DIGITAL TWIN - HOW TO GENERATE AND VALIDATE MODELLED MICROSTRUCTURES FROM 2D AND 3D IMAGES

MSE Congress 2018, Darmstadt, 27.09.2018
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Tim Schmidt, Florian Schimmer (IVW GmbH)
What is GeoDict?

Digital Twin of a Short Fiber Reinforced Polymer

Other Examples of Digital Twins
The idea is the beginning. Design a material from scratch or import images from an existing material to create a digital model.

Discover the geometric properties and compute the physical properties of the material. This is the start of creating a Digital Twin.

A Digital Twin is the statistical representation of the material in the digital world. Here begins the design process.

Digital prototypes are easily and rapidly created. Simulate and evaluate in a loop to find the material with the desired properties.

The materials of the future are within reach and we help you find them faster.

This is innovation through simulation.
01  What is GeoDict?

02  Digital Twin of a Short Fiber Reinforced Polymer

03  Other Examples of Digital Twins
What material are we looking at?

- PA6GF50
  - Polyamide 6 matrix
  - Short glass fiber reinforcement
  - 50% fibers by weight

- Produced by injection molding

- Used in mass production for structural components (e.g. engine bearer)
Digital Twin of a SFRP

6 Steps to the Digital Twin

1. Import, process and segment the µCT-scan
2. Calculate the mechanical properties directly on the µCT-scan
3. Determine the geometrical properties of the material (fiber diameter, fiber orientation, fiber length)
4. Model the digital twin
5. Calculate the mechanical properties of the digital twin
6. Comparison of the results
Digital Twin of a SFRP Import and Segmentation

- Import a stack of 2d images
- Image processing to improve quality for segmentation
  - noise reduction, edge sharpening

Applying a Non-Local Means Filter for noise reduction
DIGITAL TWIN OF A SFRP IMPORT AND SEGMENTATION

- automated thresholding using OTSU¹ algorithm

automated thresholding using OTSU\(^1\) algorithm

**Digital Twin of a SFRP Mechanical Analysis - CT Scan**

- **linear elastic simulation of 6 different load cases**
  - 3 uniaxial experiments
  - 3 shear experiments

- **used material properties**
  - PA6: $E=2.8$ GPa / $\nu=0.39$
  - Glass: $E=72$ GPa / $\nu=0.22$

- **computation time: 589 s**
  - 4 CPUs
  - 0.5 GB memory
Digital Twin of a SFRP Mechanical Analysis - CT Scan

- calculated engineering parameters and stiffness tensor

<table>
<thead>
<tr>
<th>Orthotropic Approximation</th>
<th>Strain Equivalence</th>
<th>Energy Equivalence</th>
<th>Mean Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young's Modulus $E_1$ / (GPa)</td>
<td>7.1211</td>
<td>7.1213</td>
<td>7.1212 + 0.0001</td>
</tr>
<tr>
<td>Young's Modulus $E_2$ / (GPa)</td>
<td>7.9283</td>
<td>7.9285</td>
<td>7.9284 + 0.0001</td>
</tr>
<tr>
<td>Young's Modulus $E_3$ / (GPa)</td>
<td>11.3851</td>
<td>11.3852</td>
<td>11.3852 + 0.0000</td>
</tr>
<tr>
<td>Poisson Ratio $\nu_{12}$</td>
<td>0.3547</td>
<td>0.3547</td>
<td>0.3547 + 0.0000</td>
</tr>
<tr>
<td>Poisson Ratio $\nu_{13}$</td>
<td>0.2160</td>
<td>0.2160</td>
<td>0.2160 + 0.0000</td>
</tr>
<tr>
<td>Poisson Ratio $\nu_{23}$</td>
<td>0.2517</td>
<td>0.2517</td>
<td>0.2517 + 0.0000</td>
</tr>
<tr>
<td>Poisson Ratio $\nu_{21}$</td>
<td>0.3949</td>
<td>0.3949</td>
<td>0.3949 + 0.0000</td>
</tr>
<tr>
<td>Poisson Ratio $\nu_{31}$</td>
<td>0.3454</td>
<td>0.3454</td>
<td>0.3454 + 0.0000</td>
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<tr>
<td>Poisson Ratio $\nu_{32}$</td>
<td>0.3614</td>
<td>0.3614</td>
<td>0.3614 + 0.0000</td>
</tr>
<tr>
<td>Shear Modulus $G_{12}$ / (GPa)</td>
<td>2.7558</td>
<td>2.7557</td>
<td>2.7558 + 0.0001</td>
</tr>
<tr>
<td>Shear Modulus $G_{13}$ / (GPa)</td>
<td>3.0113</td>
<td>3.0111</td>
<td>3.0112 + 0.0001</td>
</tr>
<tr>
<td>Shear Modulus $G_{23}$ / (GPa)</td>
<td>3.8636</td>
<td>3.8635</td>
<td>3.8636 + 0.0001</td>
</tr>
</tbody>
</table>

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<th>Anisotropic Elasticity Tensor</th>
</tr>
</thead>
</table>

Stiffness Formulation for Strain Equivalence / (GPa)

