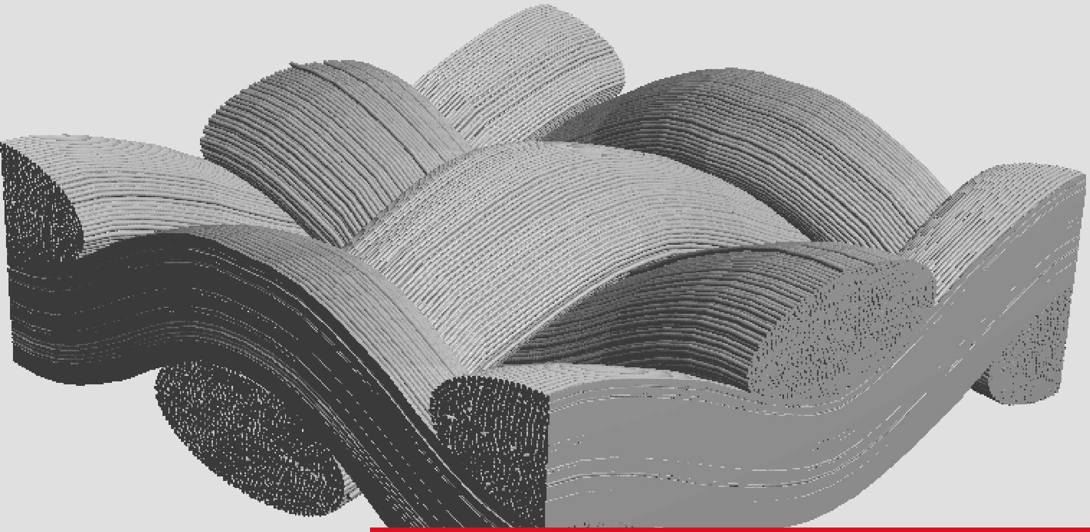


GeoDict
The Digital Material Laboratory

Innovative development of composite materials using GeoDict

22. Symposium „Verbundwerkstoffe und Werkstoffverbunde"

Martina Hümbert, Aaron Widera, Sebastian Rief, Erik Glatt, Constantin Bauer, Tim Schmidt, Florian Schimmer, Nicole Motsch, David May

MATH 2 MARKET

Benefits of Microstructure Simulation

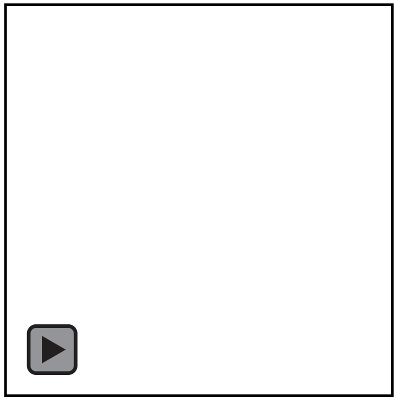
GeoDict

Get unique insights into the material

Micromechanics with plastic deformation and damage

✓ Simulation

✗ Experiment

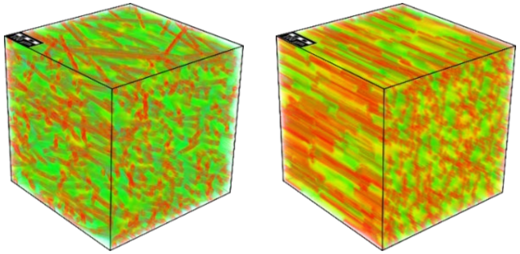


Single parameter studies

E. g. change fiber volume fraction without changing laminate thickness

✓ Simulation

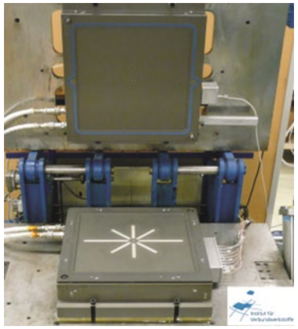
✗ Experiment



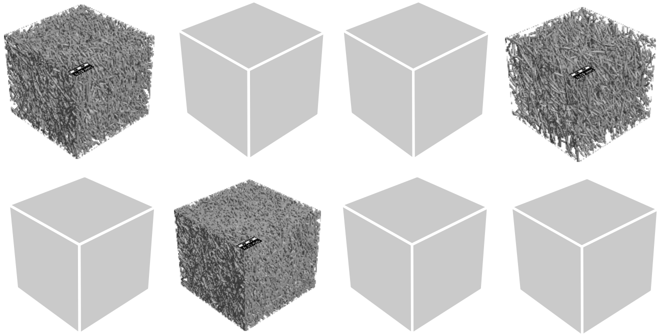
Reduce experimental effort

Replace time consuming experiments

- Predict physical and mechanical properties
- Run parameter studies



Manufacture only the most promising prototypes



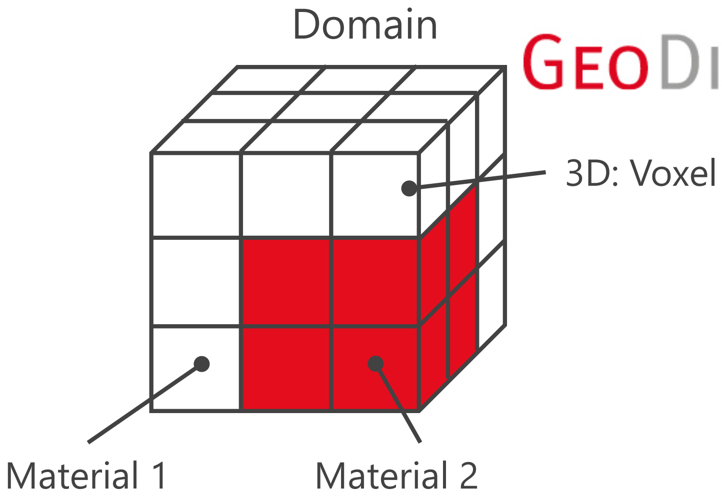
MATH 2 MARKET

OUTLINE

What is Voxel-based FEA?

GeoDict

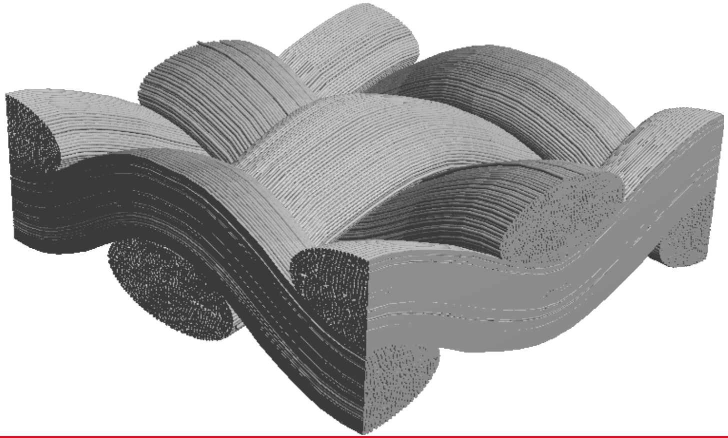
- Structures are composed of voxels instead of elements
- Entire domain consists of voxel grid



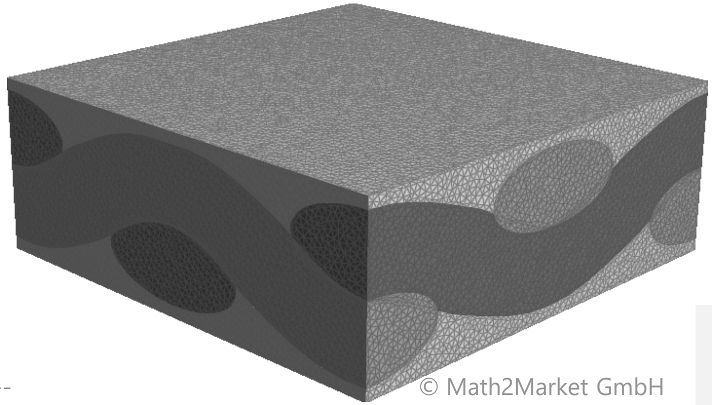
Voxel advantages:

