings with stitching



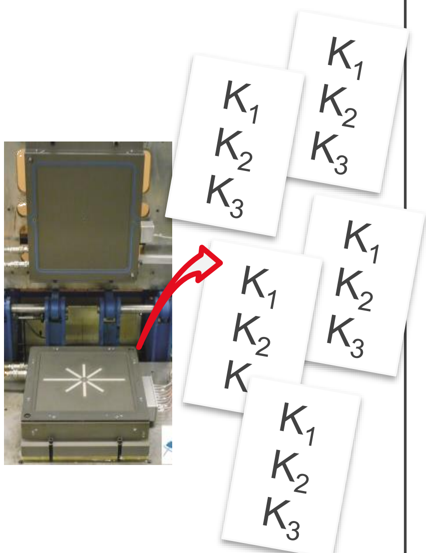


Virtual compaction with mechanics solver

MATH 2 MARKET

Digitalization of the specimen: Calibration

Measurement of 5 different specimens



DIGITALIZATION OF THE SPECIMEN: CALIBRATION

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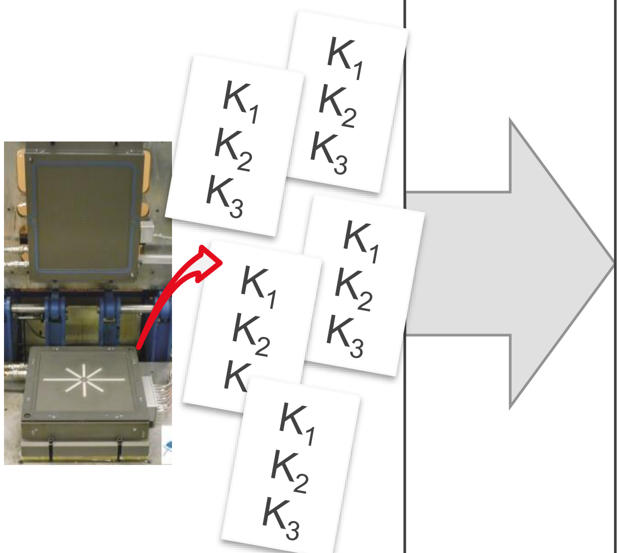
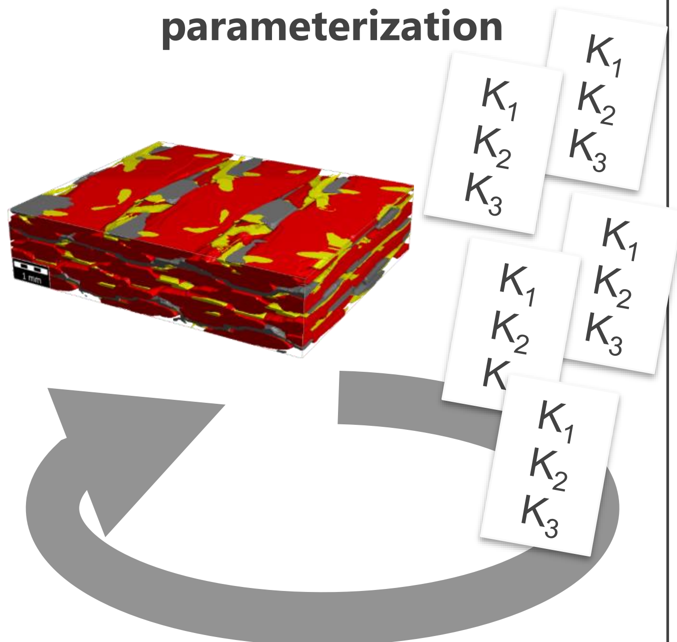
GEODICT

