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Effect of gas diffusion layer compression on PEM fuel cell performance

Jiabin Ge, Andrew Higier, Hongtan Liu *

Department of Mechanical and Aerospace Engineering, University of Miami, Coral Gables, FL 33124, United States

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Abstract

The gas diffusion layer (GDL) plays a very important role in the performance of Proton Exchange Membrane (PEM) fuel cells. The amount of compression on the GDL affects the contact resistance, the GDL porosity, and the fraction of the pores occupied by liquid water, which, in turn, affect the performance of a PEM fuel cell. In order to study the effects of GDL compression on fuel cell performance a unique fuel cell test fixture was designed and created such that, without disassembling the fuel cell, varying the compression of the GDL can be achieved both precisely and uniformly. Besides, the compression can be precisely measured and easily read out. Using this special fuel cell fixture, the effects of GDL compression on PEM fuel cell performance under various anode and cathode flow rates were studied. Two different GDL materials, carbon cloth double-sided ELAT and TORAY^{TM} carbon fiber paper were used in these studies. The experimental results show that generally the fuel cell performance decreases with the increase in compression and over-compression probably exists in most fuel cells. In the low current density region, generally there exists an optimal compression ratio.

Keywords: PEM fuel cell; Gas diffusion layer; GDL compression

1. Introduction

Generally, a GDL made of either carbon fiber paper or carbon cloth is used in a PEM fuel cell and it plays a very important role in the cell performances [1]. Desirable functions of an ideal GDL include effectively transporting the reactant gas to the catalyst layer and removing liquid water to the gas channels, conducting electrons with low resistance, and having a low contact resistance at the various interfaces. The mass transport in the diffusion layer has been shown to have a strong effect on PEM fuel cell performance [2].

In a fuel cell stack, the cell components are held together under high compressive loads mainly to prevent gas leakages. Gas leakages would cause poor performance and lead to potentially dangerous situations; while over-compressing the GDL increases mass transfer resistance and thus reduces cell performance. High contact pressure can decrease the contact resistance and it has been shown that physical compression of the gas diffusion layer directly increases its electrical conductivity [3].

Lee et al. [4] studied the effect of GDL compression with three different GDL materials, but the results are difficult to be generalized since the compressions are characterized by the torque on the bolts that clamp the fuel cells.

The objective of this study was to determine the effects GDL compression on fuel cell performance for different types of diffusion layers and under different fuel cell operating conditions. The compressions were measured by the compression ratio, which can be easily duplicated and generalized. Two types of gas diffusion layers studied in this experiment are carbon fiber cloth double sided ELAT and carbon fiber paper TORAY^{TM}. Using the specially designed fuel cell test fixture the compression can be easily and precisely adjusted by changing the separation between the anode and cathode collector plates. The test fixture permits the user to test fuel cell performance at different GDL compressions without disassembling the fuel cell; moreover, this unique design allows for an accurate reading of the GDL compression.

2. Experimental

The fuel cell test station was manufactured by Fuel Cell Technologies Inc. and its description was given in [5]. The test fuel cell used in this work was specially designed to ensure precise

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* Corresponding author. Tel.: +1 3052842019; fax: +1 3052842580.
E-mail address: hliu@miami.edu (H. Liu).

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and uniform compression and the amount of compression can be changed without disassembling the fuel cell. The compression ratio of the GDL is defined as the ratio of the operating thickness to its original thickness. This thickness can be varied while the cell is running and without disassembling the cell. Also, the compression ratio can be constantly measured with two gauges, one on each side of the cell. This unique single cell design yields results that previously would have been otherwise unattainable with any commercial single cell test fixture.

2.1. *The single cell fixture*

As shown in Fig. 1, the special fuel cell consists of a regular membrane, electrodes and GDL assembly, two collector plates, anode and cathode end plates, an additional compression end-plate, and a central compression screw and eight boundary compression screws.

In order to achieve a uniform compression, the compression force was distributed across one endplate, then having the endplate compress the collector plates. Besides, further uniform compression and incremental compression changes are achieved by placing another plate, termed the compression plate, in front of the endplate, and by placing a large center screw through a finely threaded hole in the compression plate. The central screw, together with the eight tie-rods acts as the driving mechanism in changing the compression across the fuel cell. Finite element analyses were performed on the end plates as well as the compression plate and the results showed that the bending deformations of the end plates were negligible.

It is well known that the performance of a fuel cell changes considerably when a fuel cell is disassembled and re-assembled, even if the compression can be precisely duplicated. This is due to the compressive loads that are repeatedly placed on the GDL and MEA when the cell is assembled and dissembled. Thus, to study the effect of GDL compression on the fuel cell performance, the amount of compression needs to be varied without disassembling the fixture. Such requirement precludes the regular sealing technique and poses a challenge for the design. To satisfy this requirement, rubber gaskets with a special sealing arrangement was devised. This arrangement can ensure sealing at low compression and allow for high compression. The ability for the fuel cell test fixture (Fig. 2) to vary the compression is unique in that this operation may be performed without disassembling the test fixture. This fixture also allows the user to vary the compression while cell is running and see the effects of compression change in real-time. There is no such test fixture available on the commercial market today. These tests results would not have been possible without first designing and building this unique fixture.

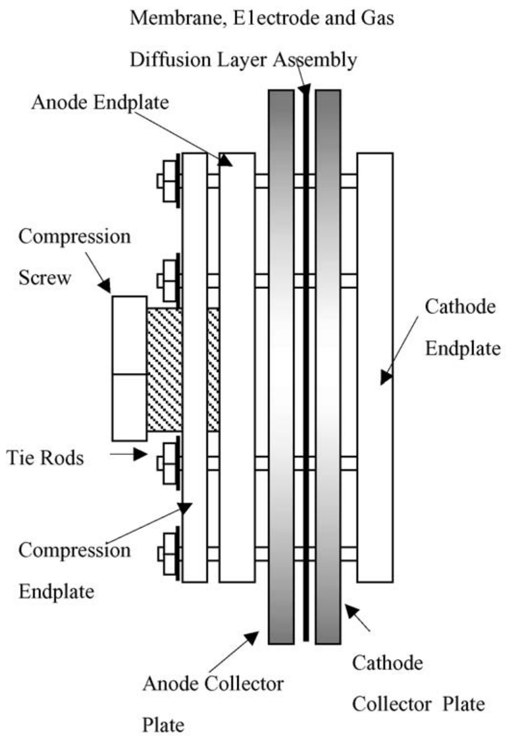

Fig. 1. The schematic of the precision–compression fuel cell fixture.

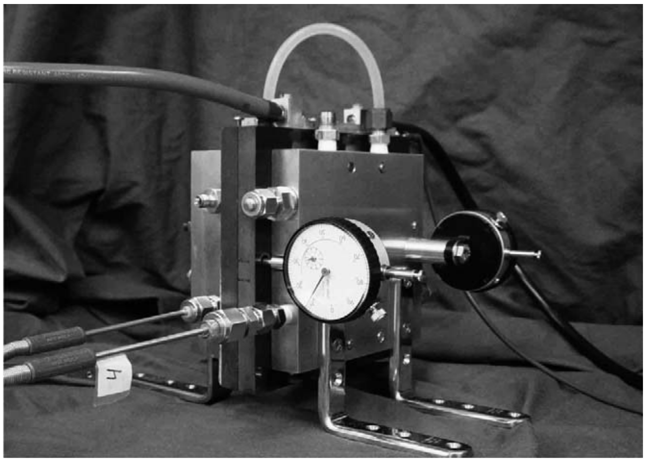

Fig. 2. A photograph of the assembled test fuel cell fixture.

To ensure relative uniform temperature across the fuel cell, a liquid cooling/heat loop ran through both the anode and cathode endplates and the liquid was circulated through an isothermal bath with precision temperature control. In addition, to increase the usability of the fuel cell fixture, a simple electrical heating and fan cooling method can also be used. Two cylindrical electrical heaters can be placed in the center of both the cathode end plate and the anode endplate to provide heating. The electrical heating can be used where an isothermal bath unit with precision temperature control is not available.

2.2. *Experimental materials and operation conditions*

Two types of gas diffusion layers were used. An ELAT carbon cloth with double micro-diffusion layers and a carbon fiber paper TORAY^{TM} with an added micro-diffusion layer to the surface that was in contact with the catalyst layer. These two types of GDLs were chosen because they are the most common among the industry and between the two of them, represent a major portion of the GDL market. Though there are a wide variety of GDLs available on the market today, almost all of them fall into the category of carbon paper or carbon cloth GDL. These GDLs were chosen also because they are widely accepted as the industry standard.