- µCT-voxel is directly converted into microstructure-voxel
- No meshing necessary
- Models > 1 000 000 000 voxels can be solved on standard workstations
- ➢ Delicate structures can be modeled based on voxels

Voxel model - plain weave unit cell with 1000 filaments in each thread

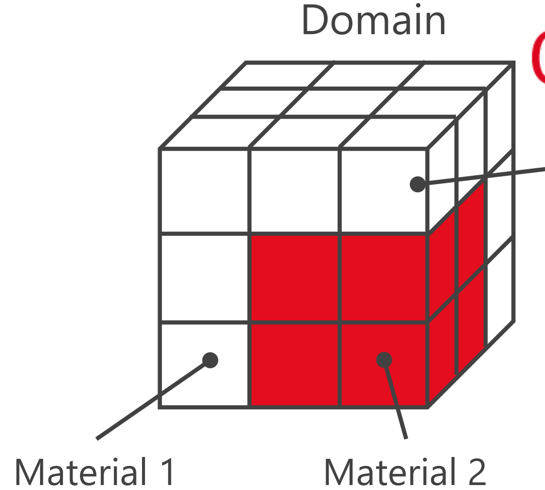


Standard FE model - plain weave unit cell



MATH 2 MARKET

What is Voxel-based FEA?



GeoDict

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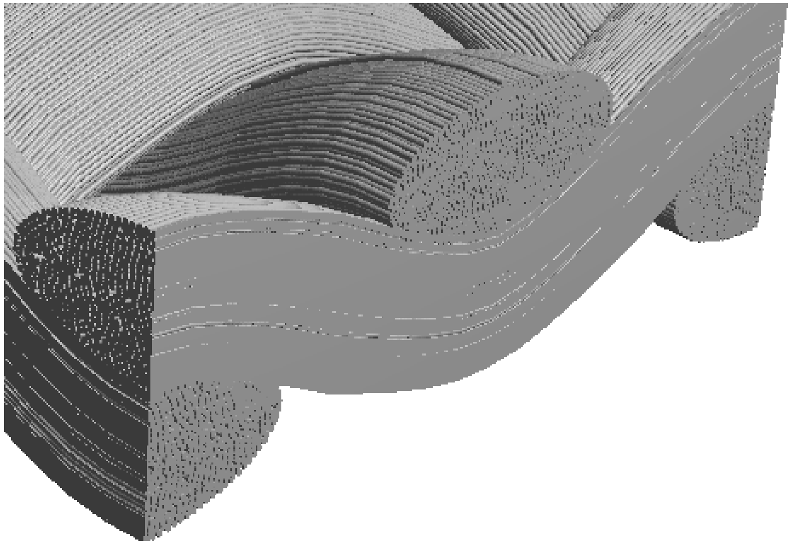
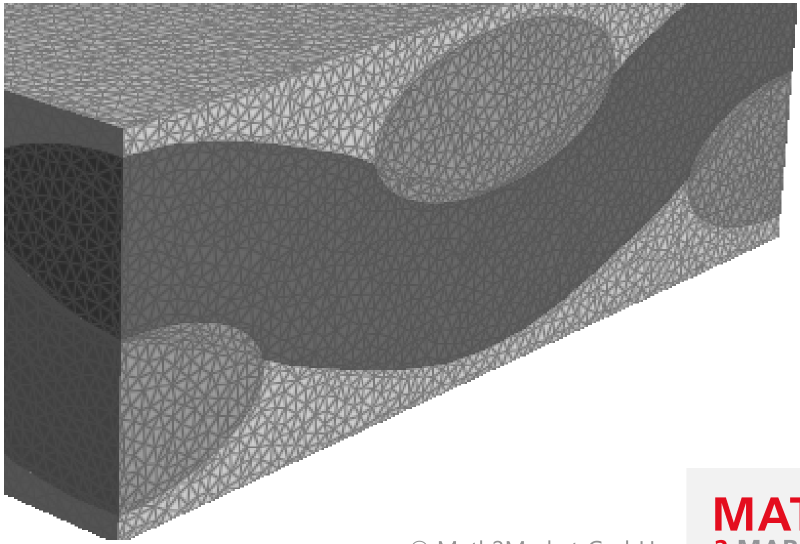
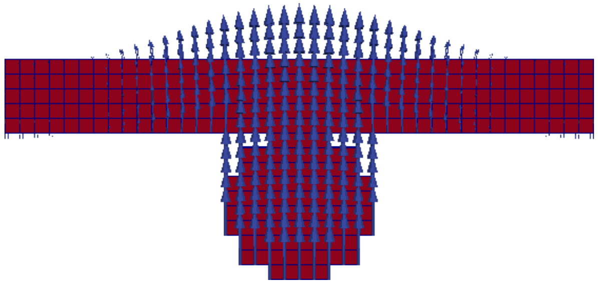




MATH 2 MARKET

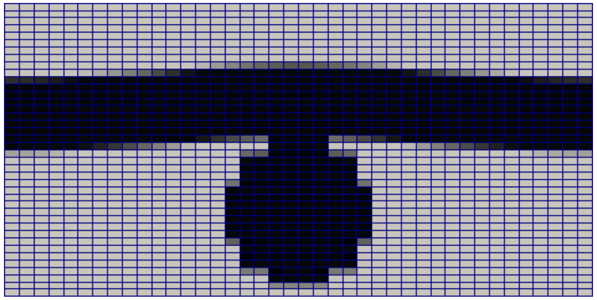
Deformation of Voxel Geometries

Fraunhofer ITWM GeoDict



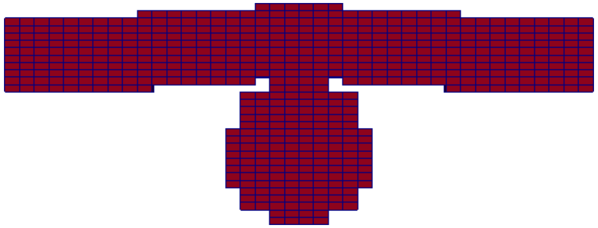
Step 1

- Solve one iteration of mechanical problem
- Integrate strain field to obtain displacement vector field on the undeformed geometry



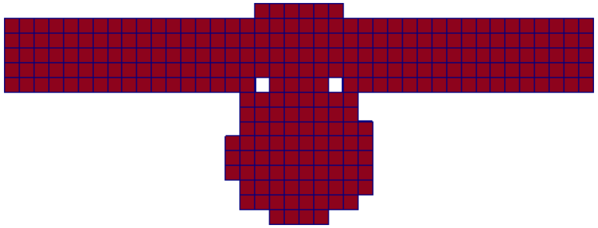
Step 2

- Move voxel according to displacement field
- Cut voxel with deformed mesh



Step 3

- Determine optimal threshold
- Perform segmentation of the grey value image
- Result: “boxel” image