Measurement of 5 different specimens

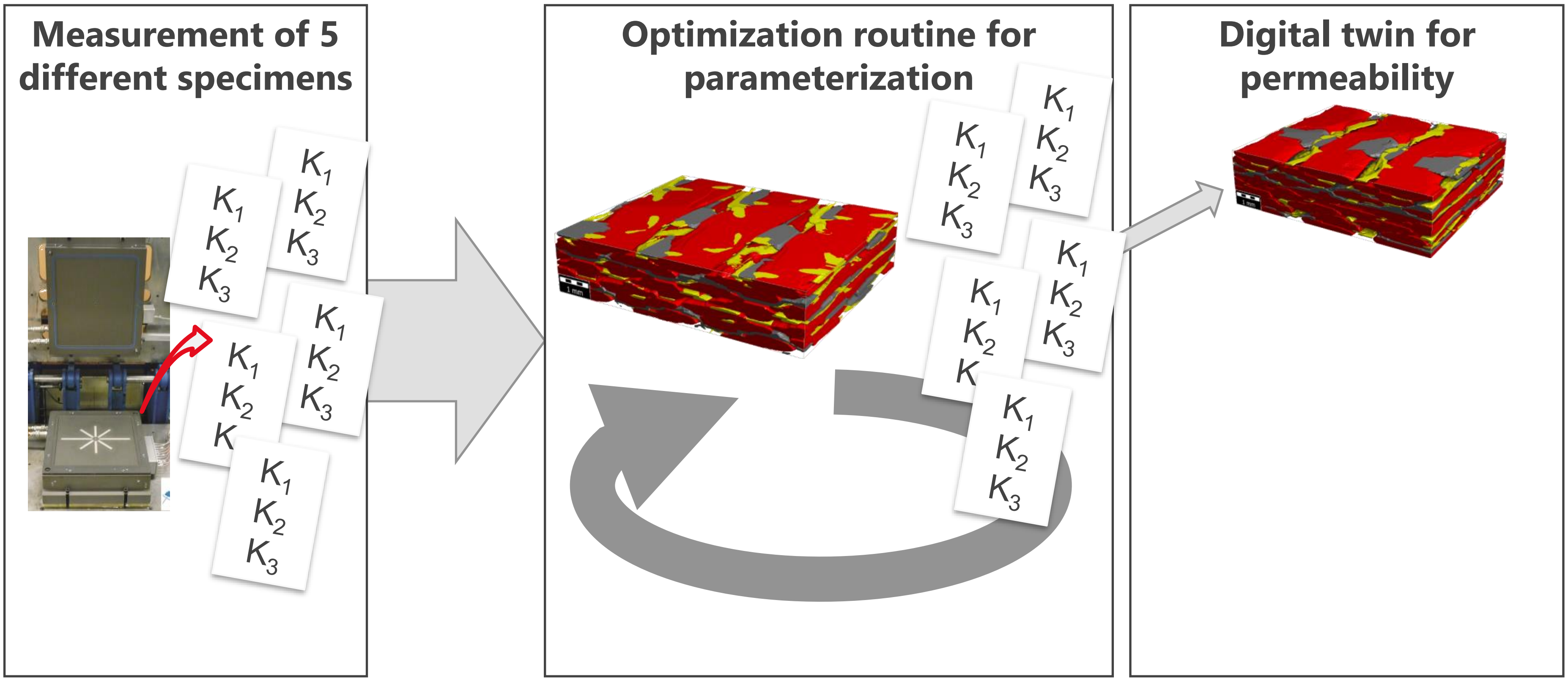


Optimization routine for parameterization



MATH 2 MARKET

DIGITALIZATION OF THE SPECIMEN: CALIBRATION

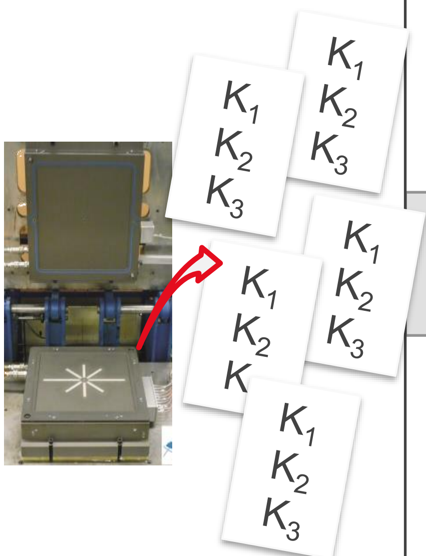


DIGITALIZATION OF THE SPECIMEN: CALIBRATION

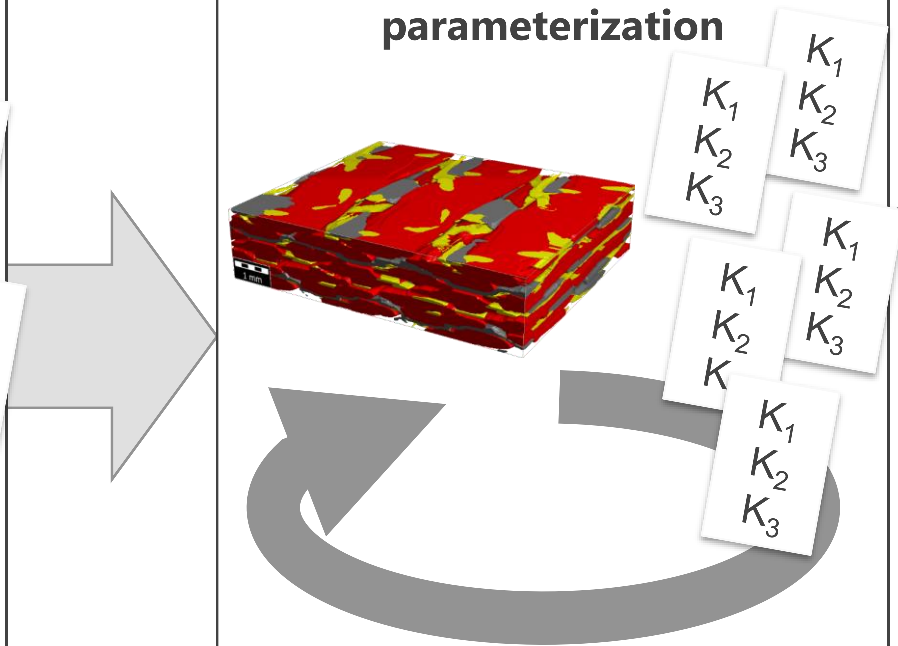
Institut für Verbundwerkstoffe

GEODICT

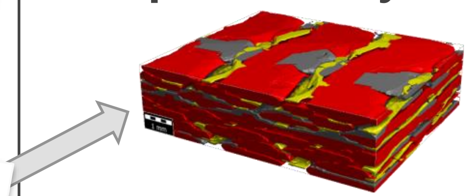
Measurement of 5 different specimens