The membranes used were Nafion 115 with a 50 cm^2 active area and a platinum loading of 0.4 $mg\,cm^{-2}$ on both the anode and cathode sides. A flow field with a single serpentine channel and 31 passes was used. The compression of the gas diffusion layers was varied unidirectionally, from low to high. This was done without ever disassembling the fuel cell. The operating conditions were as follows unless stated otherwise. Fuel cell temperature and pressure were 65 °C and 101 kPa, both anode and cathode humidification temperatures are 80 °C, and the time intervals between readings were 30 s.

2.3. Operation process

Systematic tests on the sealing were conducted to determine the minimal compression for proper sealing. For each set of experiments, the fuel cell was assembled and the compression was set at a value a little above the pre-determined minimal compression to ensure good sealing. Then a leak-check was performed to ensure no-leakage. After the leak-check, the fuel cell was run at pre-determined operating conditions. Then the compression was increased a small amount and the test was repeated at the same operating conditions. This procedure continued till the maximum compression was reached. The operating conditions were as follows unless stated otherwise. The fuel cell temperature and pressure were 65 °C and 101 kPa, both anode and cathode humidification temperatures were 80 °C, and the time intervals between readings were 30 s. A break-in test using pure oxygen was carried out to ensure the cell performance was stable during the compression experiments. For each compression condition, several tests were conducted to verify the performance was repeatable under the same operational conditions.

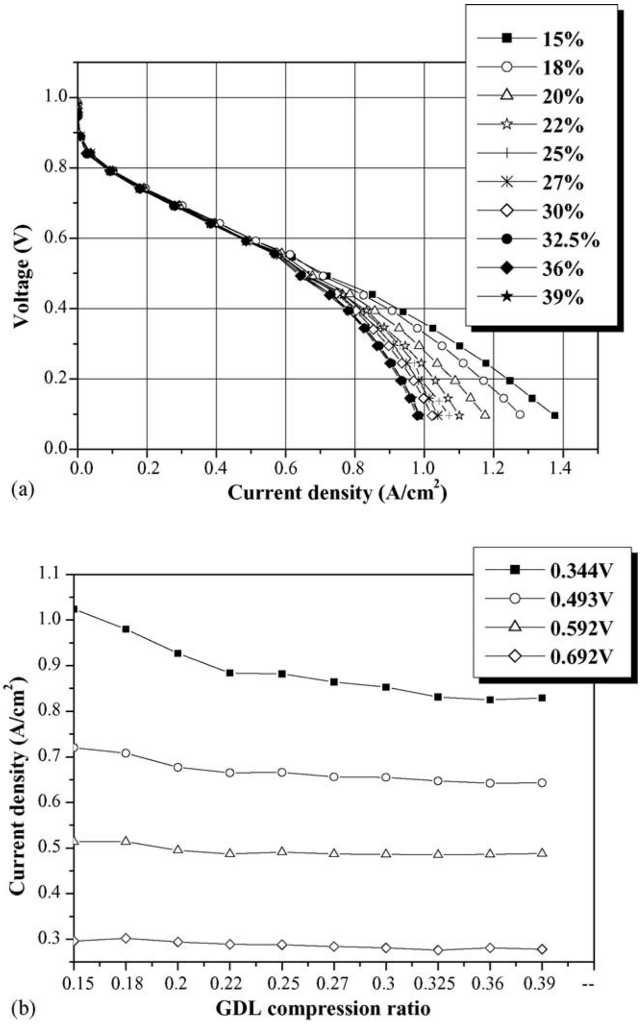

Fig. 3. Effect of compression with carbon cloth as GDL. (a) Polarization curves at different compressions; (b) current density vs. compression at different cell voltages. Anode H_2 flow rate 600 sccm, air low rate 2200 sccm, cathode back pressure 1 atm, cell temperature 65 °C, anode humidification temperature 80 °C, and cathode humidification temperature 80 °C.