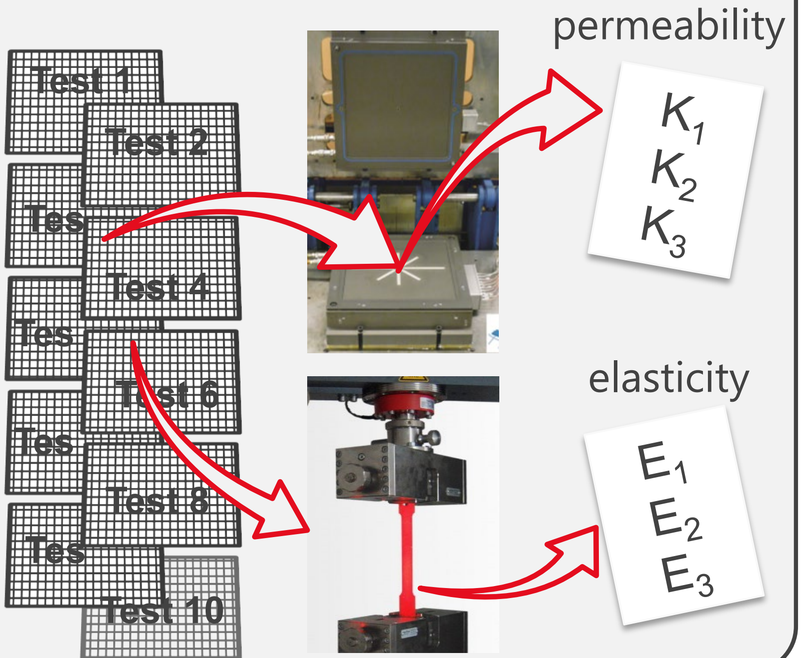
Step 4

- Resample the “boxel” image to obtain a voxel image (with the original resolution)

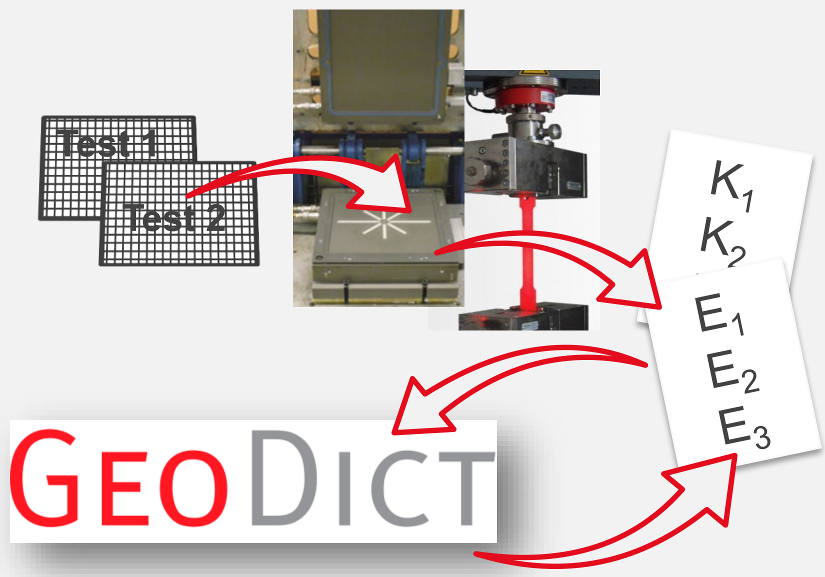
MATH 2 MARKET

Research Project „Math2Composites“

Large amount of experiments for the determination of material properties



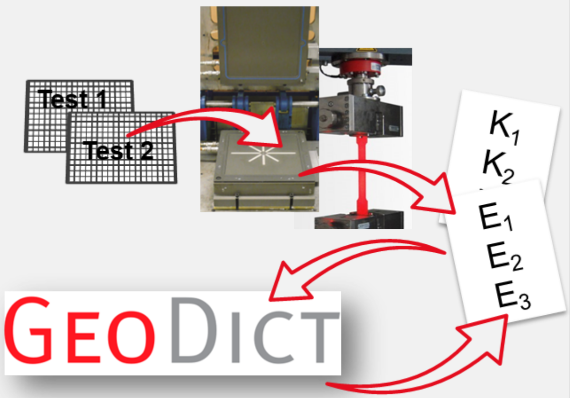
Novel simulative-experimental approach for the determination of material properties



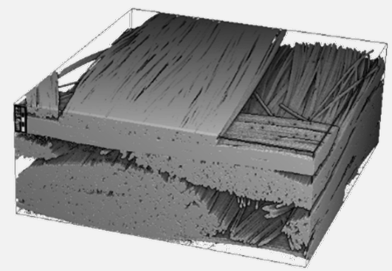
Replace a large amount of experiments by validated simulations

Research Project „Math2Composites"

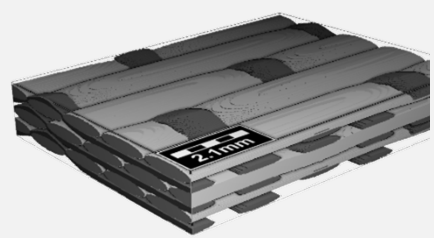
Novel simulative-experimental approach for the determination of material properties



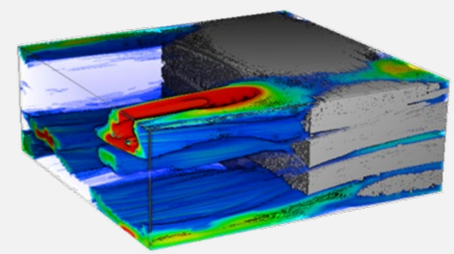
µCT-scan

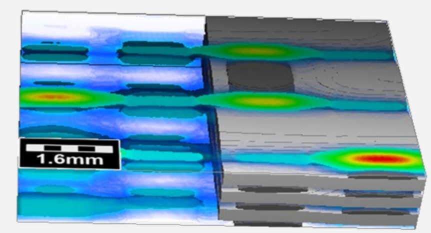


Model



Simulation





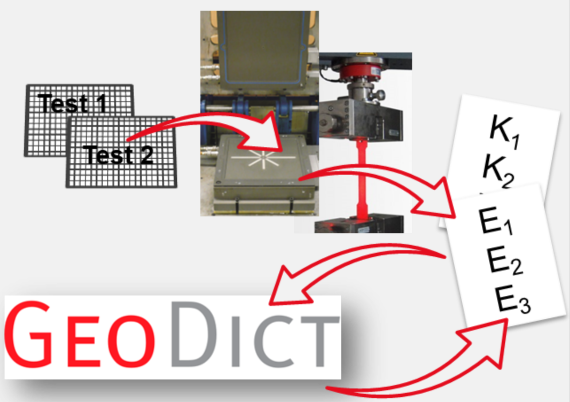
PREDICTION ← Validated simulation ← Calibration of the simulation

NEW ACHIEVEMENTS IN RESEARCH PROJECT „MATH2COMPOSITES“

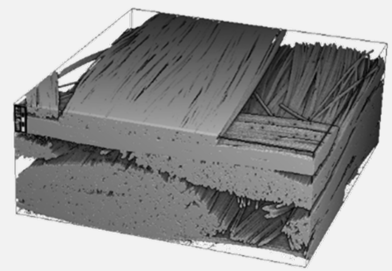
GEODICT

Institut für Verbundwerkstoffe

Novel simulative-experimental approach for the determination of material properties



