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Influence of hydrophobic treatment on the structure of compressed gas diffusion layers

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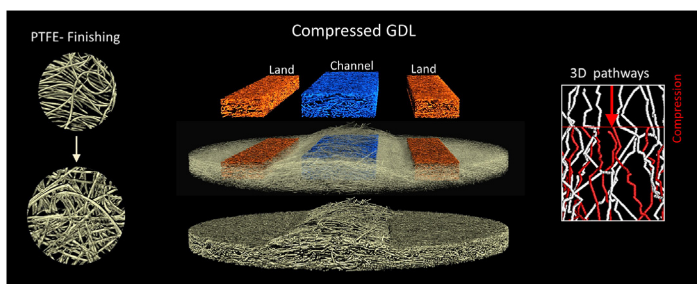
HIGHLIGHTS

- Tomographic study on the influence of PTFE-treatment on structure of GDL.
- Transport-relevant changes in microstructure and shape of compressed GDL detected.
- PTFE improves shape of compressed GDL underneath the channel.
- More continuous water transport paths available in PTFE treated material.
- PTFE-treatment enhances the water transport capacity of the porous material.

GRAPHICAL ABSTRACT



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ABSTRACT

Carbon fiber based felt materials are widely used as gas diffusion layer (GDL) in fuel cells. Their transport properties can be adjusted by adding hydrophobic agents such as polytetrafluoroethylene (PTFE). We present a synchrotron X-ray tomographic study on the felt material Freudenberg H2315 with different PTFE finishing. In this study, we analyze changes in microstructure and shape of GDLs at increasing degree of compression which are related to their specific PTFE load. A dedicated compression device mimicking the channel-land pattern of the flowfield is used to reproduce the inhomogeneous compression found in a fuel cell. Transport relevant geometrical parameters such as porosity, pore size distribution and geometric tortuosity are calculated and consequences for media transport discussed. PTFE finishing results in a marked change of shape of compressed GDLs: surface is smoothed and the invasion of GDL fibers into the flow field channel strongly mitigated. Furthermore, the PTFE impacts the microstructure of the compressed GDL. The number of available wide transport paths is significantly increased as compared to the untreated material. These changes improve the transport capacity liquid water through the GDL and promote the discharge of liquid water droplets from the cell.

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1. Introduction

The gas diffusion layer (GDL) is a key component for the liquid water and gas transport in polymer membrane fuel cells (PEFCs) [1–4]. It features a porous transport structure that allows the transfer of reactant gases from the flowfield channels to the electrodes and the concurrent removal of liquid water produced at the catalyst layer. At the same time, the GDL must keep the membrane humidified to maintain its proton conductivity. Careful adjustment of water transport and storage capacity of the GDL material is, therefore, an important aspect of fuel cell water management. There exist several types of carbon fiber based GDL materials with distinct microstructures. For instance, carbon paper GDLs consist of randomly orientated straight fibers, while the microstructure of carbon felt materials is characterized by curved fibers with random orientation. In contrast, carbon cloth GDLs are made of a woven carbon tissue, i.e. possess a regular microstructure. In general, the transport properties of a GDL are closely linked to its microstructure and can, furthermore, be adjusted by suitable finishing procedures. In particular, the application of hydrophobic additives such as PTFE as well as the addition of a micro porous layer (MPL) are common strategies to tune the transport behavior according to the requirements of specific applications. Precise understanding of the functionality requires, therefore, detailed knowledge about the GDL morphology including the spatial distribution of hydrophobic additives. In a fuel cell the GDL compression is a function of the clamping force. The influence of compression on fuel cell behavior is shown in Refs. [5,6].

Neutron [7–26] and X-ray [27–42] imaging are suitable noninvasive tools to investigate water and other liquid media in porous materials such as GDLs [43–52]. Neutrons have high penetration depths into most metals while they are very sensitive to hydrogen at the same time [53–56]. High resolution synchrotron absorption X-ray tomography provides excellent imaging conditions to analyze the microstructure of GDLs three-dimensionally [57–64]. In a previous paper, we reported on the impact of inhomogeneous compression on the microstructure of a carbon fiber-based felt material (GDL type H2315 produced by Freudenberg FFCCT) [65].

