New approach for validating the segmentation of 3D data applied to individual fibre extraction

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The CINEMA alliance
the alliance for Imaging and Modelling of Energy Applications

• AIM:
  • Develop methods to characterise the internal structure of complex materials used for energy technologies.
  • Correlate performance under realistic conditions to the microstructure and its changes.

• PURPOSE: Optimise materials to make devices
  • More efficient
  • Longer lasting
  • Lower in cost
Uni-directional fibre reinforced composites

References
Individual fibre segmentation

• **AIM:**
  Extract/segment fibres individually from tomograms of UD glass and carbon fibre reinforced composites with high fibre volume fraction.

• **PURPOSE:**
  Relate fibre orientation to compression strength

Reconstructed volume  Slices  Centre detections over slices  Fibre trajectories

References
Individual fibre segmentation: orientation

References
Individual fibre segmentation: compression

\[ \sigma_c = \frac{G}{1 + \frac{\theta}{\gamma}} \]

<table>
<thead>
<tr>
<th>Material</th>
<th>GFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; $\theta$ &gt;</td>
<td>2.75°</td>
</tr>
<tr>
<td>&lt; $</td>
<td>\theta_x</td>
</tr>
<tr>
<td>&lt; $</td>
<td>\theta_y</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>0.44 GPa</td>
</tr>
<tr>
<td>$\sigma_x$</td>
<td>0.49 GPa</td>
</tr>
<tr>
<td>$\sigma_y$</td>
<td>1.14 GPa</td>
</tr>
<tr>
<td>$\sigma_m$</td>
<td>(0.82 ± 0.07) GPa</td>
</tr>
</tbody>
</table>

References
Individual fibre segmentation: validation

Centre points over a small region from the test image with a scale bar indicating 40 μm. In yellow the reference points from the manual annotation and in red the detected ones, missed detections are circled in pink.

References
Individual fibre segmentation: applications

- Micromechanical finite element modeling.
- Understanding damage in fibre composites.
- Quantification for each bundle.
  - Number of fibres
  - Contact points
  - Average diameter per bundle
  - Fibre volume fraction
  - Tex value [g/km], amount of fibre material per km.

(a) The normal horizontal stress contour plot of a transverse loaded 45° backing bundle and (b) the 3D structure where the resulting constitutive law will be implemented.

References
Individual fibre segmentation: applications

- Understanding fracture initiation and progression under tensile loading.
- Understand fibre microbuckling and kink-band formation.

**References**
Wang Y, Emerson MJ, Dahl VA, Conradsen K, Dahl AB and Withers PJ. Understanding the evolution of fibre micro-buckling leading to kink bands by means of computed tomography and image analysis. *In progress, to be submitted 2017.*
Validation of geometrical parameters estimated from tomograms applied to fibre composites

References
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Diameter distributions for the XCT image using the four different single diameter estimation methods.

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Diameter distributions for the different modalities

<table>
<thead>
<tr>
<th>Modality</th>
<th>SEM</th>
<th>OM</th>
<th>XCT (min)</th>
<th>mean</th>
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</thead>
<tbody>
<tr>
<td>average</td>
<td>15.85</td>
<td>16.02</td>
<td>15.44</td>
<td>15.77</td>
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<tr>
<td>std</td>
<td>1.30</td>
<td>1.17</td>
<td>1.13</td>
<td>1.2022</td>
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</tbody>
</table>

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Conclusions

• Described a pipeline for individual fibre segmentation applicable to large scans that do not need to be high quality and can contain densely packed fibres.

• Introduced a range of applications for this pipeline.

• Presented our initial work regarding quantitative validation, important so that we can trust future models and estimations derived from the use of this pipeline.