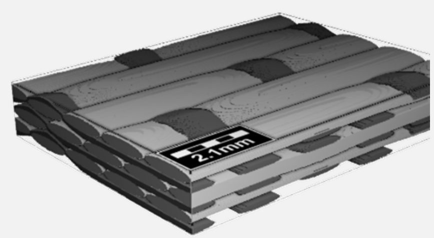
µCT-Scan



- ✓ good simulation results
- ✗ huge experimental effort

Cannot be reduced

Model



- ✓ low experimental effort
- ✗ deviation from simulation and experiment too high

can be reduced by improved modeling techniques

Digital Twin for permeability simulation

Mechanical simulation

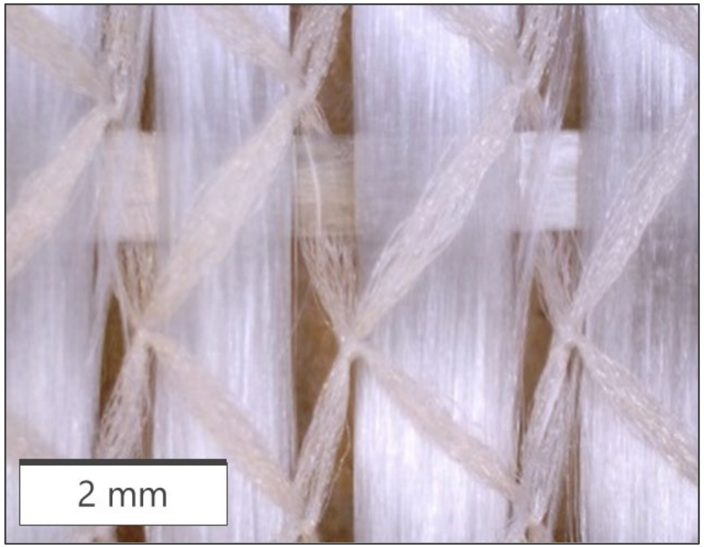
MATH 2 MARKET

Outline

Generation of a Digital Twin

- **Microstructure of non-crimped fabric Hacotech G300U-1270mm**

µCT-scan image

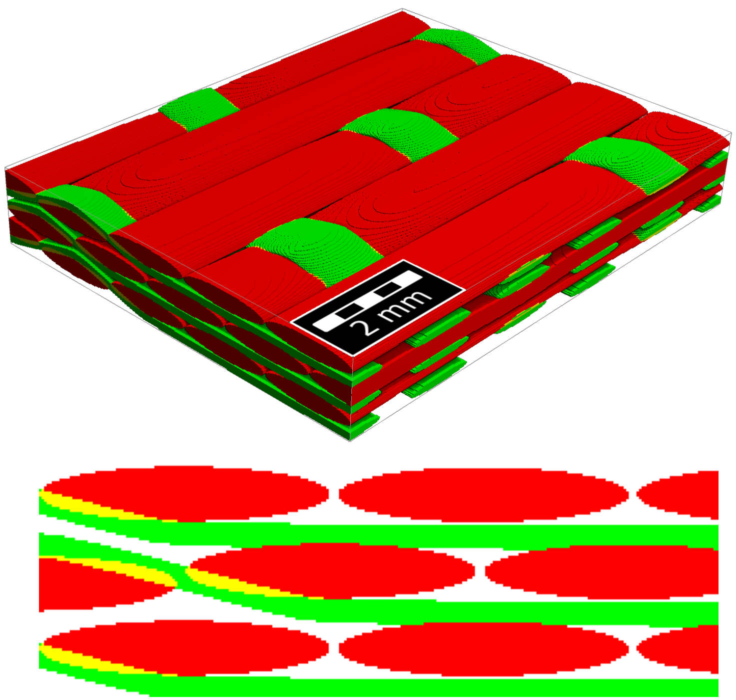


Microscopy image

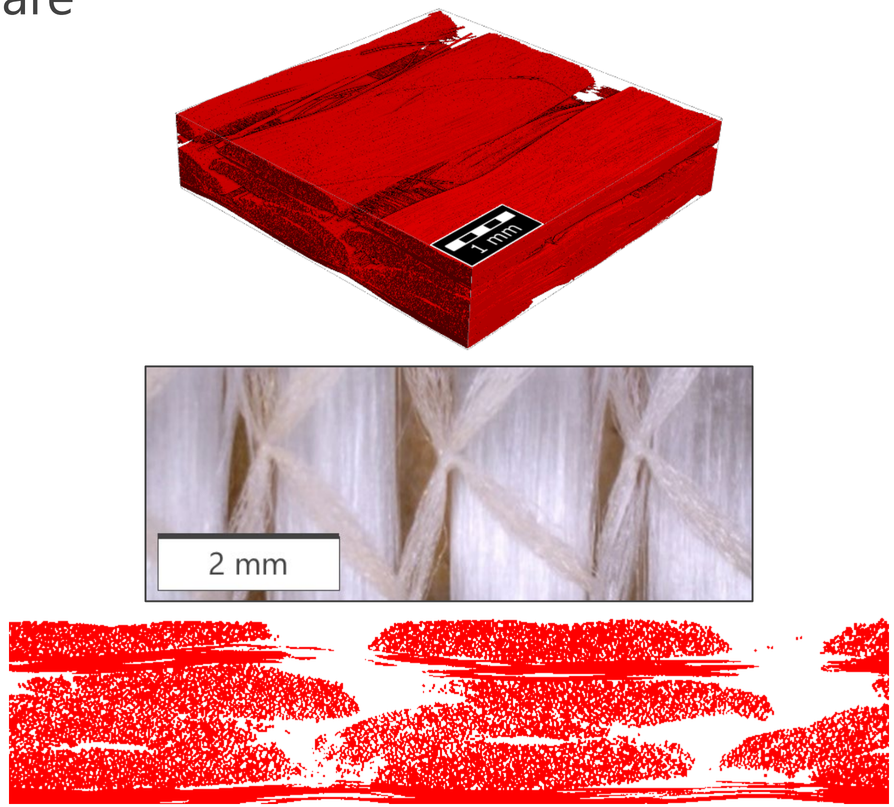
Generation of a Digital Twin

GeoDict

- **Generation of a model with WeaveGeo**
- Properties of homogenized modes are predicted with GeoDict



First model

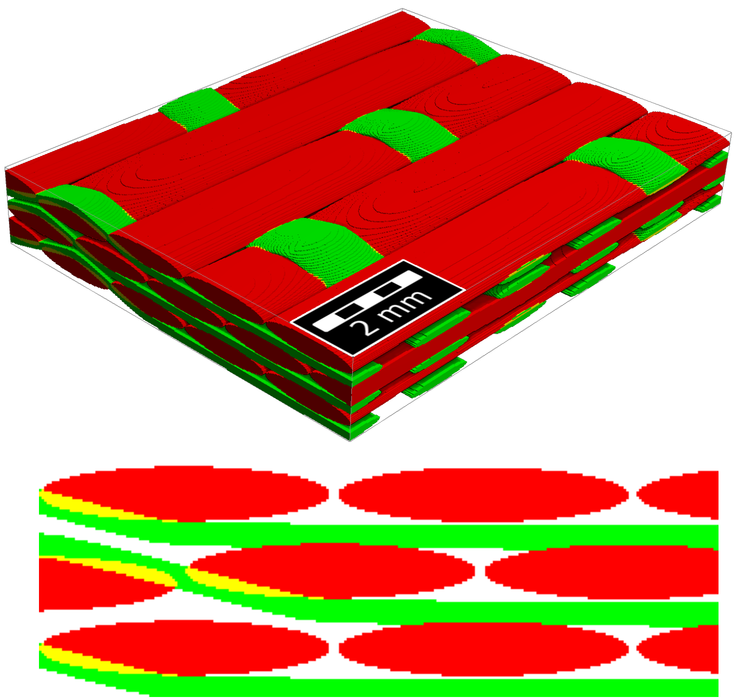


µCT-scan

GENERATION OF A DIGITAL TWIN

GEODICT

- **Generation of a model with WeaveGeo**



3rd cousin

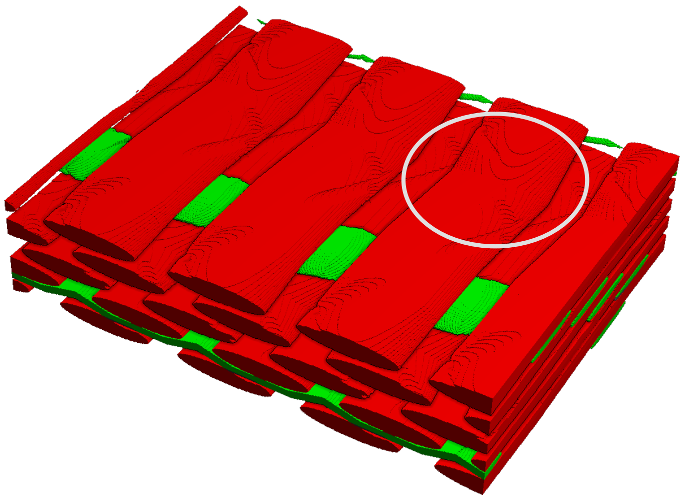
µCT-scan

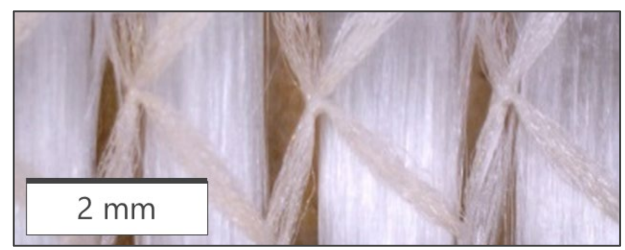
MATH 2 MARKET

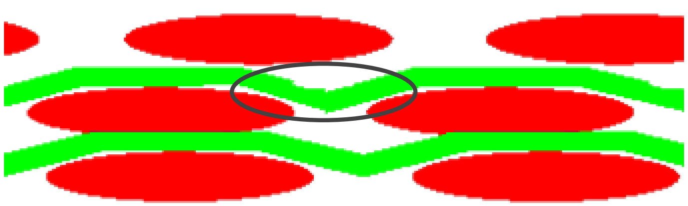
Generation of a Digital Twin

GeoDict

- **Implementation of roving undulation**







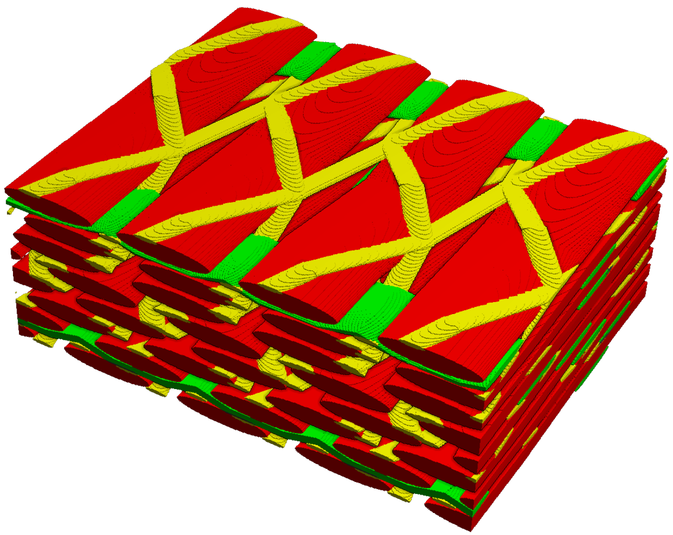
“2nd cousin“ model

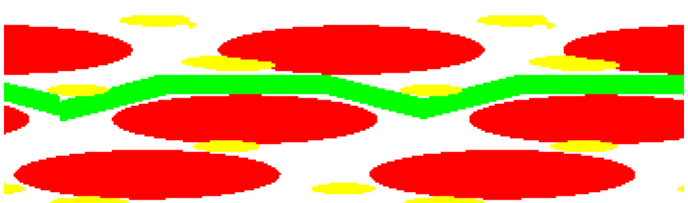
µCT-scan

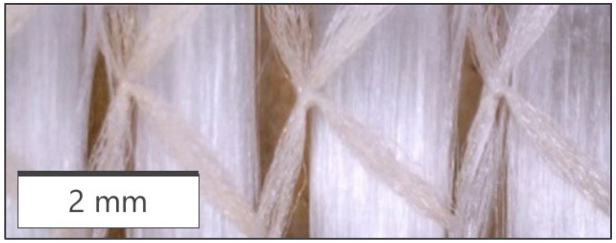
MATH 2 MARKET

GENERATION OF A DIGITAL TWIN

- **Modeling the PET stitching (yellow)**





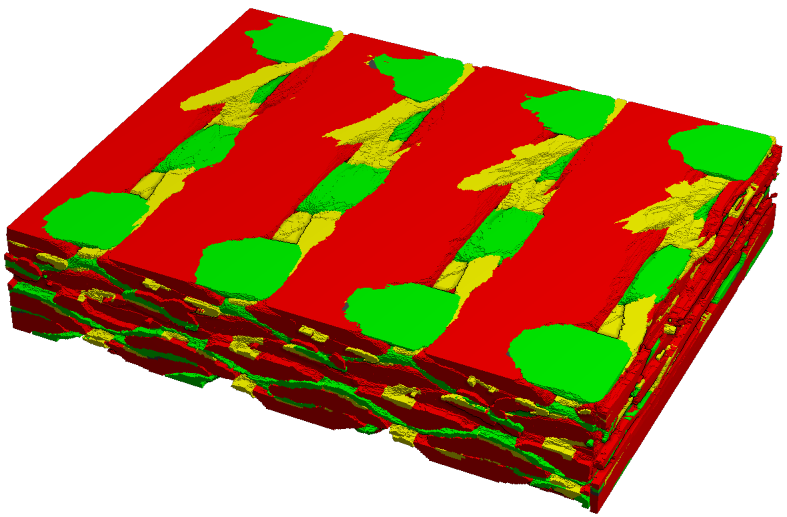


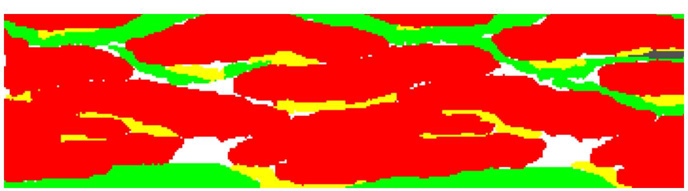
“1st cousin“ model

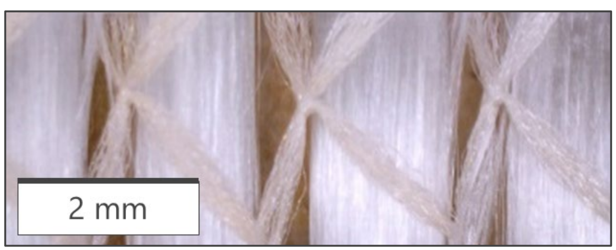
µCT-Scan

GEODICT

- **Compaction of the modeled structure with FeelMath-LD**







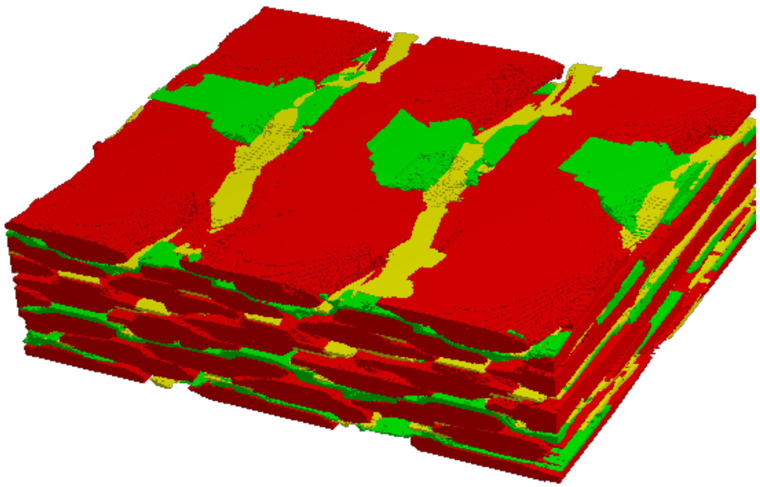
"brother / sister" model

