Finer-scale characterization and modeling at UIBK – 
Application to optimization of FRC components

Roman Lackner
Unit for Material Technology, University of Innsbruck
[https://www.uibk.ac.at/mti/]
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1. Introduction

Motivation for Multiscale Modeling

… consideration of material microstructure

(1) Material properties as a function of properties of material phases and their composition

(2) Consideration of physical/chemical processes at scale of occurrence

(3) Optimization of materials
1. Introduction

Hybrid Nature of Research – Experimental & Theoretical

Identification experiments
... for identification of properties of material phases

Validation experiments
... for validation of employed upscaling scheme (homogenization)

Effective properties, application to structural analysis
2. Characterization

NanoLab @ uibk

Characterization of …

a) Atomic and molecular composition

b) Material morphology

c) Mechanical properties

d) Coating technology

e) Fire protection

[https://forschungsinfrastruktur.bmwfw.gv.at/de/fi/core-facility-nanolab-innsbruck_2620]
2. Characterization

Scanning Electron Microscope (SEM)

Focused Ion Beam - Scanning Electron Microscope (FIB-SEM)

Investigation of pore-space characteristics within steatite ceramics:

FFG Project „High Performance Ceramics“
in cooperation with Steka

Steatite ceramics

Induced pore space
2. Characterization

Infinite Focus Microscope (IFM)

Characterization of surface topology (vertical resolution = 10 nm)

Investigation of surface roughness and its effect on the friction behaviour:

KRegio project „Ski Technology“ in cooperation with Department of Sport Science at uibk

[Rohm et al. (2016). Effect of Different Bearing Ratios on the Friction between Ultrahigh Molecular Weight Polyethylene Ski Bases and Snow. Applied Materials & Interfaces]
2. Characterization

Nanoindentation (NI)

Investigating …
- bulk material
- surfaces
- coatings

Determination of …
- Young’s modulus
- hardness
- Viscous response

Grid indentation in case of heterogenous materials:
2. Characterization

Cone Calorimetry

Controlled heating of protected and unprotected specimens, monitoring …
→ the mass loss as a function of time
→ ignition temperature
→ composition of exhaust gases

KRegio project „Innovative Wood Protection“ in cooperation with M. Flach, H. Schottenberger, Adler, Binder Holz, and Pfennig
1. Introduction

Hybrid Nature of Research – Experimental & Theoretical

Scanning Electron Microscope
Infinite Focus Microscope
Nanoindentation

Effective properties, application to member analysis

Cone Calorimetry
3. Scale Transition

Homogenization – Scale Transition – Upscaling

- Regular morphology
- Irregular morphology

→ Repetitive Unit Cell (RUC)
→ Representative Volume Element (RVE)


3. Scale Transition

Influence of the Microstructure

Matrix-Inclusion
Material:

Open-Cell
Foam:

Closed-Cell
Foam:

Granular
Medium:

Material microstructure defines appropriate homogenization scheme
3. Scale Transition

Matrix-Inclusion Material

Continuum micromechanics for upscaling of strength properties:

Plasticity problem $\rightarrow$ Elastic substitution problem $\rightarrow$ Closed-form solution:

$$F = \frac{1}{f_M} X_\mu^{-1} \Sigma_d^2 + \frac{1}{f_M} b X_k^{-1} \Sigma_m^2 + \ldots$$

Effective yield surface (model validation by numerical results):

- 20% pores
- 20% rigid particles

Continuum micromechanics \textbf{fails} to capture dependency of elastic and strength properties on matrix fraction.
3. Scale Transition

Thin-Shell Model

\[
\frac{E_{\text{eff}}}{E_m} \propto f_m^{3/2}
\]


\[
\frac{\sigma_{y,\text{eff}}}{\sigma_{y,m}} \propto f_m^{3/2}
\]

3. Scale Transition

Transport Properties – Thermal Conductivity

Random-packing model:

\[
\frac{k_{\text{eff}}}{k_m} = \frac{f_m N}{\pi} \approx 3.8 f_m^2
\]

4. Innovative Tube Design

K-Regio Project (2015-2018)

Project Partners:

- thöni
- superTEX® composites
- INTALES

Team at UIBK:

- M. Luger
- U. Hofer
- M. Maier
- R. Traxl
- S. Riml
4. Innovative Tube Design

**Motivation**

- Development of improved and new structural components (springs, tubes)
- Simulation-based optimization of material and structural performance
- Virtual prototyping
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Material Characterization of Matrix Material