Optimization routine for parameterization



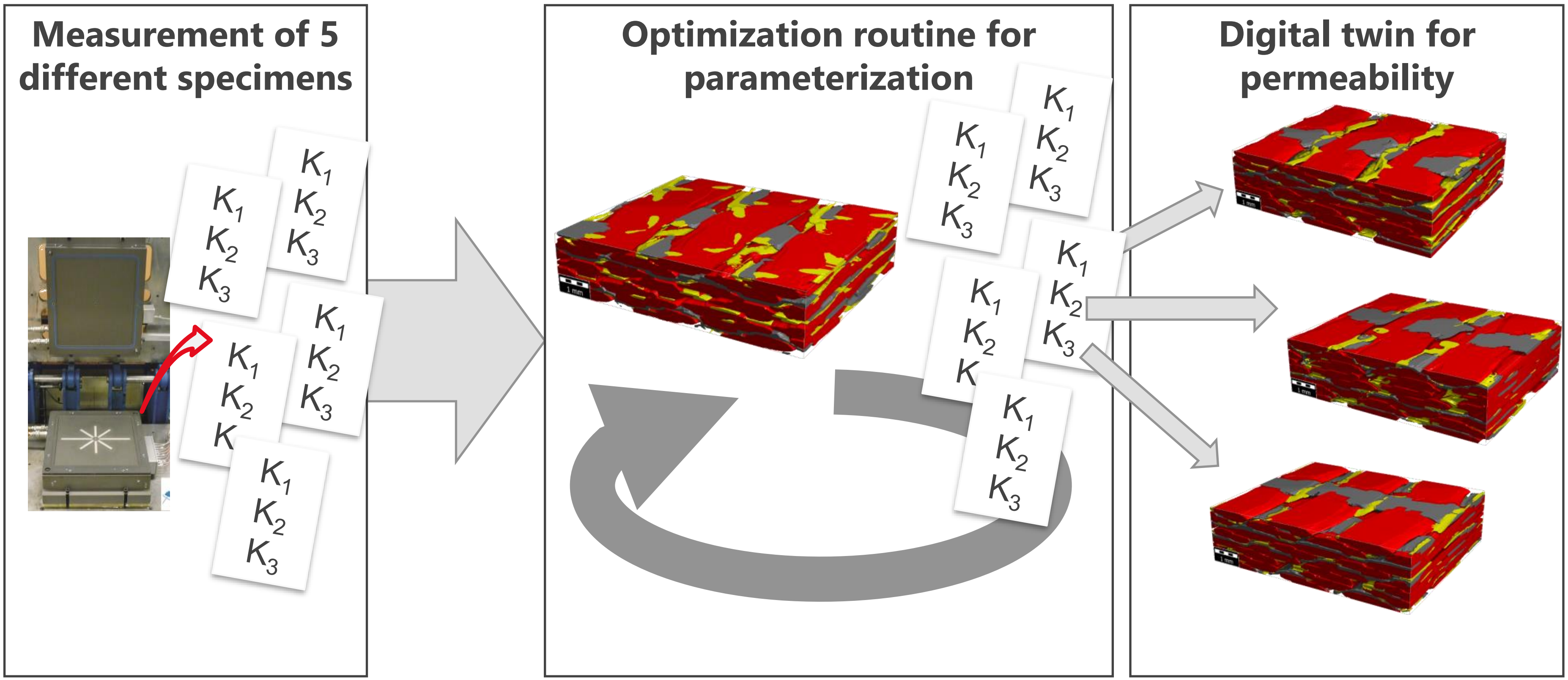
Digital twin for permeability



- Same statistical properties
- Other random seeds

MATH 2 MARKET

Digitalization of the specimen: Calibration



Digitalization of the Specimen: Calibration at 50% FVC

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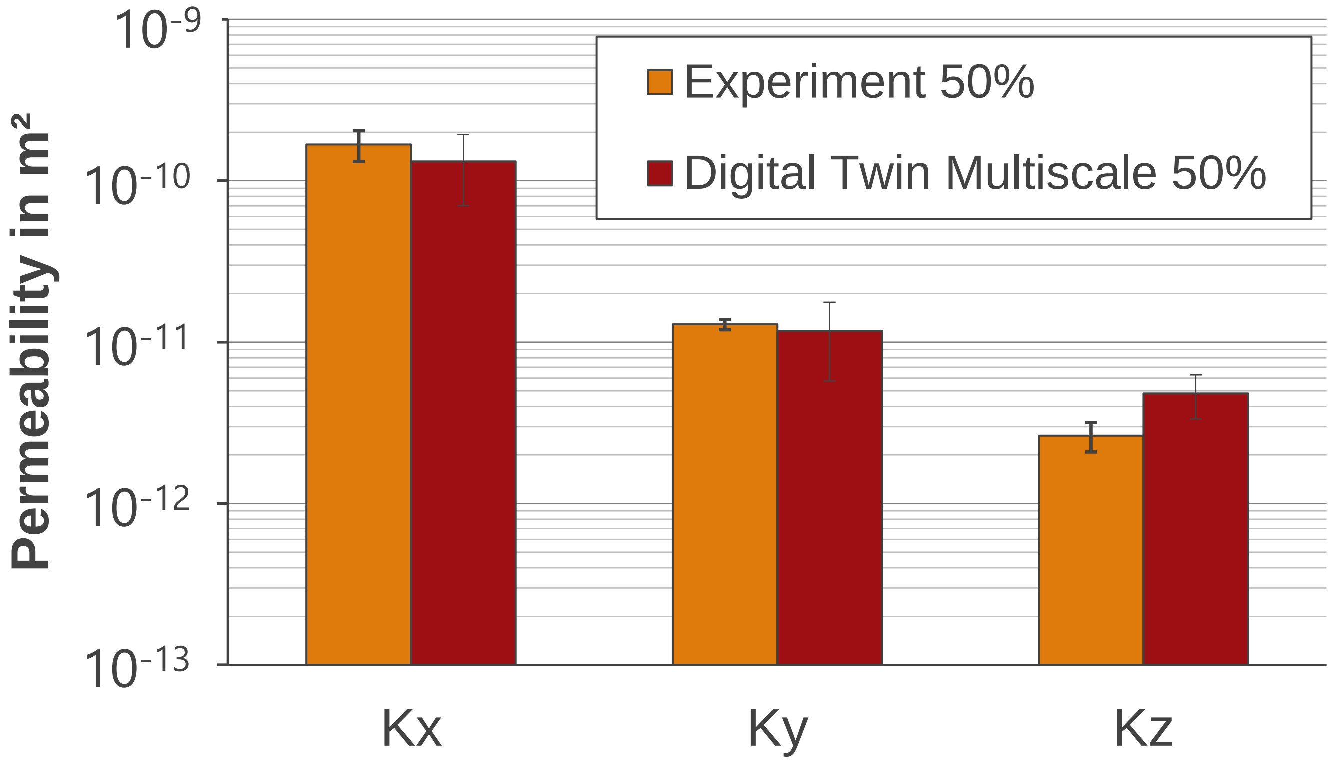
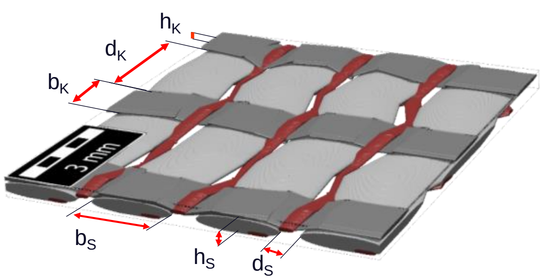
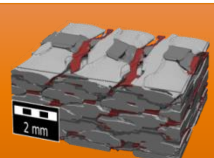
GeoDict