µCT-scan

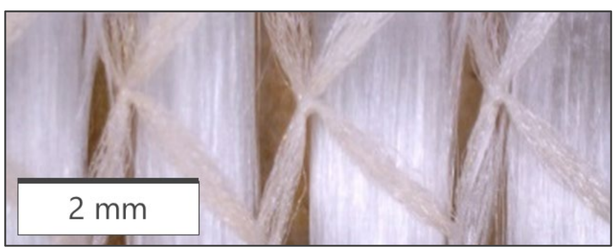
MATH 2 MARKET

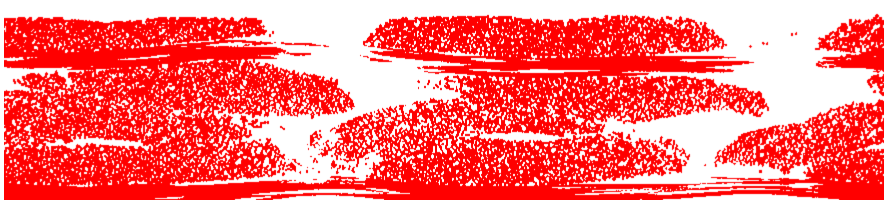
Generation of a Digital Twin

- **Optimization of the model by calibration with permeability experiment at IVW**



Digital Twin





µCT-scan

Outline

GeoDict

MATH 2 MARKET

Materials and Setup

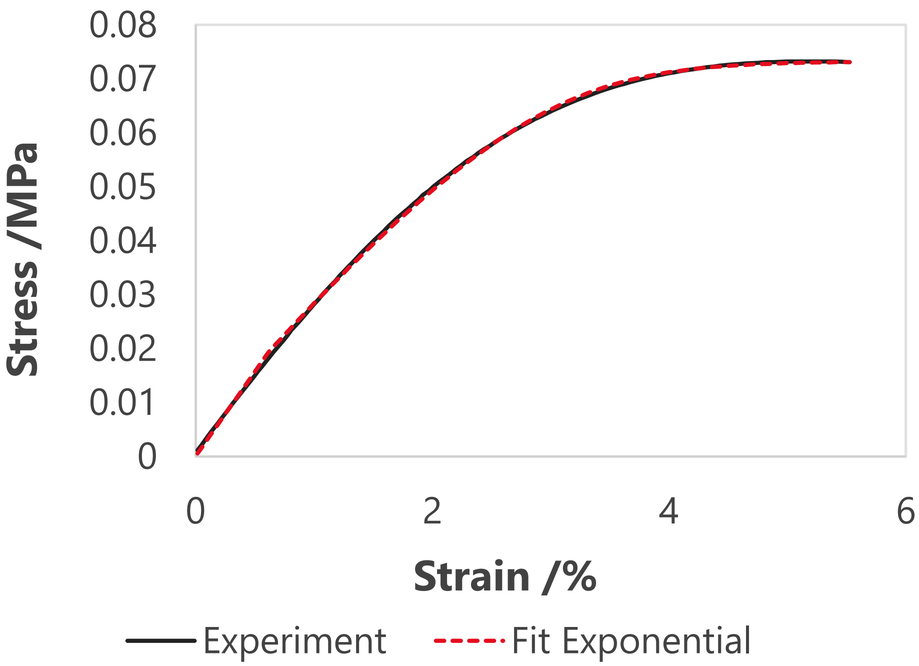
GeoDict

Experiments and simulations:

- Experiments were performed at IVW on a Zwick universal testing machine
- Strain measurement with Aramis
- Mechanical simulations were performed by Math2Market using GeoDict 2019

Materials

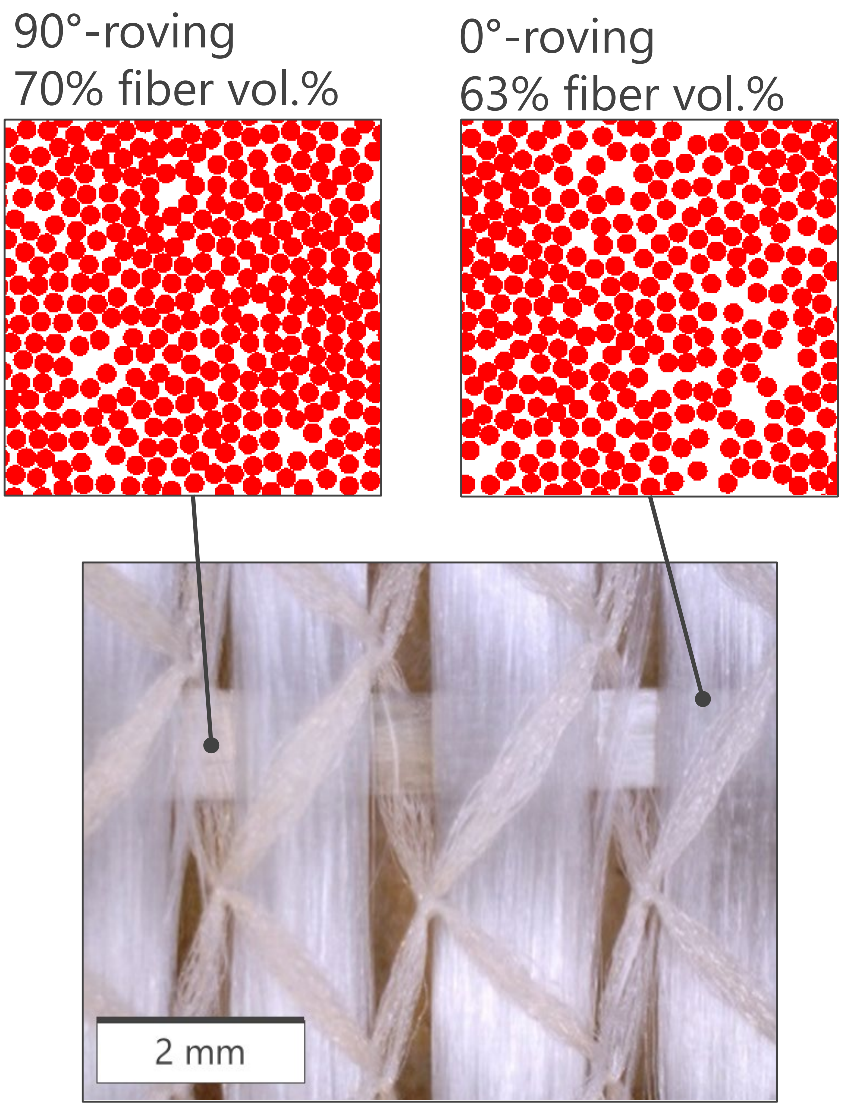
- Epoxy resin:
  - Epikote RIM935 + RIMH 936
  - Material model for elastic-plastic deformation of epoxy fitted to experimental data
- Non-crimp fabric
  - Hacotech G300U 1000 1270
  - Properties of glass fibers:
    - $E_{Glass} = 72000\ MPa$
    - $\sigma_{max,Glass} = 2000\ MPa$
    - $\nu = 0.22$



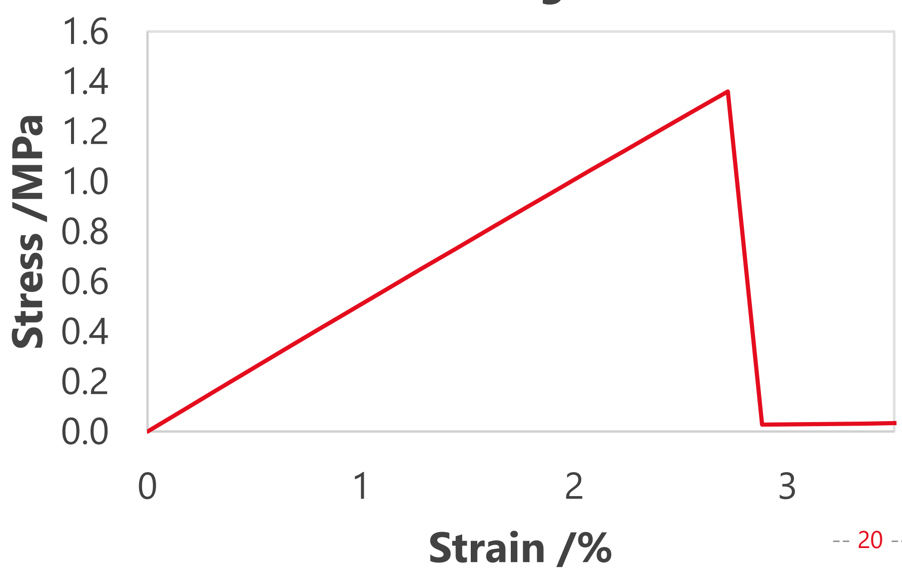
MATH 2 MARKET

Step 1: Prediction of Homogenized Properties

- Homogenized material properties for impregnated rovings
- Epoxy resin: Material model fitted to experimental data
- Glass fibers: Linear elastic deformation with failure at maximum stress
- $E_{0°} = 51362\ MPa, E_{90°} = 54816\ MPa$



Stress-strain-curve of 0°-roving in fiber direction



Step 1: Prediction of Homogenized Properties

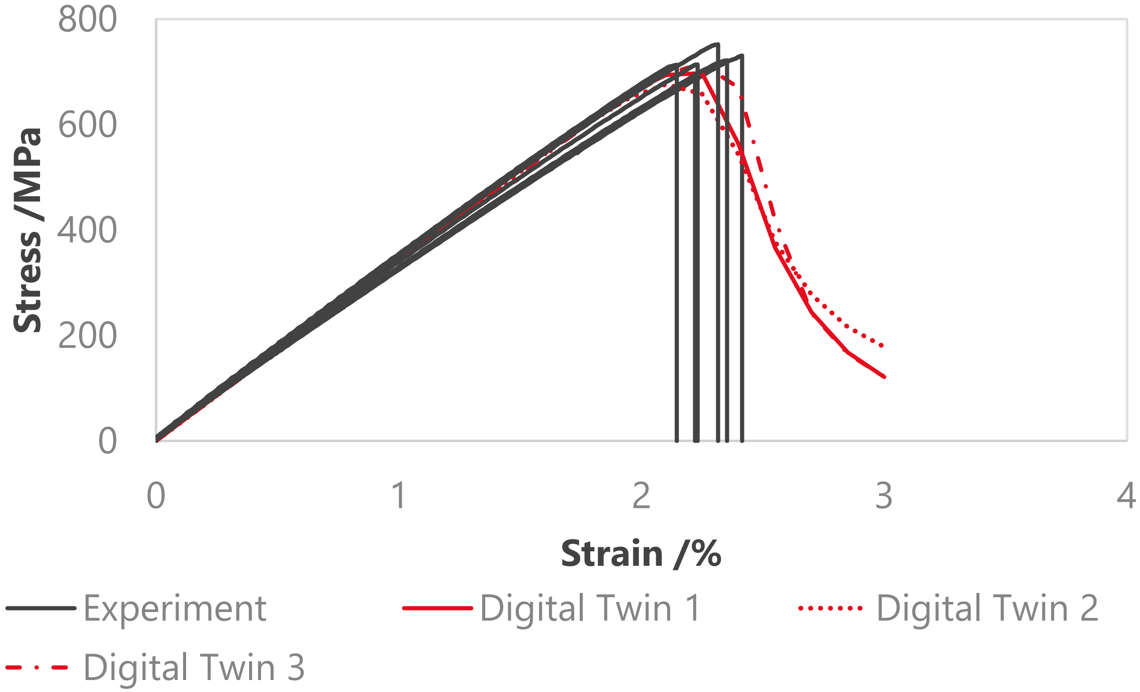
GeoDict

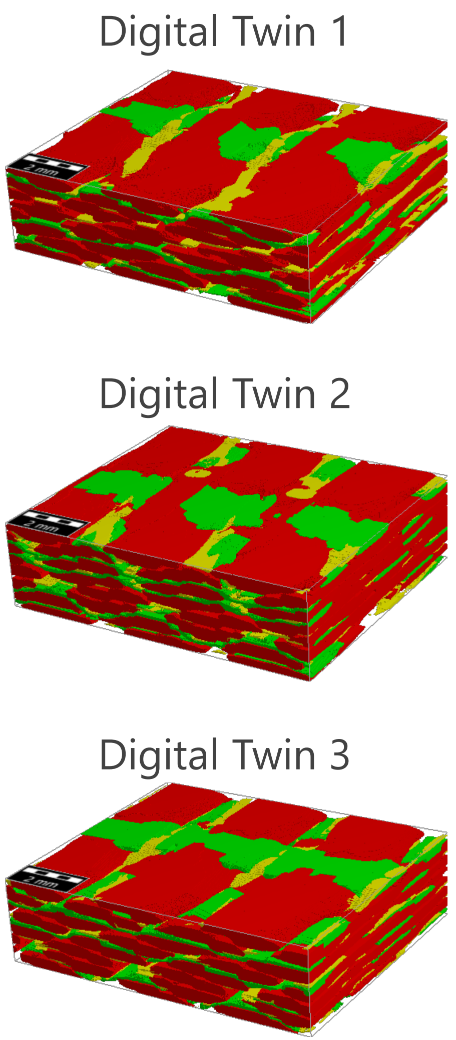
Stress in fibers during loading in fiber directions

STEP 2: EXPERIMENT VS. SIMULATION OF TENSILE TEST OF DIGITAL TWINS

GEODICT

- Large deformation of three Digital Twins was simulated
- All twins have same statistical properties but are different
- Comparison with tensile tests in direction of 0°-rovings





➢ **Good compliance with experiments**

MATH 2 MARKET

Step 2: Experiment vs. Simulation of Tensile Test of Digital Twins

GeoDict

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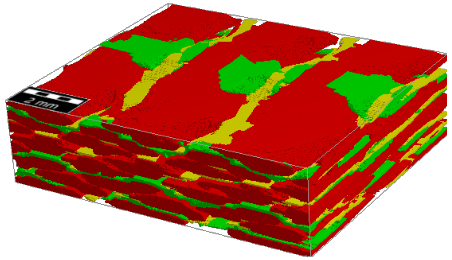
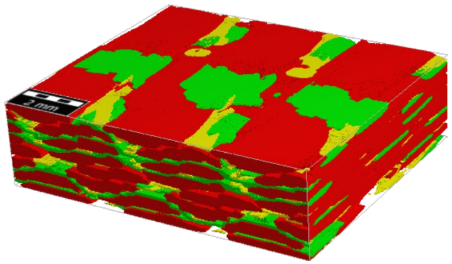
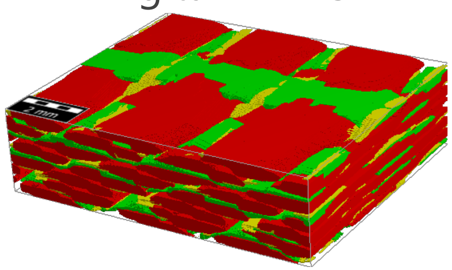
Digital Twin 1

