Quantitative Analysis of Microstructures in GDLs Using Local Structural Characteristics from 3D Image Data

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Transport processes in porous materials, such as the gas diffusion layer (GDL) in PEM fuel cells (Figure 1 and 2), strongly depend on the microstructure, especially the shape of the pore space, of the considered media. Therefore, the pore space is studied in more detail using an off-grid graph representation that allows for the computation of probability distributions of local structural characteristics such as tortuosity parameters or pore sizes [1]. The results can be employed for a structural comparison of different types of GDL materials, solely based on information from digital microscopic images. In Figure 1 and 2, two different GDL materials (mainly consisting of carbon fibers) are displayed in order to demonstrate the structural differences which lead to the assumption that the pore systems should differ as well. The results of our structural characterization using the graph representation of the pore systems allows then to describe the geometric differences in a quantitative way.

The detailed analysis of the 3D microstructure of the pore space is based on 3D images gained by means of synchrotron tomography [2]. The 3D image data are preprocessed and segmented to get binary representations with one phase describing the pore space and the other phase the solid phase, i.e., the carbon fibers and binder, respectively. In order to compute structural characteristics of GDLs, we apply a 3D skeletonization of the pore space, see e.g. [3], which is thereby described by (voxel given) line segments located in the ”middle” of the pore space, see Figure 3. These segments are transformed into vector data, i.e., Euclidean coordinates of the end points are given and connected by polygonal tracks. In other words, the pore space is replaced by a 3D off-grid graph. To take into account the local capacities of the pore space, we additionally mark the segments with the maximum radius of a ball that can be scrolled along them just touching the solid phase.

Besides global structural characteristics like the (mean) porosity we consider important local characteristics describing, e.g., local tortuosity parameters or pore sizes of GDL materials [1]. In particular, we compute the probability distributions of characteristics. The gained information is used to quantify the structural differences between the considered GDL materials, the paper-type GDL shown in Figure 1 and the velt-type GDL shown in Figure 2.

The tortuosity of a porous medium, one of the main structural characteristics next to the porosity, is defined as the ratio of the mean effective path length through a porous

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material and its thickness. We approximate the effective paths by a shortest-path approach along the edges of the 3D graph representing the pore space. The advantages of this method are on the one hand the fact that the shortest-path length along a graph is a uniquely defined structural characteristic which can be computed in a comparatively easy way and this length can be seen as a random variable, i.e., its probability distribution can be considered, which contains more information than the (physical) tortuosity, see Figure 4. However, we are aware that the effective paths through a material are in reality not always the shortest ones. Therefore a weighting of the shortest paths with the radius of a ball that can be scrolled along is used to get a more realistic approximation of the effective path length.

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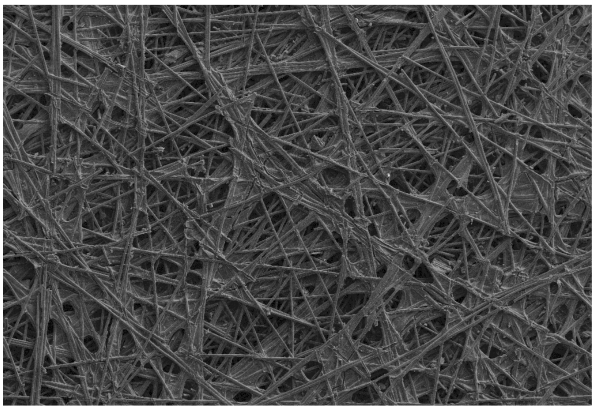

Figure 1. SEM image of a paper-type GDL

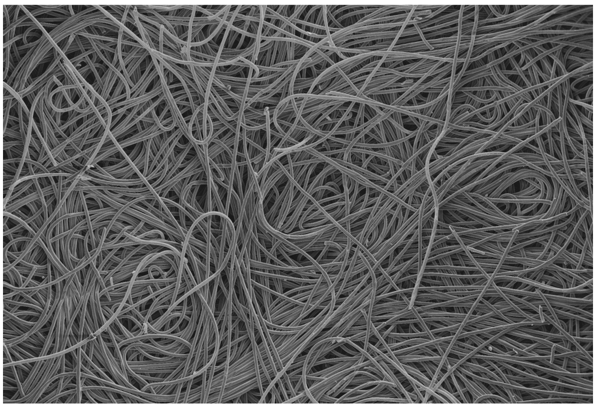

Figure 2. SEM image of a velt-type GDL

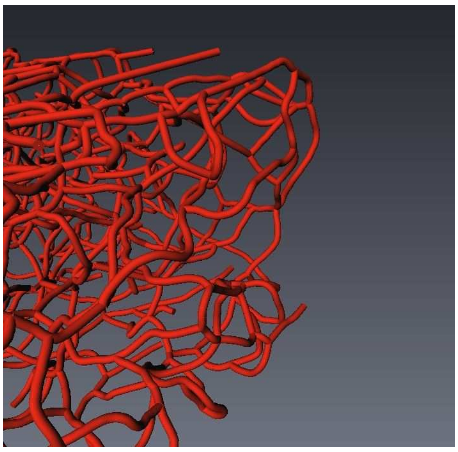

Figure 3. Skeleton, representing the pore space

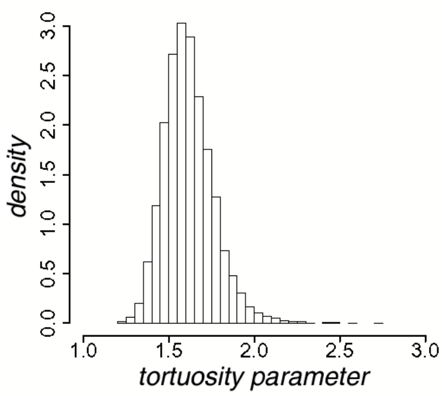

Figure 4. Distribution of a local tortuosity parameter

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