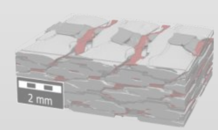
Successive adaption of geometrical parameters of woven fabric prior to compaction



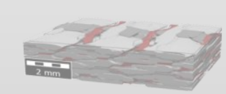
Calibration (50% FVC)



Validation (55% FVC)



Validation (60% FVC)



MATH 2 MARKET

DIGITALIZATION OF THE SPECIMEN: VALIDATION AT 55% FVC

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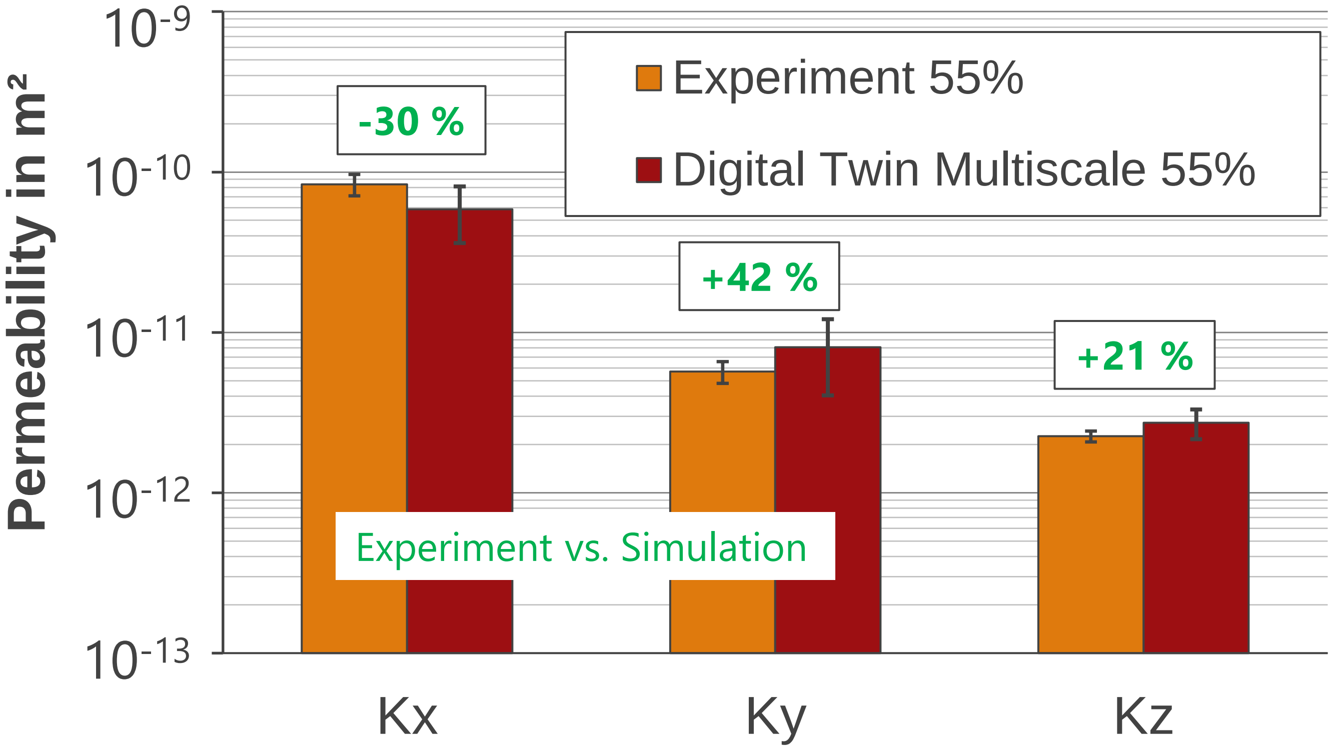
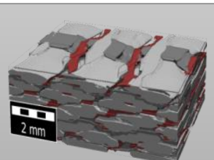
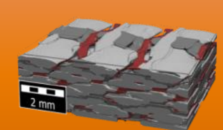
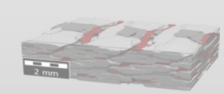
GEODICT