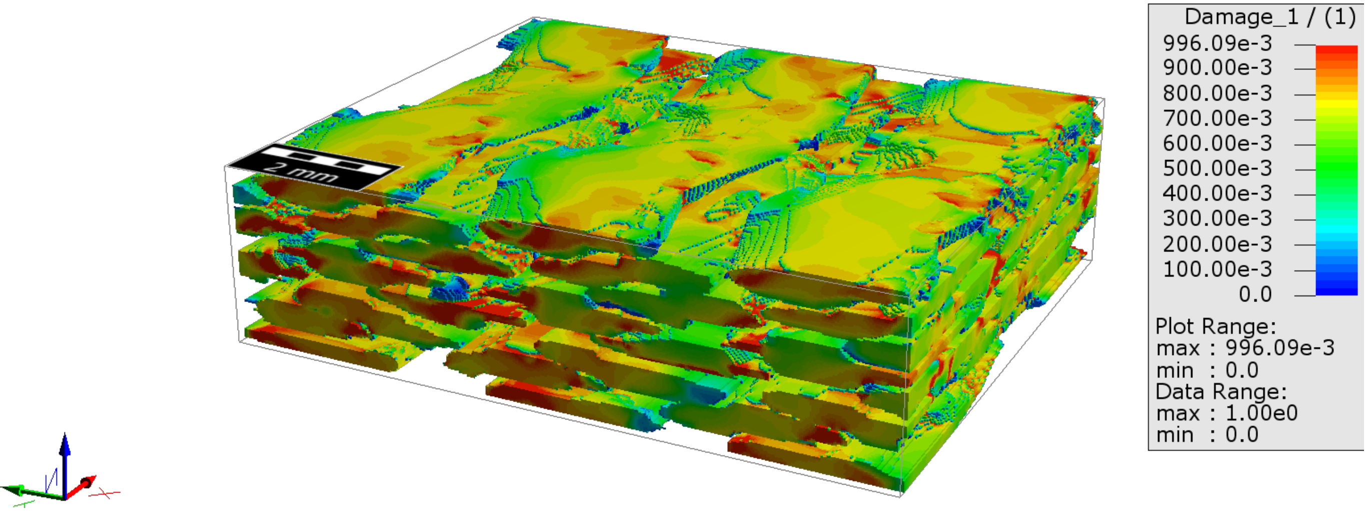


Digital Twin 2



Digital Twin 3





➢ **Good compliance with experiments**

MATH 2 MARKET

Outline

Summary and Outlook

Summary:

- Microstructure simulation unlocks new possibilities for material development
- Voxel-based FEA allows simulation of detailed models without meshing
- A Digital Twin can drastically reduce the number of µCT-scans needed, but it must include all important features
- Calibrated Digital Twins can be used for mechanical simulations
- Reliable material datasheets and material models are crucial for a successful simulation

Outlook:

- Validation of this workflow with Digital Twins of weaves
- Extension and improvement of plastic deformation and damage models in cooperation with IVW

ACKNOWLEDGEMENT

GeoDict

The project "Math2Composites" is funded by the ZIM program of the Federal Ministry for Economic Affairs and Energy (BMWi), funding reference: ZF40523110EB6

Supported by:

Federal Ministry for Economic Affairs and Energy

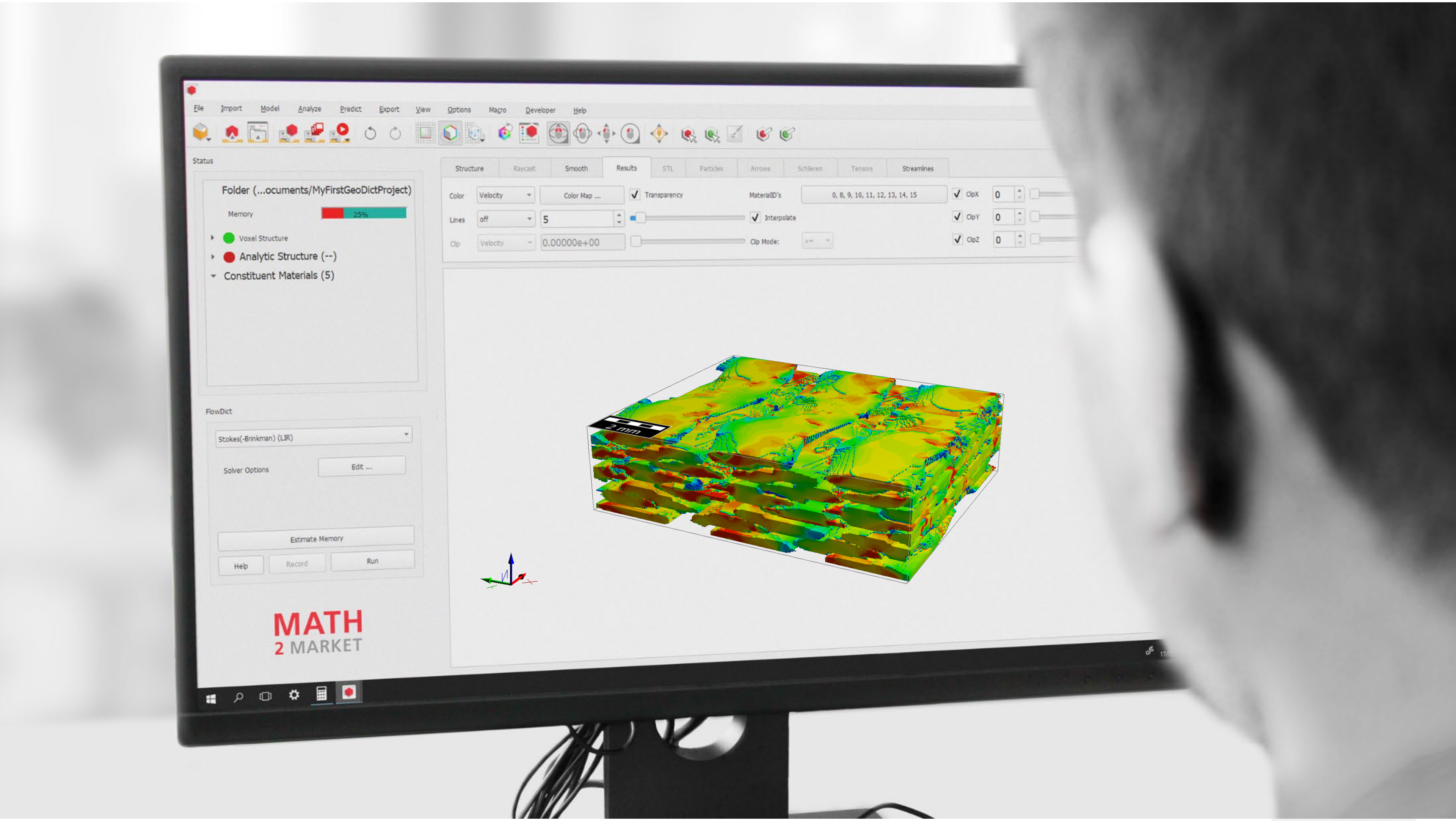
on the basis of a decision by the German Bundestag

ZIM

Zentrales Innovationsprogramm Mittelstand

MATH 2 MARKET

THANK YOU



MATH
2 MARKET