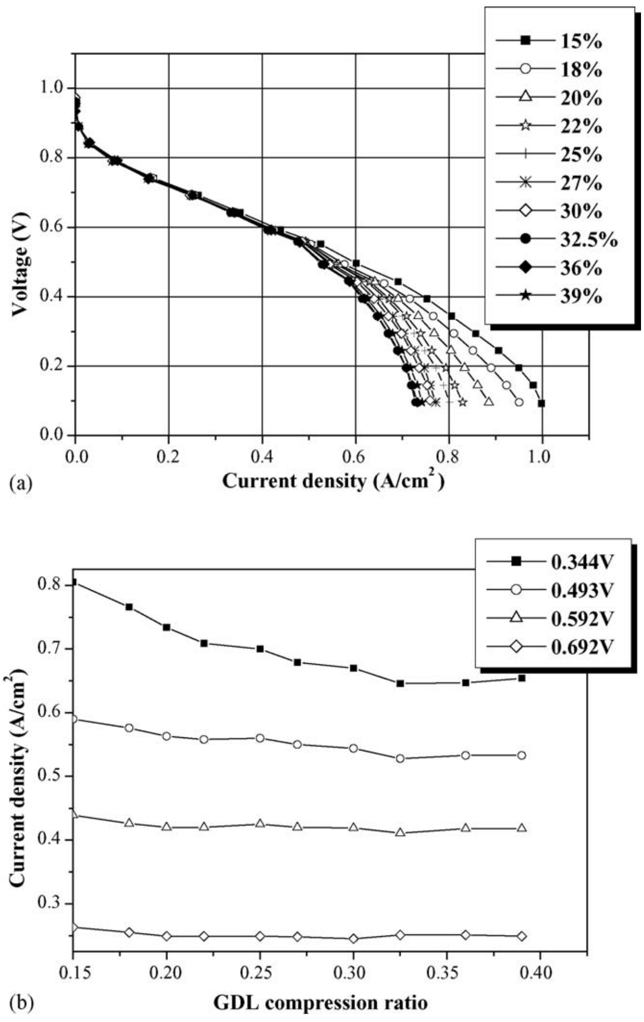

Fig. 4. Effect of compression with carbon cloth as GDL. (a) Polarization curves at different compressions; (b) current density vs. compression at different cell voltages. Anode H_2 flow rate 600 sccm, air low rate 1100 sccm, cathode back pressure 1 atm, cell temperature 65 °C, anode humidification temperature 80 °C, and cathode humidification temperature 80 °C.

3. Results and discussions

The effect of gas diffusion layer was investigated only by comparing the polarization curves under different compression conditions. Compression conditions affected the GDL porosity, species diffusions in GDL and the GDL electrical resistance, etc. However, only the resultant effect on cell performance was studied.

3.1. *Carbon cloth GDL*

Figs. 3–5 are the experimental results using carbon cloth as the GDL. Fig. 3(a) shows the polarization curves at different GDL compression with a hydrogen flow rate of 1200 sccm and a cathode air flow rate of 2200 sccm. Fig. 3(b) shows the current density variations with GDL compression at different fuel cell output voltages. From these two figures, it can be inferred that the fuel cell performance decreases with increasing compression, and this effect increases with increasing current density or decreasing cell voltage. At low current density/high cell voltage, the effect of GDL compression was negligible. The effect was mainly caused by mass transfer resistance. At high current densities, the concentration polarization played a greater role and the high compression obviously caused a significant decrease in mass transfer rate.

Comparing the results in Figs. 3 and 4 with the same anode flow rate and different cathode flow rates, it can be seen that at a higher air flow rate, the fuel cell performance increased and the limiting current increased considerably; the effect of compression was similar. Comparing the results of Figs. 3 and 5 with the same cathode flow rate but different anode flow rates, the fuel cell performance and the effect of GDL compression are both very similar. From these results it is clear that the effect of GDL compression on the performance is significant and cannot be ignored. There exists an optimal compression ratio under certain conditions. This optimal value is the result of counter effect of compression on contact resistance and mass transfer.