Extrapolation to 55% FVC and comparison with experimental results



Calibration (50% FVC)  → Validation (55% FVC)  → Validation (60% FVC) 

➤ Successful transfer and validation of the calibrated model to 55% FVC

MATH 2 MARKET

DIGITALIZATION OF THE SPECIMEN: VALIDATION AT 60% FVC

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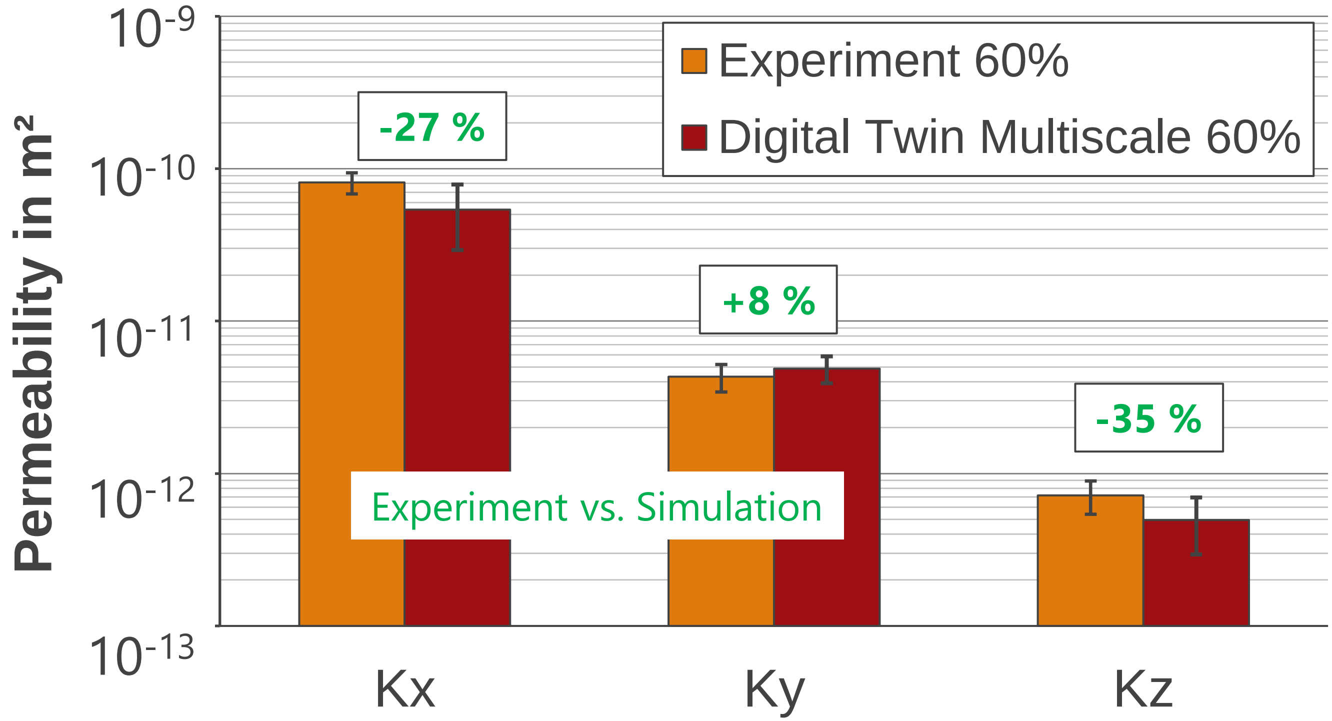
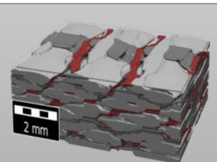
GEODICT

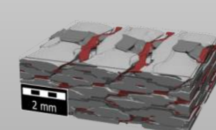
Extrapolation to 60% FVC and comparison with experimental results



Calibration (50% FVC)



Validation (55% FVC)



Validation (60% FVC)

➢ Successful transfer and validation of the calibrated model to 60% FVC

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OUTLINE

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EFFICIENCY OF EXPERIMENTAL COMPONENT DEVELOPMENT

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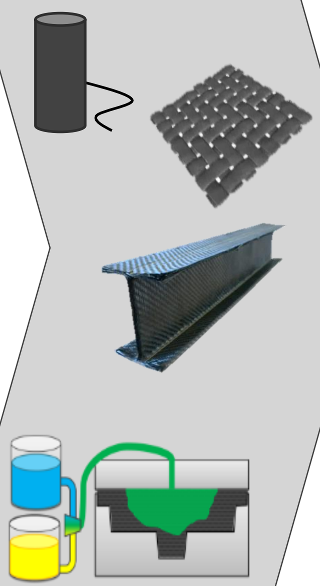
Specimen manufacturing



Manufacturing of 5 specimen to ensure statistical variance

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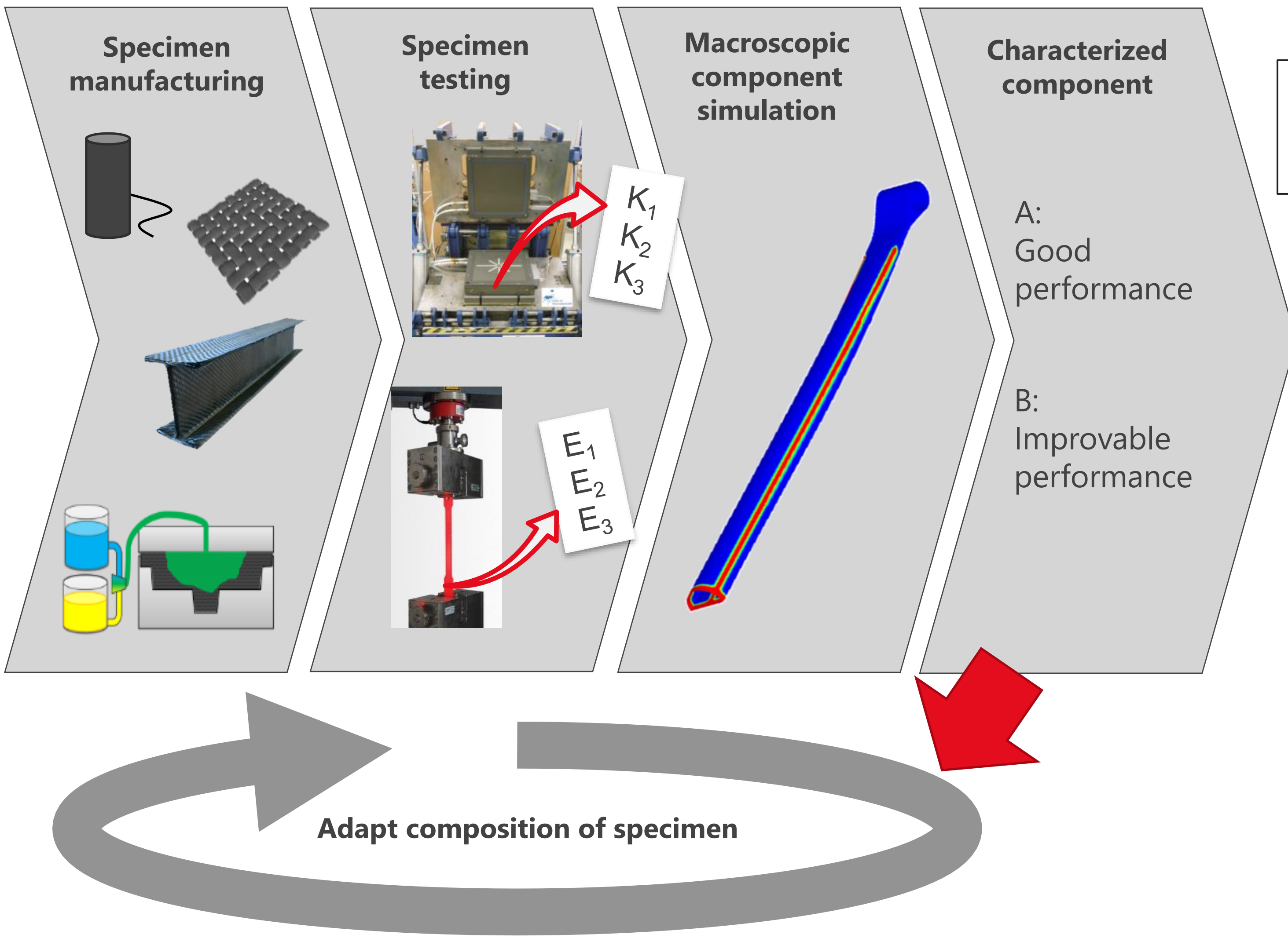
Efficiency of experimental component development



