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The Impact of Cathode Gas Diffusion Layer Structure on Fuel Cell Performance

Nicholas McCarthy*, Ahmad El-kharouf**, Rui Chen*, Waldemar Bujalski**

* Dept. Aeronautical and Automotive Engineering, Loughborough University, LE11 3TU, U.K. ** PEM Fuel Cell Research Group, Centre for Hydrogen and Fuel Cell Research, School of Chemical Engineering, The University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

Abstract

Four gas Diffusion Layer (GDL) materials have been investigated. Each Membrane Electrode Assembly (MEA) was manufactured with identical catalyst and binder loadings. MEAs were tested in-situ using a ‘Fuel Cell Component Analyser’ and polarisation curves produced and compared. GDL properties obtained in a previous work were considered for the analysis of the results. Results show differences in the polarisation response for different GDL structures; indicating changes in resistance loss, mass transport loss, and the flooding effects on fuel cells due to GDL structure.

Introduction

Polymer Electrolyte Membrane Fuel Cells (PEMFCs) offer the potential of efficient, sustainable power solutions for the future. A key element in these devices is the Gas Diffusion Layer (GDL). It is critical for the transport of reactants to the catalyst active sites, the transport of charge into and out of the cell, and water management in the MEA. The variation in performance for different GDLs has been reported in the literature \(^1,2\). The difference is explained by the variation in the characteristics of the samples tested, however, due to the many variables in the GDL materials properties, explaining the variation in GDL performance can prove to be challenging. Some studies have focused on testing GDL properties in order to achieve a better understanding of GDLs behaviour and the relationship between the different properties \(^3,4,5\).

Usually, a GDL consists of a carbon fibre substrate that is carbonised and teflonated. Commonly GDLs have a Micro-Porous Layer (MPL) painted on one side of the substrate to enhance water transport away from the catalyst layer, and provide a smooth surface with lower contact resistance for the catalyst layer. Different fibre structures are used for GDLs, namely; woven cloths, non-woven straight fibres paper, and non-woven felt paper. The fibre structure of the substrate in the GDL plays an important role in its
function and therefore affects the performance of the cell. Previous work has indicated that woven carbon GDLs have higher power densities \(^{(6)}\), \(^{(7)}\) and are more efficient at higher humidity \(^{(8)}\). In comparison non-woven carbon fibres, ‘Papers’ and ‘Felts’, are competitive on price, easier to work with, and mechanically stiffer (which in turn facilitates the design of simpler flow field geometries in the fuel cell).

This paper discusses preliminary results to date of in-situ testing for MEAs of different GDLs with the variation of structure and bulk density.

**Method**

Two, Intelligent Energy Ltd (I.E. Ltd), Fuel Cell Component Analysers (FCCA) were used to establish baseline measurements on a wide variety of commercially available GDLs. Both consist of four test chambers, each with independent anode and cathode gas flow and pressure control. Cell humidification is achieved through a humidification membrane supplied by the exhaust gases from the cell reaction, achieving 100% relative humidity once a steady state is established\(^{(9)}\).

The fabricated MEAs active surface area is 11.34 cm\(^2\). The mono-polar plates used are graphite, with a circular, single serpentine, flow field.

The Gas Diffusion Electrode (GDE) anode material was held constant. Commercial JM electrode ELE00165 is used with a catalyst loading of 0.4 mg.cm\(^{-2}\). A variety of other GDLs were tested on the cathode side. TKK Pt/C catalyst based ink was hand painted on the GDLs to achieve a loading of 0.4 ±0.05 mg.cm\(^{-2}\). Nafion 212 Polymer Electrolyte Membranes (PEM) are used. The electrodes and the membrane are hot pressed at 125°C and 1800kg. The following cathode materials are presented in this paper. All cathode GDLs had a Micro Porous Layer (MPL) on one side of the GDL.

- E-TEK LT1200N (Non-woven carbon paper)
- E-TEK LT1200W (Woven carbon cloth)
- Sigracet SGL 24 BC (Non-woven carbon paper)
- Sigracet SGL 25 BC (Non-woven carbon paper)
- Sigracet SGL 34 BC (Non-woven carbon paper)
- Sigracet SGL 35 BC (Non-woven carbon paper)

Three MEAs of each cell type were fabricated to limit any errors resulting from MEA fabrication and during testing.

<table>
<thead>
<tr>
<th>product code</th>
<th>measured data</th>
<th>in plane resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT1200N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT1200W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDL 24 BC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDL 25 BC</td>
<td></td>
<td></td>
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<tr>
<td>GDL 34 BC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDL 35 BC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Selected materials data for GDLs \(^{(3)}\)
The study will focus on the samples LT1200W and LT1200N to study the effect of structure, and SGL 24BC and SGL 25BC to study the effect of substrate bulk density. Samples SGL 34BC and SGL 35BC are also analysed in this paper.

