X-Ray Computed Tomography of PEM Fuel Cells

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Abstract

Proton exchange membrane (PEM) fuel cells were investigated by 3D x-ray computed tomography at a voxel size of 0.7 µm. It is shown that this lab-based technique is not only suitable for the investigation of gas diffusion layers (GDL) as well as the investigation of membrane electrode assemblies (MEA), but also allows the calculation of macroscopic physical properties.

The resolution of computed tomography is clearly sufficient to image the carbon fiber structure of gas diffusion layers in the as received GDLs as well as GDLs integrated into membrane electrode assemblies. It is also possible to visualize the catalyst layer within the MEA, which allows the investigation of layer thickness and structural defects on a larger scale than with conventional techniques.

The macroscopic effective thermal conductivities of the gas diffusion layers were computed based on the 3D GDL structure reconstructed from tomography data to produce more reliable input data for fuel cell modeling. The computation was carried out by solving the energy equation considering a pure thermal conduction problem. The computations show – in agreement with the expectation and experimental data – that the through-plane thermal conductivities are lower than the in-plane thermal conductivities.

Materials and Methods

Three different carbon fiber based gas diffusion layers were investigated: a carbon cloth EC-CC1-060T (ElectroChem, Woburn, USA), a Toray carbon paper EC-TP1-060T (ElectroChem, Woburn, USA) and a carbon paper Sigracet GDL 35 BC (SGL Group, Wiesbaden, Germany). Both samples from ElectroChem were treated with 30 wt% of PTFE by the manufacturer, the third sample from SGL Carbon contains 5 wt% of PTFE and has a microporous layer (MPL). Additionally, membrane electrode assemblies containing Sigracet GDLs were investigated before and after use, i.e. after 30000 square wave cycles between 0.7 V and 0.9 V.

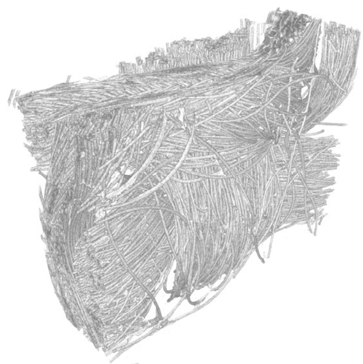

Figure 1: Carbon cloth EC-CC1-060T (thickness 330 µm) as imaged by x-ray computed tomography.

Strips cut from the sample were investigated by a nanotom® x-ray computed tomography system (GE Sensing & Inspection Technologies, phoenix x-ray, Wunstorf, Germany).

The computation of the effective thermal conductivity of fibrous materials requires the resolution of the steady, purely diffusive, three-dimensional heat transfer equation. In this work the commercially available GeoDict software (Fraunhofer ITWM, Kaiserslautern, Germany) was used to compute thermal conductivity. In this software, the energy equation is solved by harmonic averaging. Fast Fourier transform and biconjugate gradient stabilized (BiCGStab) methods are then used to solve the Schur-complement formulation [1].
PTFE could not be distinguished from the carbon fibers in the CT data using a simple thresholding method for construction of the 3D model. As an approximation, all solid voxels were assumed to have a thermal conductivity that was calculated as the weighted average of the thermal conductivity of the carbon fibres of 120 W m^{-1} K^{-1} and the thermal conductivity of PTFE of ca. 0.25 W m^{-1} K^{-1} (see last column of Table 1). Further details about the investigation of the GDLs can be found in [2].

Results and Discussion

Fig. 1 shows a reconstruction of the CT data of the carbon cloth EC-CC1-060T. The lateral resolution is sufficient to resolve the carbon fibers and the reconstruction shows that the cloth contains mainly curved fibers, as expected.
Table 1 shows the values for the thermal conductivity for in-plane and through-plane directions calculated for the different GDLs based on the 3D structure data. In addition, the thermal conductivity assumed for the solid voxels of the 3D model is given.

Sample	**Porosity**	**Thermal conductivity / W m^{-1} K^{-1}**			
		In-plane x	**In-plane y**	**Through-plane**	**Solid voxels**
EC-CC1-060T	75 %[a]	**5.6**	**6.2**	**1.4**	93
EC-TP1-060T	72 %[b]	**8.9**	**8.0**	**1.7**	93
Sigracet 35 BC (without MPL)	90 %[c]	**1.9**	**2.0**	**0.16**	114

[a] calculated based on measured area density
[b] calculated from data given by the manufacturer
[c] given by the manufacturer

Table 1: Thermal conductivities calculated for the different gas diffusion layers (together with the thermal conductivity used for the solid voxels of the 3D model).

Carbon fibers are highly conductive, but in most gas diffusion layers they are mostly mainly oriented in-plane i.e. perpendicular to the dominant direction of heat flow. Therefore, it can be expected that the in-plane thermal conductivity is dominated by the conductivity of the fibers while the through-plane conductivity depends strongly on the contact between the fibers. Overall, this results in a lower effective through-plane thermal conductivity.
This in agreement with the calculated results for all samples. The average in-plane thermal conductivity is larger than the average through-plane thermal conductivity by about a factor 4 for the carbon cloth, 5 for EC-TP1-060T and 13 for Sigracet 35 BC. The average in-plane thermal conductivities for both in-plane directions x and y agree for all samples within 5 - 11 %.

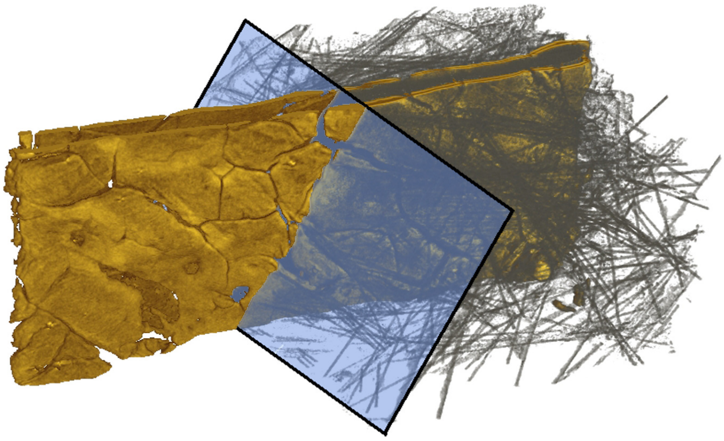

Figure 2: Membrane electrode assembly of a used PEM fuel cell (thickness 700 µm) as imaged by x-ray computed tomography.

Fig. 2 shows a reconstruction of the CT data of a membrane electrode assembly of a used fuel cell. Also for the imaging of a whole MEA – instead of only one GDL – the resolution is sufficient to image the carbon fibers. The electrode layers are shown in golden color. In the right part of the image, the fibers of the GDL are shown as well as the electrode layers. In the left part of the image only the electrode material is shown to show more clearly the fractures which were observed in the electrode layers. These fractures were also observed in an MEA before use and the similar fracture densities before and after use strongly suggest that the fractures are not related to fuel cell degradation. Even though in this case no significant difference was found when comparing MEA microstructure before and after use, CT can be a valuable tool for this comparison, e.g. to check the integrity of the electrode layer on the micro-scale.

Conclusions

Commercially available gas diffusion layers as well as membrane electrode assemblies were investigated by 3D x-ray computed tomography (CT). The carbon fibers were clearly resolved for both types of samples. Based on the 3D structure reconstructed from the complete CT datasets of the GDLs, the macroscopic, anisotropic effective thermal conductivities of the gas diffusion layers were computed and found in good agreement with experimental data.

References

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