About 5 iterations until A occurs

EFFICIENCY OF EXPERIMENTAL COMPONENT DEVELOPMENT

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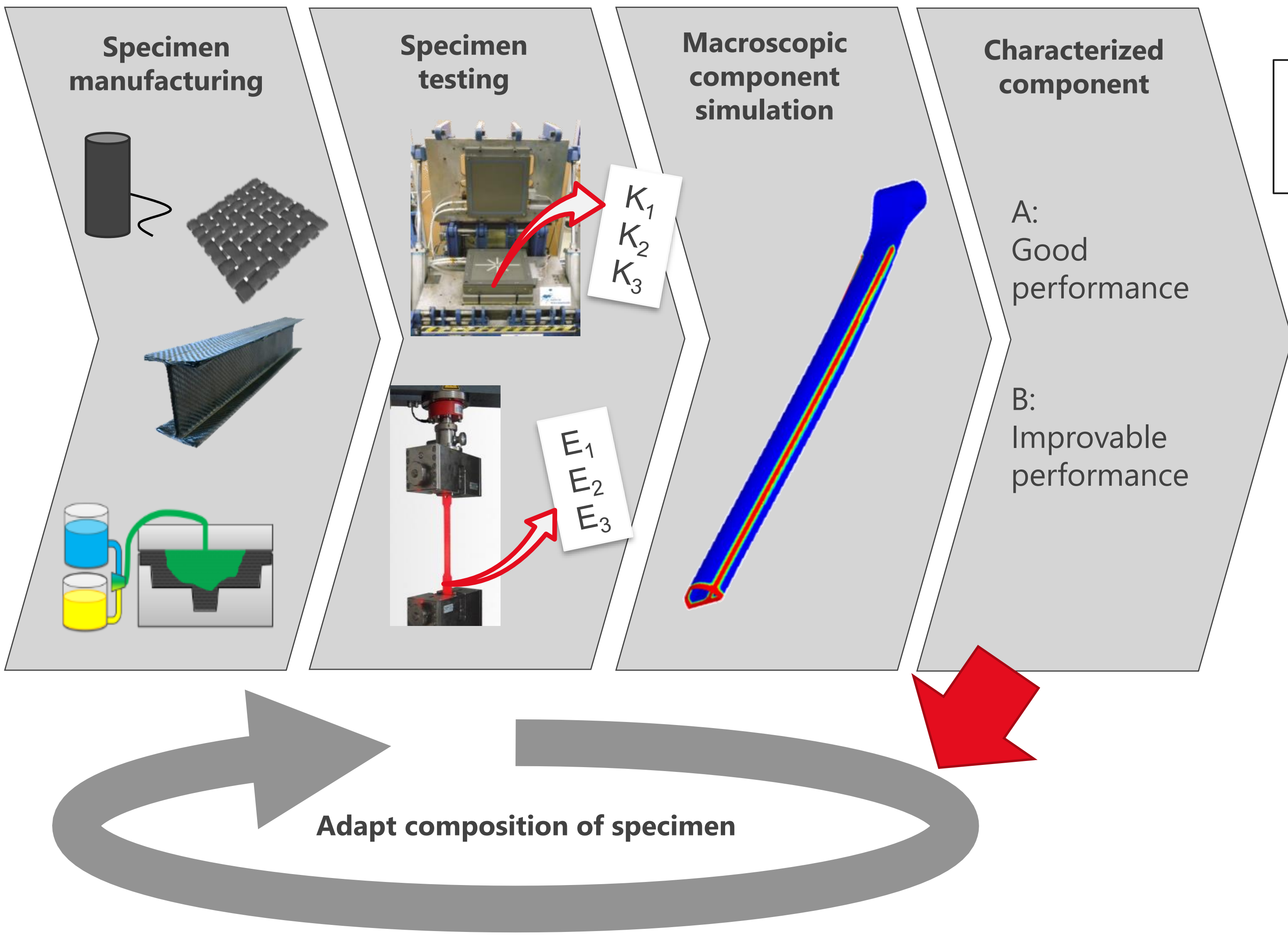

About 5 iterations until A occurs

Total number of specimen
25

Number of evaluated parameter sets
5

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EFFICIENCY OF SIMULATION-AIDED COMPONENT DEVELOPMENT

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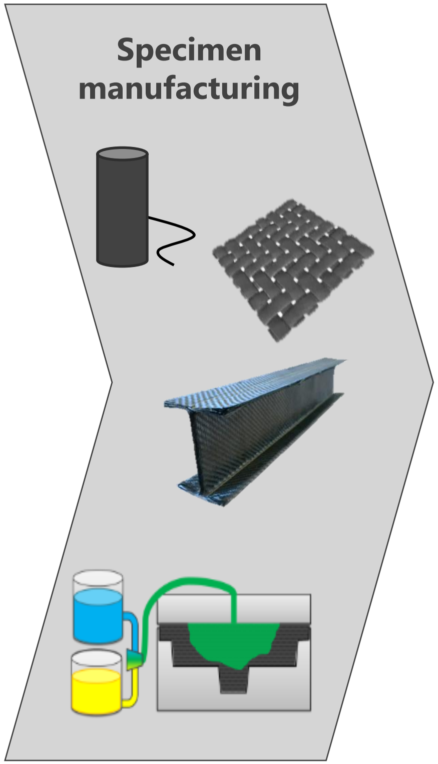

Manufacturing of 5 specimen to ensure statistical variance

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EFFICIENCY OF SIMULATION-AIDED COMPONENT DEVELOPMENT

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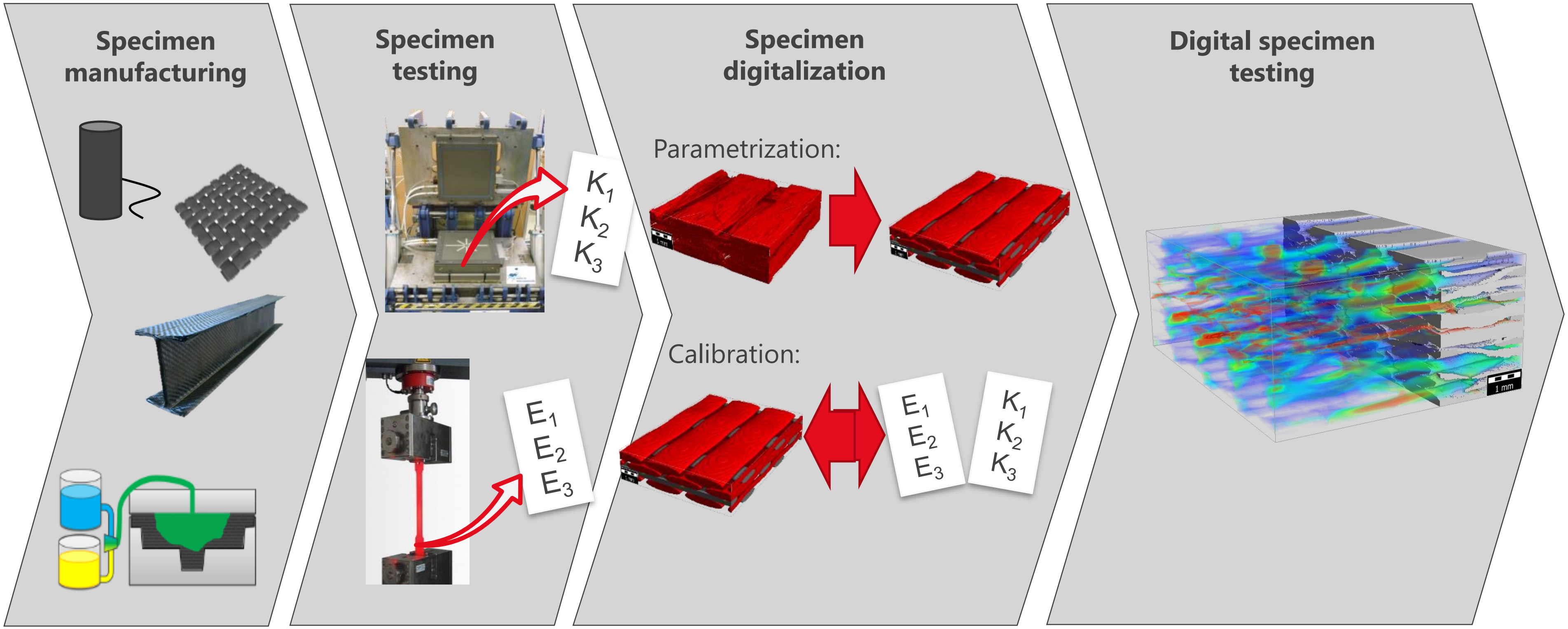