The MEAs were soaked in deionised water (resistivity = 18MΩ.cm) overnight to accelerate the membrane activation process. The MEAs were then randomly assigned to one of seven test chambers for in-situ testing, under the following operating conditions:

- H₂ flow rate: 80 sccm
- Air flow rate: 200 sccm
- Back pressure: 2 Bar
- Cell temperature: 70°C (+/- 2°C)
- Data logging rate: 1 Hertz
- Relative humidity: 100%

MEA ‘conditioning’ was achieved by holding the cells at variable current load to induce a potential of 0.6 ± 0.03 V for a period of three hours. Once completed the MEA was subjected to 25 ‘rapid’ polarisation curves. A three second time step was initiated, with 25 current settings increasing to the maximum current load achievable by the MEA. Polarisation curve number 25 of the sequence was recorded. A further polarisation curve with a 10 second step time was also carried out and recorded. Polarisation curves are plotted by averaging the V / I values across each time step.

Results

Figure 1: polarisation curves for all GDLs
Figure 2: polarisation curves for all GDLs with peak power

Figure 2 shows the result of the polarisation curve from the best, representative, test sample from each material.

Figure 3: Comparison of LT1200W and LT1200N samples
Figure 3 shows a higher performance for the non woven LT1200N compared to the woven LT1200W.

Figure 4: Comparison of 24BC and 25BC samples

In Figure 4 we see a reduced performance for the 25BC variant of GDL.

Figure 5: Comparison of 34BC and 35BC samples
Figure 5 shows a more uniform performance from the two GDLs, with 34BC being marginally better, especially in the mass transport section of the curve

**Discussion**

Comparison of the ‘LT’ variant GDLs in Figure 3, show that the non woven GDL outperforms the woven sample. Closer examination of the temperature during testing shows that the non woven GDL was actually tested at a significantly lower temperature (65.9°C for LTN 2A, compared to 70.2°C for the LTW 3A test sample). This leads to the conclusion that the improved performance of the LTN sample has actually been suppressed by the test conditions. Comparison to Table 1 shows that hydrophobicity (indicated by water contact angle), resistivity and permeability values are similar. Density, thickness, porosity and mean pore diameter are all significantly different. It should be kept in mind that the test cells have undergone uniform clamping pressures, and gasket heights have not been optimised for each GDL. The increased thickness for the woven sample (LTW) could limit the effective porosity of the material still further through excessive clamping force.

The 24 and 25 BC GDLs are examined in Figure 4 and in this case there is a similarity in the GDL thickness, with porosity, density mean pore diameter and water contact angle differ. In the BC tests, both samples have been tested in a narrower temperature range (68.7°C and 72.1°C respectively). If we refer to the previous results for the LT woven and non-woven materials; we see that smaller mean pore diameter and a greater porosity volume are linked to improved performance.

In the 34 BC and 35 BC GDLs we can examine the mean pore diameter and total porosity. Table 1 reveals a smaller mean pore diameter and a larger total pore volume in 35 BC. From our recent discussion we would expect to see 35 BC as outperforming the 34BC GDL. However comparison to Figure 5 at first glance indicates that 34 BC is marginally superior. The test temperature for the two samples was extremely uniform, with 70.3°C for the 34 BC and 69.9°C . This narrow temperature range should not have a significant impact based on our previous observations. The thickness of the sample is also at the higher end of the ranges tested, with 35 BC being the thickest of all the GDLs tested. The compression force experienced in the test cell will be greatest for this material. Plotting the peak power for these two samples, shows a very close match between the two, and the highest recorded peak power in this set is 0.3847W.cm⁻² for sample 35 BC, exactly as predicted. We suggest that the effect could be even more pronounced if the gasket height were optimised for both of these samples (thereby eliminating excessive compression forces closing of the porous structure).
Figure 6: Peak power 34 BC and 35 BC

Table 2: Key material properties and measured outputs

<table>
<thead>
<tr>
<th></th>
<th>24BC 2A</th>
<th>25BC 2A</th>
<th>34BC 2A</th>
<th>35BC 1A</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature during test</td>
<td>68.7</td>
<td>72.1</td>
<td>70.3</td>
<td>69.9</td>
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<tr>
<td>mean pore D</td>
<td>2.45</td>
<td>0.84</td>
<td>2.20</td>
<td>1.47</td>
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<tr>
<td>% porosity</td>
<td>40.0</td>
<td>36.5</td>
<td>47.5</td>
<td>52.6</td>
</tr>
<tr>
<td>Ohmic Loss</td>
<td>-0.4456</td>
<td>-0.4109</td>
<td>-0.4017</td>
<td>-0.4084</td>
</tr>
<tr>
<td>Rate of Mass transport Loss</td>
<td>-2.7576</td>
<td>-2.305</td>
<td>-2.1787</td>
<td>-3.889</td>
</tr>
<tr>
<td>maximum current</td>
<td>0.7561</td>
<td>0.7391</td>
<td>0.7411</td>
<td>0.7388</td>
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<tr>
<td>Peak power</td>
<td>0.3570</td>
<td>0.3958</td>
<td>0.3835</td>
<td>0.3947</td>
</tr>
</tbody>
</table>

Table 2: Key material properties and measured outputs
Initial Observations:

Based on the tests to date (55 of 90 test specimens completed):

- Woven structures do not out-perform non-woven materials in these tests
  - This may be due to the lack of cell optimisation for the increased through plane thickness of the woven sample used
- Reduced mean pore size and increased total porosity dominate in determining peak power output for MEA assemblies

Future work

- Complete remaining samples in this test run
- Identify preferred examples for further study in each type (woven and non-woven)
- Optimise clamping force and gasket thickness for next series of tests to establish dominance or otherwise of woven structures compared to mean pore size in non-woven materials

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References


