ABSTRACT
In this work, micro-computed tomography was employed to characterize the effect of rib and channel compression on the through-plane porosity distributions of polymer electrolyte membrane fuel cell (PEMFC) gas diffusion layers (GDLs). Two GDLs with micro-porous layers (MPLs): a paper based GDL (GDL A), and a felt GDL (GDL B) were compressed at 1.2 MPa in an ex situ flow field apparatus with 1mm x 1mm channels. Porosity distributions of compressed GDLs were compared with those of uncompressed GDLs, and the microstructural differences caused during the manufacturing of paper, felt, and cloth GDLs are discussed. The results of this study will aid modellers in generating realistic stochastic GDL pore structures for multiphase flow simulations.

INTRODUCTION
The porous gas diffusion layer (GDL) in a polymer electrolyte membrane fuel cell (PEMFC) plays an important role in providing pathways for reactants to reach the catalyst layer, and product water to reach the exhaust channels. The GDL exhibits high electronic conductivity and provides the added benefit of structural stability for the membrane electrode assembly (MEA) [1]. Although the GDL is typically treated to be hydrophobic to enhance liquid water wicking, excess liquid water presence prevents reactants from reaching the catalyst layer thereby decreasing the performance of the fuel cell [1-4]. Through an improved understanding of GDL material properties such as porosity and hydrophobicity, new materials can be designed for enhanced water management strategies. Both water generation and fuel cell compression decrease the porosity of a GDL, which in turn decreases the available pore space for reactant transport.

While over-compression can damage the GDL [5, 6], it is known that an optimal amount of compression is needed to maximize the fuel cell performance [7-11]. Using a specially designed fuel cell, Ge et al. [8] observed that there is an optimal GDL compression ratio for maximizing the fuel cell performance in both paper and cloth GDLs. They also noted that compression affected the performance of paper GDL to a greater extent than that of the cloth GDL. Roshendal et al. [12] found that a decrease in the average porosity led to a decreased oxygen consumption thereby decreasing the fuel cell performance. Additionally, they noted that the change in porosity has a greater effect on the performance of a fuel cell operating at a higher current density as opposed to one operating at a lower current density.

Fishman et al. [13], used computed micro-tomography (μCT) to calculate through-plane porosity profiles of uncompressed GDLs, where the term through-plane porosity profiles refers to the porosity distribution of the GDL along its
thickness. Though Hinebaugh et al. [14], used through-plane porosity profiles of uncompressed GDLs as inputs of their stochastic GDL model, the effect of compression on the porosity of a GDL was not considered. Recently, Wang and Chen [15] modelled the liquid water distribution in GDLs using spatially varying GDL properties and uniform land compression ratio as their inputs. Since the GDL experiences compression in an operating PEMFC, it is important to investigate the impact of this compression on the GDL. In the work presented here, through-plane porosity distributions of various compressed GDL microstructures are determined from 3D reconstructions of μCT visualizations. To the author’s best knowledge, this is the first comprehensive experimental investigation into characterizing the compressed GDL pore structures of varying microstructures to date. Results from this study will help these modellers improve their GDL modelling by using the through-plane porosity distributions provided here to inform their GDL reconstructions.

METHODS

The porosity of a GDL varies from microstructure vis-à-vis paper, felt, and cloth, and is an important design parameter for GDL manufacturers. The effect of compression on the pore structure of a) paper based GDL (GDL A), and b) felt based GDL (GDL B) is investigated in this paper. To test the compression effects, GDL samples (5 X 4 mm²) are compressed to 1.2 MPa in a compression device using a torque wrench. The base plate of the compression device has two channels that are 4 mm long, 1 mm wide, and 0.5 mm deep, mimicking the flow field in a fuel cell. The applied compression on the GDL is calibrated using Prescale pressure sensitive films (Tekscan Inc., Boston, MA). This technique was also used by Tan et al. [11], to arrive at a relation between the applied torque and translated pressure on the GDL in a fuel cell.

Image Processing

Figure 1 pictorially depicts the process of reconstruction starting from a raw in-plane image. After reconstructing the obtained 2D raw images, a through-plane cross-section of the reconstructed 3D pore space is processed using an edge detection algorithm to identify the edges of the GDL. After detecting the edges of the GDL, the GDL is cropped out of the device and is binarized using a variant of the IsoData thresholding method. From the 3D binary microstructure, the through-plane porosity profile is obtained by calculating the porosity values of pixel thick in-plane slices and plotting them against their through-plane position in the GDL. A typical through-plane cross-section of a reconstructed GDL, identifying the different phases such as the compression plate, the GDL, and the flow field, is shown in Fig. 2(a). Fishman et al. [13] observed that the minimum representative area to extract porosity profiles from a GDL is 1 mm². This ensured that porosity distributions of GDLs lie within 4% of the published curves. Given that, the porosity profiles are obtained from sample sections that had an area greater than 1 mm².