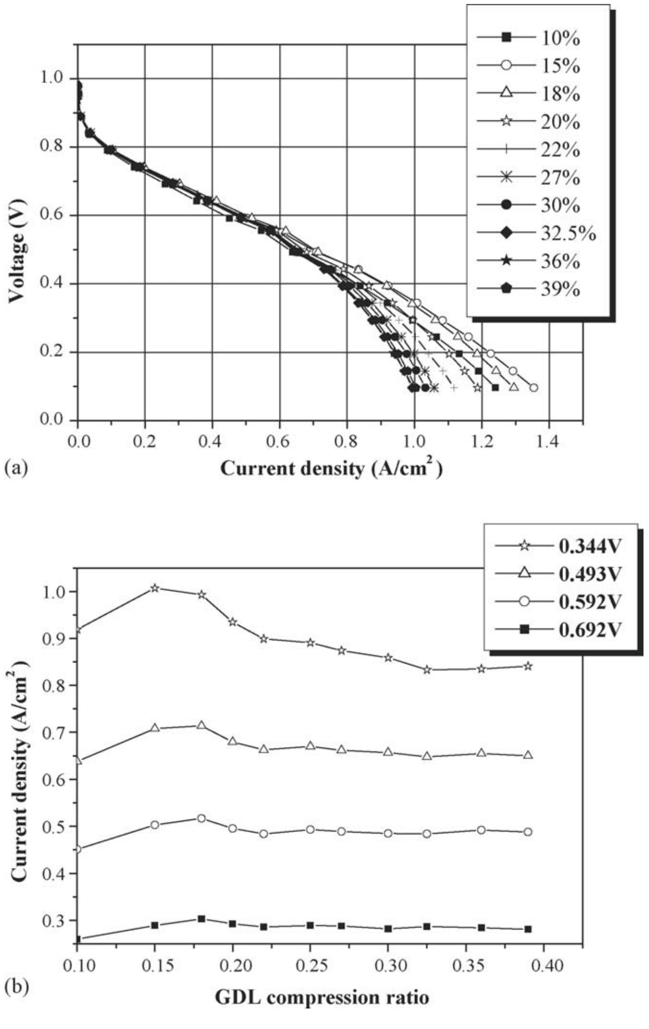

Fig. 5. Effect of compression with carbon cloth as GDL. (a) Polarization curves at different compression; (b) current density vs. compression at different cell voltages. Anode H_2 flow rate 1200 sccm, air flow rate 2200 sccm, cathode back pressure 1 atm, cell temperature 65 °C, anode humidification temperature 80 °C, and cathode humidification temperature 80 °C.

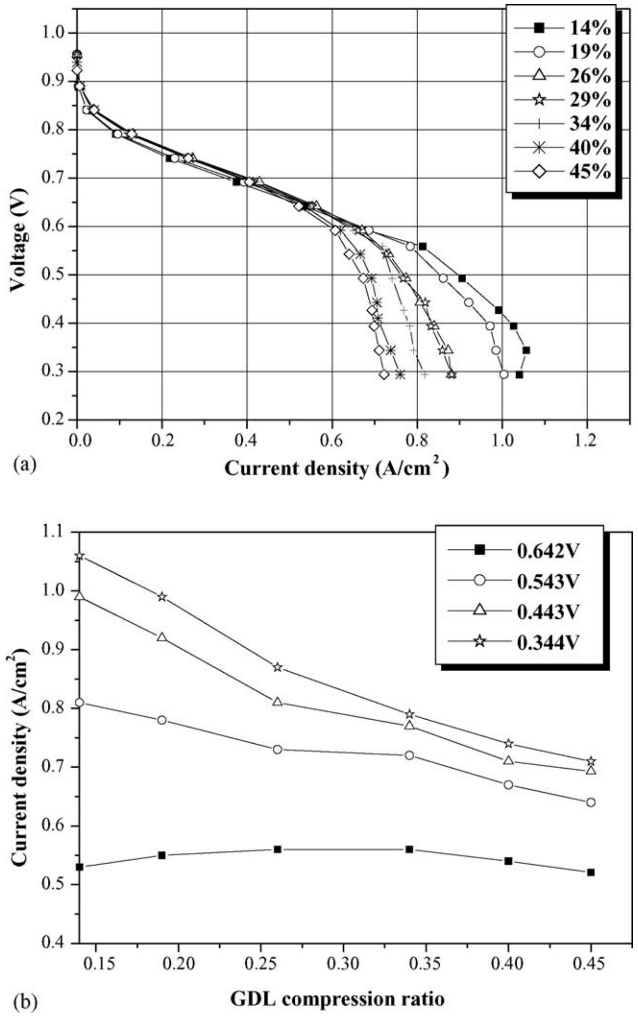

Fig. 6. Effect of compression with carbon fiber paper as GDL. (a) Polarization curves at different compressions; (b) current density vs. compression at different cell voltages. Anode H_2 flow rate 1200 sccm, air low rate 1100 sccm, cathode back pressure 1 atm, cell temperature 65 °C, anode humidification temperature 80 °C, and cathode humidification temperature 80 °C.