5 specimen needed for digitalization

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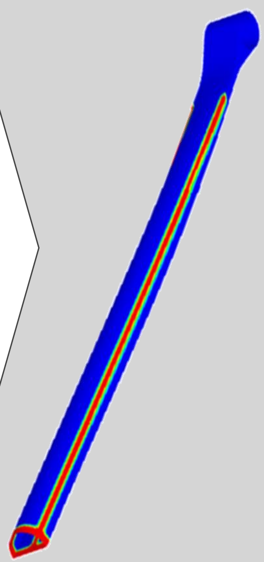
EFFICIENCY OF SIMULATION-AIDED COMPONENT DEVELOPMENT

Macroscopic component simulation

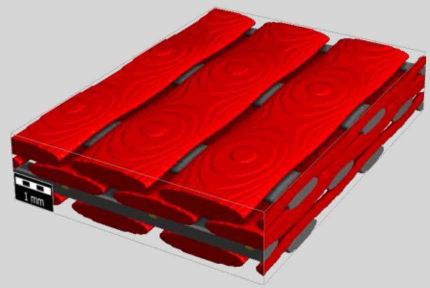


Characterized component

A:
Good
performance

B:
Improvable
performance

Digital specimen adaptation



Digital parameter
variation

About 15 parameter variations.
Validation of each 3rd

EFFICIENCY OF SIMULATION-AIDED COMPONENT DEVELOPMENT

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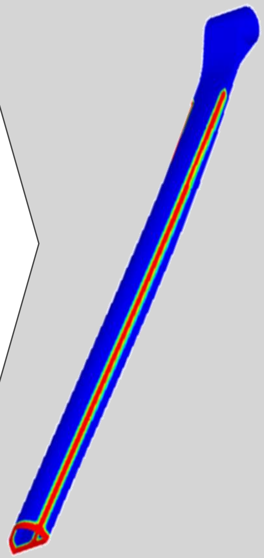
Macroscopic component simulation

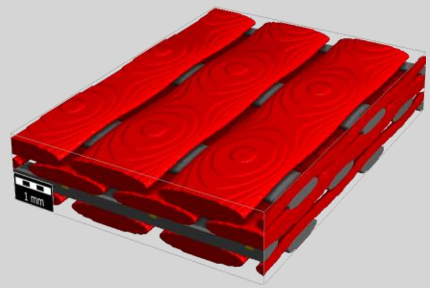


Characterized component

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

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EFFICIENCY OF SIMULATION-AIDED COMPONENT DEVELOPMENT

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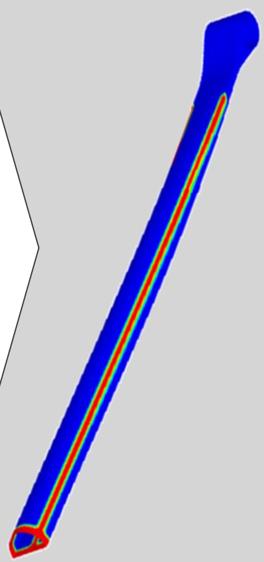
Macroscopic component simulation

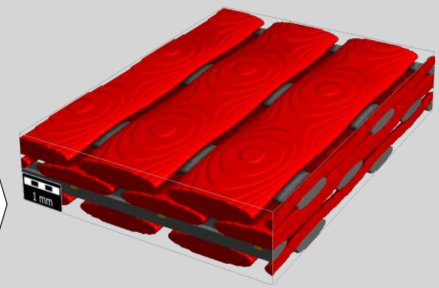


Characterized component

A:
Good performance

B:
Improvable performance

Digital specimen adaptation



Digital parameter variation

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

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COMPARISON: EXPERIMENTAL VS. SIMULATION-AIDED DEVELOPMENT

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Solely experimental development	Simulation-aided development
Total number of specimen **25**	**Total number of specimen** **10**
Number of evaluated parameter sets **5**	**Number of evaluated parameter sets** **15**

Reduce number of manufactured specimen by **50% and less**

Increase number of evaluated parameter sets by **factor 3**

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Math2Composites Acknowledgment

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Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

ZIM

Zentrales Innovationsprogramm Mittelstand

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Thank You For Your Attention!

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