The present work covers a high-resolution synchrotron X-ray tomographic study on PTFE coated GDL materials (Type H2315 T10A and H2315 T20A produced by Freudenberg). While focusing on the same carbon felt material, the actual scope is to analyze the influence of hydrophobic treatment on shape and microstructure of inhomogeneously compressed gas diffusion layers including the evaluation of its potential consequences for the liquid water and gas transport.

2. Methods and materials

2.1. Imaging conditions

The experiments were performed at the synchrotron light source BESSY II (Helmholtz-Zentrum Berlin/Germany) using the tomography station of the BAMline [66]. The imaging conditions were adapted to the previous study of compressed GDLs [65,67]: A W-Si multilayer monochromator with an energy resolution of $\Delta E/E = 10^{-2}$ was used to turn the white synchrotron X-ray beam into a monochromatic beam. The beam energy was adjusted to 15 keV where contrast for fiber material was optimal. A PCO camera (4008 × 2672 pixels) in combination with a lens system and a 20 μm thick CWO scintillator screen provided a pixel resolution of 0.88 μm, i.e. a respective physical spatial resolution of about 2 μm, capturing a field of view of 3.6 × 2.3 mm^2 [68]. The incident beam was narrowed to the field of view by a slit system in order to avoid detector backlighting [69]. A sample holder bearing circular GDL samples of 3 mm diameter was mounted on a translation/rotation stage. During tomography, the sample was stepwise rotated over an angular range of 180°. A radiographic set of 1500 projections and 500 flat-field images was acquired and subsequently reconstructed to a 3D image volume. The exposure time was 2.5 s plus 1.7 s readout time for a single radiograph adding up to an acquisition time of 140 min for an entire tomogram.

2.2. Sample compression device

A dedicated compression device designed and constructed at Forschungszentrum Jülich was used to provide well-defined compression conditions during tomography.

A detailed description and illustration of the compression tool is provided by Tötzke et al. [70]. The main components of the device are a base unit with a circular platform (Ø 3 mm) on which the sample is placed on and the main compression unit including the compression punch. The main unit is fastened to the top of the base element allowing for quick and easy exchange of GDL samples. A 0.8 mm wide and 1.0 mm deep channel profile was manufactured into the punch to mimic the channel-land-pattern of the flowfield, thus reproducing the local pressure conditions found in a fuel cell. Vertical positioning of the punch with an accuracy of about ±5 μm, allowed for precise adjustment of the GDL compression.

2.3. Materials

H2315 is a nonwoven, carbon fiber-based felt material produced by the company Freudenberg FFCCT. It is used as standard GDL in many fuel cells where its physical properties are adapted to the requirements of the respective application, e.g. by adding water proofing compound. The present investigation focusses on the influence of PTFE finishing on microstructure and shape of GDLs. Two PTFE treated H2315 GDL types, T10A and T20A containing 10 wt% and 20 wt% PTFE, were chosen and compared to the untreated material. The thickness as specified by the manufacturer at precompression of 0.025 MPa are $Z = 218$ μm, 212 μm and 216 μm for H2315 (without PTFE), H2315 T10A and H2315 T20A, respectively. The precompression is applied to create a plain and smooth GDL surface needed for the thickness determination. Further manufacturer specifications for the GDL materials under study can be found in the supplementary material (see Table S1).

Circular samples with a diameter of 3 mm were prepared and placed in the compression device. High resolution synchrotron X-ray absorption tomograms were acquired at four different degrees of compression: 0 vol%; 10 vol%; 20 vol% and 30 vol%. The actual compression values do slightly deviate ($\Delta C \leq 1.4\%$) due to the accuracy limits of punch adjustment ($\leq \pm 5$ μm). For all sample H2315 the initial thickness underneath land of Z_0 was successively reduced to Z_{10}, Z_{20} and Z_{30} with corresponding degrees of compression of C_0, C_{10}, C_{20} and C_{30}. The actual values for Z and C as measured in the reconstructed sample volumes are stated in Table 1. Note that we refer to manufacture specification of Z when calculating the degree of compression.

3. Results and discussion

In this section, we present a synchrotron tomographic analysis of compressed carbon felt GDL materials with different PTFE finish. The influence of the hydrophobic agent on shape and microstructure of GDL is evaluated and implications for the water and media transport are discussed. Two samples H2315 T10A and T20A containing 10 and 20 wt% PTFE, respectively, are measured and