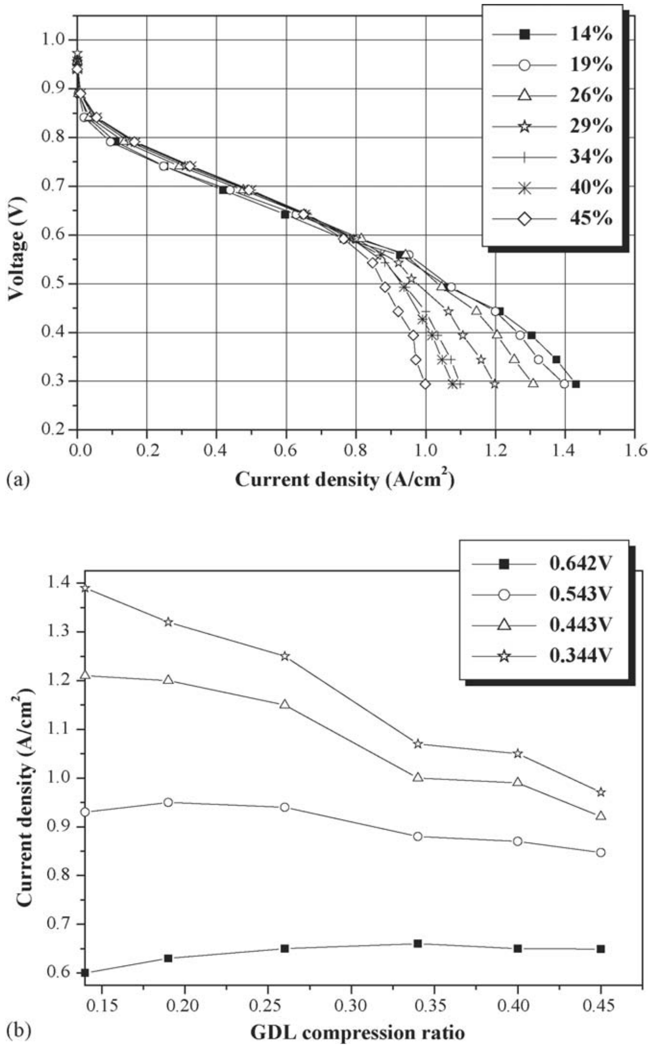

Fig. 7. Effect of compression with carbon cloth as GDL. (a) Polarization curves at different compressions; (b) current density vs. compression at different cell voltages. Anode H_2 flow rate 1200 sccm, air low rate 2200 sccm, cathode back pressure 1 atm, cell temperature 65 °C, anode humidification temperature 80 °C, and cathode humidification temperature 80 °C.