Thermomechanical Analysis (TMA)

Netzsch TMA

Compression Test

3-Point Bending Test
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TMA – Static Loading, First Results

Load history

M2M-MT-02_02

Time (min)

dL corr (um)

Temp (°C)

Force (N)
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TMA – Static Loading, First Results

Temperature history

- dL corr (um)
- Time (min)
  - M2M-MT-02_02
  - 20
  - 30
  - 40
  - 50
  - 60
  - 70
- Force (N)
  - 0
  - 2
  - 4
  - 6
  - 8
  - 10
  - 12
  - 14
- Temp (°C)
  - 0
  - 2
  - 4
  - 6
  - 8
  - 10
  - 12
  - 14

Legend:
- dL corr
- Temp
- Force
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TMA – Static Loading, First Results

Displacement history

![Graph showing displacement history with time, force, and temperature as variables.]

- Graph shows the displacement history over time, with markers for force and temperature changes.
- The graph is labeled with axes for time (min), displacement (um), temperature (°C), and force (N).

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**Innovative Tube Design**

**TMA – Static Loading, First Results**

**Displacement history**

![Graph showing displacement history with time, force, and temperature as variables.]

- Graph shows the displacement history over time, with markers for force and temperature changes.
- The graph is labeled with axes for time (min), displacement (um), temperature (°C), and force (N).
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TMA- Identification of Thermal Properties

Thermal expansion coefficient:

- 3PB Average Thermal expansion coefficient - compression test

Graph showing temperature (°C) on the x-axis and thermal expansion coefficient (α_T) on the y-axis. The graph includes data points for different temperature ranges and shows the relationship between temperature and thermal expansion coefficient.
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TMA - Identification of Viscous Behaviour

Creep results (average of all 3PB tests)
Derivative Creep - M2M-MT-02_02 - linear fit in [0.001, 0.1]

<table>
<thead>
<tr>
<th>T [°C]</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>-0.94</td>
</tr>
<tr>
<td>40</td>
<td>-0.83</td>
</tr>
<tr>
<td>50</td>
<td>-0.80</td>
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<tr>
<td>60</td>
<td>-0.81</td>
</tr>
<tr>
<td>70</td>
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</tr>
</tbody>
</table>

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TMA- Identification of Viscous Behaviour
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TMA – Cyclic Loading, First Results

Access to ...
- Phase angle
- Complex modulus
→ Storage modulus
→ Loss modulus
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Material Characterization – Morphology
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Homogenization of Mechanical Properties

The “Repetitive Unit Cell” – RUC

Diamond Braid (1/1):
Biaxial Braidings at ±45°

Regular Braid (2/2):
Biaxial Braidings at ±45°

RUC model is obtained in 4 steps …
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Step 1: On the Use of Subcells

Every braiding can be composed by six subcells

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- Subcells 1 to 4 (two rovings straight, two ondulated) are created via similarity transformation
- Subcell 5 (four rovings straight)
- Subcell 6 (four rovings ondulated)
Step 2: Composing the RUC

In order to build up regular braids, four subcells are sufficient …
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Step 3: Filling of the Matrix Pockets – Completion of the RUC’s

Once the rovings are braided and positioned, the pockets are filled with matrix.

Roving itself is composed of fibers and matrix material:

[Badel et al. (2008). Simulation and tomography analysis of textile composite reinforcement deformation at the mesoscopic scale. Composite Science and Technology]
Step 4: Boundary Conditions

1) **Displacement** boundary conditions
2) **Traction** boundary conditions
3) **Periodic** boundary conditions

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**First Results**

- Carbon-fiber-reinforced epoxy resin
- Regular braid (±45°)
- Fiber-volume ratio = 20%

**Input parameters**

Matrix: $E = 5500 \text{ MPa}, \nu = 0.37$
Carbon fiber: $E = 232000 \text{ MPa}, \nu = 0.28$

**Output – effective elastic properties**

- $E_{11} = 13000 \text{ MPa}$
- $\nu_{12} = 0.26$
- $G_{12} = 3300 \text{ MPa}$
5. Outlook

**Optimization Cycle**

- **Thöni/SuperTex**: Specification of production parameters; product specification
- ** UIBK**: Material properties based on RUC approach
- **Intales**: Structural analysis and optimization
- **RUC [uibk]**
- **Numerical model [Intales]**
- **Effective properties**
Thank you for your attention!

Acknowledgement

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