Thresholding

Thresholding is a histogram-based technique that is used to find a ‘threshold’ value, which is necessary to convert a greyscale image into a binary image. Various thresholding techniques have been proposed in the past: Fishman et al. [13] used Otsu’s method, whereas Jhon g et al. [16], in a recently published paper, use a visually determined threshold and AMIRA’s filament tracing method to binarize a GDL. In this work, FIJI, a free and open source image processing software, was used to binarize GDLs using a variant of the IsoData technique. It was observed that this variant of IsoData produced similar results as the Otsu’s method, when the GDL was binarized by individually binarizing the pixel-thick in-plane slices based on their corresponding greyscale histograms.
Figure 2: (a) A 2D reconstructed μCT through-plane slice of GDL B compressed between the flow field and the compression plate of the compression device. (b) A through-plane slice of GDL B compressed under a channel obtained after cropping the reconstructed image in 2(a). (c) 2(b) after running the Edge Identification algorithm. (d) Edge Identification based on the rate of change in the average intensity of the in-plane slices.
RESULTS

To study the effect of compression in a GDL, it is important to compare the compressed GDL porosity profiles with the uncompressed GDL porosity profiles. In Fig. 3, the porosity profiles of uncompressed, rib compressed, and channel compressed GDLs A and B are plotted with their centers aligned. From Fig. 3, it can be noted that both the average uncompressed, and the average compressed porosity values of paper based GDL A are higher than that of GDL B. Additionally, we can notice that the through-plane compression in both the GDLs is not uniform, and that it affects the surface regions of the GDL more than the bulk region of the GDL. Also, the effect of compression appears much higher on the felt based GDL than the paper based GDL, which means that paper GDLs have a greater number of pore spaces available for product and reactant transport. In both Fig. 3 (a) and (b), it can further be observed that the compressed porosity on the MPL side seems higher than the uncompressed porosity on the MPL side. It is because the uncompressed sample was discarded after the scan and a new sample was cut to obtain the compressed 3D reconstruction. Additionally, the compressed porosity profile is the average porosity profile of two separate samples of a GDL, whereas the uncompressed porosity profile is obtained from a single sample.

Figure 3: Center aligned plots of uncompressed, rib compressed, and channel compressed porosity profiles of (a) GDL A and (b) GDL B.

DISCUSSION

Paper and felt GDLs are both made of non-woven carbon fibers. A binder material, typically poly-vinyl alcohol, is added to paper based GDLs to hold the fibers together, whereas the fibers in felt based GDLs are held together by a hydro-entanglement process [1]. Both paper based GDLs and felt based GDLs are then treated with a hydrophobic coating to minimize water accumulation, and subsequently a micro-porous layer (MPL) coating is applied to aid in water management. Though paper and felt are essentially comprise of non-woven carbon fibers, the dissimilar techniques used to bind those non-
woven carbon fibers in paper and felt GDLs create pore structures that are distinct from each other.

The MPL-GDL transition regions (i.e., when the porosity starts to increase after its initial decrease on the MPL side) in the uncompressed GDL A, and GDL B porosity profiles indicate that the MPL application techniques used to apply MPLs on the GDLs are dissimilar. In GDL A, the porosity drops again after the transition region, whereas in GDL B the MPL transitions into the GDL. Scanning the untreated and PTFE treated GDL A samples will further help in characterizing the change in porosity due to this particular MPL application technique. From Fig. 3, it can be observed that the difference between the average MPL porosity and the average bulk GDL substrate porosity is higher for GDL B, which could make GDL B more suited for high temperature fuel cells applications. However, these GDLs need to be characterized in an in-situ experiment to before detailed comments can be provided on the effect of MPL application technique on the performance of a PEMFC.

From Fig. 3, it can also be concluded that the effect of compression is more significant for the felt based GDL than for the paper based GDL, indicating that paper GDLs have a greater number of pore spaces available for product and reactant transport. This could be attributed to the presence of paper’s binder material, employed to hold the fibers together. The presence of binder material increases the stiffness of paper GDLs thereby making them capable of resisting compression to a greater extent than felt GDLs. However, a comment on the effective porosity, i.e. pore space available for reactant transport, can only be made after investigating the liquid water distribution in these GDLs.

CONCLUSION

In conclusion, a systematic technique was developed to experimentally characterize the effect of compression on GDLs, including the abilities for GDL edge identification and thresholding techniques, using open source image processing software (FIJI). The MPL application method used on GDL A is observed to be dissimilar from the application method used on GDL B. From the compressed scans, it was observed that the effects of compression in a GDL are not uniform through-out the thickness of the GDL, and that the effects of compression are greater for the felt based GDL B than for the paper based GDL A. The data presented in this paper will provide insights on the effect of compression on the spatially varying porosity of a GDL and can be used to inform the development of stochastic GDL models.

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REFERENCES