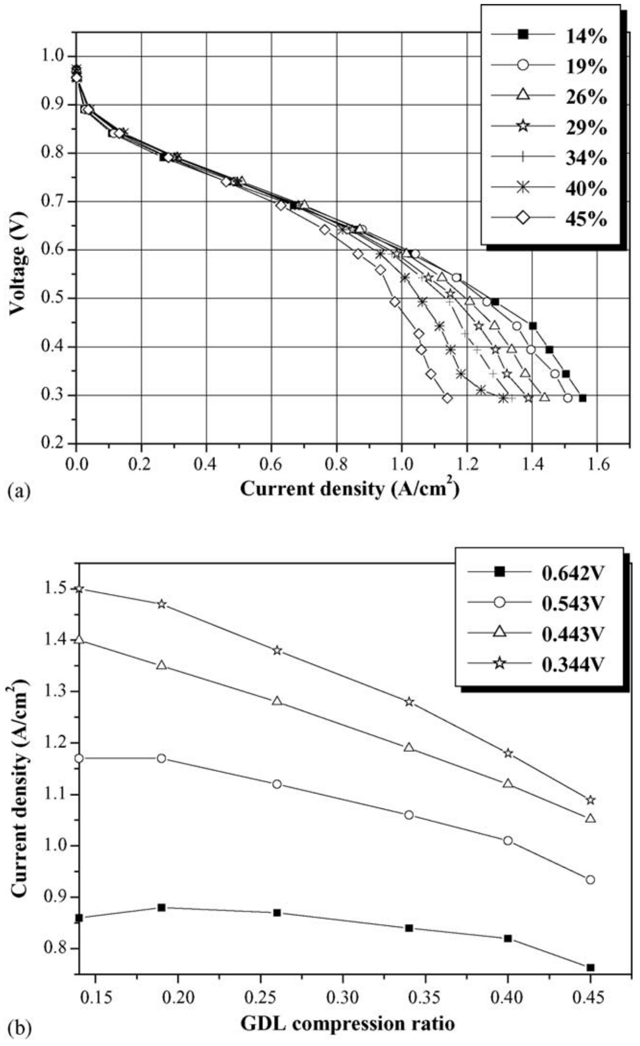

Fig. 8. Effect of compression with carbon cloth as GDL. (a) Polarization curves at different compressions; (b) current density vs. compression at different cell voltages. Anode H_2 flow rate 1200 sccm, air low rate 2200 sccm, cathode back pressure 2 atm, cell temperature 65 °C, anode humidification temperature 80 °C, and cathode humidification temperature 80 °C.

3.2. *Carbon fiber paper GDL*

Figs. 6–8 are the results for fuel cell performance using carbon fiber paper as GDL. Seven different compressions ranging from 14 to 45% are studied. From these figures, it can be seen that the compression of carbon fiber paper GDL has a significant effect on the performance of the fuel cell. Similar to the cases with carbon cloth GDL, this effect increased as the current density increased. At low current densities (high cell voltage), the cell performance increased with increasing compression to a certain extent, though this effect is not significant. This is due to the decrease in the contact resistance at high compression. At high current densities (low cell voltage), the GDL compression has a significant effect on the fuel cell performance and this effect is more pronounced than the cases with carbon cloth GDL.

Comparing the results in Figs. 6 and 8 where the only difference is the cathode air flow rate: with a lower air flow rate, the fuel cell performance was lower and the limit current density was lower. Also, the detrimental effect of over-compression was more significant at the lower air flow rate, especially at high current densities. This can be seen from the slopes of the curves in Figs. 6(b) and 7(b).

Comparing the results in Figs. 7 and 8, where the only difference is the operating pressure: the effect of compression is similar, although the performance and limiting current density are higher at higher operating pressure as expected.

Even with the lowest compression ratio set at 14%, which can be achieved with a little more than the weight of the collector plate and end plate on top of the GDL, there is still no clear optimal compression ratio for the carbon fiber paper GDL in the low current density region. There should always be an optimal compression because of the opposite effect of compression on contact resistance and mass transfer resistance. In this experiment, the optimal compression is not obtainable since with compression at or below this value the fuel cell cannot be sealed.

These experimental results clearly show that over-compression exists in most, if not all, fuel cells. The practice of over-compression is necessary probably due to the sealing considerations. With proper sealing, the fuel cell performance can be increased by simply reducing the amount of compression, especially in the high current density region.

4. Conclusion

In order to test the effects that GDL compression has on fuel cell performance, a unique fuel cell test fixture was designed. Using this special fuel cell fixture, uniform and precise GDL compression can be achieved and the compression can be varied and measured without disassembling the fuel cell. Using this special fuel cell fixture, the effect GDL compression on PEM fuel cell performance for two types of GDL material under various anode and cathode flow rates was studied.

The experimental results show that the amount of compression has a significant effect on PEM fuel cell performances and this is true for both ELAT carbon cloth and TORAY carbon fiber paper, and the effect is greater when carbon fiber paper GDL is used. The effect of GDL compression is also greater in the high current density region.

Generally, it can be seen from the experimental results that the fuel cell performance, as observed through the polarization curve, first increases with the increase of compression, then decreases with increase of compression after passing a certain point. From this data and observations, it can be noted that there exists an optimal compression ratio at which the performance of the cell is maximized. Thus to optimize fuel cell performance, GDL compression should be precisely controlled.

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