<table>
<thead>
<tr>
<th></th>
<th>10.232</th>
<th>5.4243</th>
<th>5.4948</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.025524</td>
<td>-0.010267</td>
<td>0.14141</td>
</tr>
<tr>
<td>$5.4244$</td>
<td>11.597</td>
<td>6.0651</td>
<td></td>
</tr>
<tr>
<td>$5.4949$</td>
<td>6.0652</td>
<td>15.475</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5932</td>
<td>-0.28255</td>
<td>-0.12848</td>
</tr>
<tr>
<td>$0.025595$</td>
<td>0.80212</td>
<td>1.5932</td>
<td></td>
</tr>
<tr>
<td>$-0.010275$</td>
<td>-0.088766</td>
<td>-0.28258</td>
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<td>-0.17072</td>
<td>0.091551</td>
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Digital Twin of a SFRP
Mechanical Analysis - CT Scan

- Visualization of the von-Mises stress

Material Information:
- ID 00: Polyamide (PA 6) [invis.]
- ID 01: Glass
Digital Twin of a SFRP Geometrical Analysis - CT Scan

- Fiber diameter distribution

<table>
<thead>
<tr>
<th>Type</th>
<th>Average Inner Diameter / (m)</th>
<th>Standard Deviation / (m)</th>
<th>Volume Fraction / (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>1.0216e-5</td>
<td>1.42793e-6</td>
<td>100</td>
</tr>
</tbody>
</table>

![Histogram of fiber diameter distribution with Gaussian fit](image)
Digital Twin of a SFRP
Geometrical Analysis - CT Scan

- fiber orientation analysis
  - using Star Length Distribution Algorithm
  - works on a per-voxel basis
  - analyzes the chord lengths through the voxel for a pre-defined set of directions
  - the relative length of the cords gives the per-voxel orientation tensor
  - tensors are averaged
Digital Twin of a SFRP
Geometrical Analysis - CT scan

- fiber orientation analysis
  - homogenized orientation tensor for the entire scan
  - visualization of the main orientation
- calculation of the fiber volume fraction

<table>
<thead>
<tr>
<th>Block 0,0,0: Solid Volume Fraction = 31.6262%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.166223  -0.0163009  -0.0522386</td>
</tr>
<tr>
<td>-        0.28979      0.154429</td>
</tr>
<tr>
<td>-        -            0.543987</td>
</tr>
</tbody>
</table>
Digital Twin of a SFRP
Geometrical Analysis - CT scan

- fiber length analysis using Artificial Intelligence

μCT-Scan

identified fibers
Digital Twin of a SFRP Modeling

- use all collected geometrical properties of the material for modelling the digital twin in FiberGeo
Digital Twin of a SFRP Modeling

- visual comparison of the twin and the μCT-scan
Digital Twin of a SFRP Mechanical Analysis

- comparison of the stiffness tensor

\[ \begin{array}{cccccc}
\text{Stiffness Formulation for Strain Equivalence / (GPa)} & 10.232 & 5.4243 & 5.4948 & 0.025524 & -0.010267 & 0.14141 \\
5.4244 & 11.597 & 6.0651 & 0.80216 & -0.08876 & 0.12121 \\
5.4949 & 6.0652 & 15.475 & 1.5932 & -0.28255 & -0.12848 \\
0.025595 & 0.80212 & 1.5932 & 3.8636 & -0.24775 & -0.17071 \\
-0.010275 & -0.088766 & -0.28258 & -0.24774 & 3.0113 & 0.091551 \\
0.14133 & 0.12119 & -0.12859 & -0.17072 & 0.091522 & 2.7558 \\
\end{array} \]

\[ \begin{array}{cccccc}
\text{Stiffness Formulation for Strain Equivalence / (GPa)} & 10.757 & 5.4859 & 5.5878 & 0.053966 & 0.06989 & 0.16679 \\
5.4859 & 11.688 & 6.0427 & 0.78271 & -0.070062 & 0.16912 \\
5.5879 & 6.0427 & 14.307 & 1.1605 & -0.031768 & -0.05373 \\
0.054045 & 0.78275 & 1.1605 & 3.6667 & -0.15612 & -0.11499 \\
0.069986 & -0.069923 & -0.031719 & -0.15614 & 3.1619 & 0.081569 \\
0.16684 & 0.16916 & -0.053757 & -0.11499 & 0.081581 & 2.9358 \\
\end{array} \]

\[ \text{μCT-Scan} \quad \text{Digital Twin} \]

\[ \text{very good agreement between μCT-scan and digital twin} \]
01 What is GeoDict?

02 Digital Twin of a Short Fiber Reinforced Polymer

03 Other Examples of Digital Twins
OTHER EXAMPLES OF DIGITAL TWINS
POLYSULFONE MICROMEMBRANE

- used for seawater desalination
Other Examples of Digital Twins
Sintered Ceramic

- used for soot particle filters

[Schmidt and Becker, Generating Validated 3D Models of Microporous Ceramics, 2013, Advanced Engineering Materials]
OTHER EXAMPLES OF DIGITAL TWINS
SINTERED CERAMIC

- used for soot particle filters

[Schmidt and Becker, Generating Validated 3D Models of Microporous Ceramics, 2013, Advanced Engineering Materials]
Other Examples of Digital Twins
Gas Diffusion Layer

- used in fuel cells

µCT-Scan
OTHER EXAMPLES OF DIGITAL TWINS

- used in fuel cells

Identifying binder with Machine Learning

Binder and PTFE

Carbon Fiber
**Other Examples of Digital Twins**

**Gas Diffusion Layer**

- used in fuel cells

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**μCT-Scan**

**Segmented image**
THANK YOU FOR YOUR ATTENTION!

Visit us at Booth #21

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