Aims

Structural properties of fibre-based compounds have traditionally been analyzed by fairly tedious methods based on 2D imaging or material simulations. After introduction of high resolution x-ray tomography the real 3D structural information of the sample is gained from tomographic reconstructions. The aim here is to study the process that starts from the tomographic reconstructions and leads to plausible structural information or flow simulation results of the sample.

Method

As the sample material we use mainly paper but also other woodfibre based materials. For reliable determination of the structure, noise in the tomographic image is reduced by variance based method that preserves the locations of the edges while effectively removing the noise from uniform regions not containing such features.

Figure 1: Surface detection method

In our applications it is important to find the surface of the paper as it determines many quality related parameters, e.g. gloss, ink penetration and surface pores. For surface detection / segmentation of coating layer we have developed a method based on a moving interface (see Figure 1). The gray scales of the image inflict an opposing force on the interface causing it to stop at solid surfaces. The surface stiffness can be altered. This method is insensitive to the noise remaining in the image. Method is related to well know active contours with idea of inner and outer forces. The iteration formula can be described as:

$$\frac{\partial h(x)}{\partial t} = \nu \nabla^2 h(x) + V + \eta$$

Where $\nu$ is surface tension factor, $V$ is up force and $\eta$ down force.

The void space is analyzed by separating it to individual pores and pore throats using watershed based segmentation method. This structure allows us analyze the individual pores and, furthermore, to build a pore-throat-graph that can be used to estimate the fluid transport properties of the sample [1].
For evaluation of the permeability, a measure of the ability of a material to transmit fluid, lattice-Boltzmann method (LBM) is utilized to simulate Navier-Stokes flow in the tomographic image.

**Results**

We analyzed 3D connectivity and anisotropy of pore network for 3 samples (ref1, ref2, and ref3) using geometry described by Figure 2 [2]. Numerical and experimental permeability results were determined and compared with the structural properties.

The permeabilities were analyzed experimentally, using special equipment, and numerically using the LBM. The results are shown in Table 1.

**Table 1: Experimental and numerical permeabilities**

<table>
<thead>
<tr>
<th>Sample id</th>
<th>$k_{xx}/k_{yy} [m^2 \cdot E^{-13}]$ Exp.</th>
<th>$k_{xx}/k_{yy} [m^2 \cdot E^{-13}]$ LBM</th>
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<tbody>
<tr>
<td>Ref1</td>
<td>1.09 / 1.08</td>
<td>1.14 / 0.854</td>
</tr>
<tr>
<td>Ref2</td>
<td>0.495 / 0.488</td>
<td>0.748 / 0.459</td>
</tr>
<tr>
<td>Ref3</td>
<td>4.46 / 4.44</td>
<td>27.3 / 20.3</td>
</tr>
</tbody>
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Average pore line segment length profiles for X- and Y- direction are shown as a function of sample thickness in Figure 3. And the pore chord orientation and length distribution results are shown in Figure 4. The results show a good agreement between material properties and permeability results.

**Figure 2**: Schematic illustration of analysis geometry showing three individual pores in 2D. Chords measure the distance and orientation between the centres of masses of neighbouring pores. Pore line segments measures the length of pore in particular direction.

**Figure 3**: Average pore line segment length (X- and Y- directions) profiles.
Conclusion
We have developed methods that allow us to study the structural properties of the sample while simultaneously comparing them to physical properties of the sample. CT allows us to analyze the both, structure and physical properties, of same sample and, thus, might reveal some new information of the phenomena.

References: