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Technical Note

# Effects of anisotropic bending stiffness of gas diffusion layers on the performance of polymer electrolyte membrane fuel cells with bipolar plates employing different channel depths

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ABSTRACT

The effects of the anisotropic bending stiffness of gas diffusion layers (GDLs) on the performance of polymer electrolyte membrane fuel cells with metallic bipolar plates (MBPs), having different channel depths, are investigated. The current–voltage performance of fuel cells with 90° GDLs, whose directions of higher stiffness are perpendicular to the direction of the major flow field, is generally higher than that of cells with 0° GDLs, whose directions of higher stiffness are parallel to the direction of the major flow field. In the shallowest channel, the air pressure drop ($\Delta P$) values of the 90° GDL cells are clearly lower than those of the 0° GDL cells, indicating less intrusion of the 90° GDL into the MBP channels. However, no significant difference appears between the air $\Delta P$ values of 0° and 90° GDL cells employing deeper channels. In comparison with other cells employing deeper channels, a dramatic increase in the high-frequency resistance of both the 0° and 90° GDL cells with the shallowest channel is unexpectedly observed, presumably due to the exceptional increase in the hydrogen and air pressure, which may cause more deformation and poor contact status of the GDLs in the cell. The cross-sectional images of GDLs upon compression indicate that the difference of blocked channel area between 0° and 90° GDL cells is much larger in the case of the shallowest channel, resulting in the observed air $\Delta P$, whereas it is substantially negligible for the deepest channel.



## 1. Introduction

A polymer electrolyte membrane fuel cell (PEMFC) stack for automotive application typically consists of membrane-electrode assemblies (MEAs), gas diffusion layers (GDLs), gaskets, and metallic bipolar plates (MBPs). When a clamping torque is applied to the fuel cell, the unsupported portion of the GDL in the channel may intrude into the reactant gas channels. As reported earlier [1–12], GDL intrusion into the gas channel of a bipolar plate may increase the electrical loss (*i.e.*, contact resistance) and/or the reactant gas pressure drop ($\Delta P$), degrading the electrochemical performances of the PEMFCs. As shown in Lai's work [4], the intruded GDL caused an increase in $\Delta P$ from the inlet to outlet of a bipolar plate, since the GDL intrusion reduces the hydraulic diameter of reactant gas channels of the bipolar plate. Kleemann et al. [9] examined the local compression distribution in the GDL and the coupled effects on electrical properties of the GDL. They showed that the channel area was partially blocked by the intruded GDL using microscopic flow field cross-section images and the intruded GDL increased the electrical losses, finally lowering the fuel cell performance.

In the past, anisotropy between the in-plane and through-plane characteristics of a GDL, such as the thermal conductivity [13–16], diffusivity [17,18], permeability [19–21], and electrical resistivity [22,23], has been extensively studied. These researchers focused on the fact that there is a great difference between the through-plane and in-plane characteristics of GDLs, but they did not pay much attention to the in-plane differences between the machine direction (MD) and cross-machine direction (CMD) characteristics of GDLs, which are also of great importance in improving cell performance. Recent studies have reported that GDL intrusion into the gas channel was reduced by optimizing the anisotropic characteristics between the MD and CMD of GDLs. Han et al. [24,25] first explored the effects of the in-plane anisotropic bending stiffness of GDLs on the intrusion and cell performance. They found that the performances of fuel cell stacks with GDLs whose direction of higher bending stiffness (*i.e.*, the MD) was perpendicular to the

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direction of the major flow field (denoted as 90° GDL cells) were higher than those with GDLs whose direction of higher bending stiffness was parallel to the direction of the major flow field (denoted as 0° GDL cells) owing to reduced GDL intrusion. Naing et al. [10] investigated the effect of anisotropic orientation of carbon fibers in GDLs on the liquid water distribution in the fuel cell channels. They reported that the accumulated liquid water inside the GDL under the land in 90° GDL cells can flow out to the channels more efficiently than that in 0° GDL cells, resulting in high fuel cell performance. Baik et al. [26] studied the correlation between the anisotropic bending stiffness of GDLs and the contact resistance under various flow field structures (*i.e.*, land/channel width ratios) of the MBPs.

Although the difference in the degree of GDL intrusion between 0° and 90° GDLs may change both $\Delta P$ and the electrical contact resistance between the corresponding cells, most recent studies have reported a much more pronounced difference in the electrical contact resistance, but a slight or negligible difference in $\Delta P$, between 0° and 90° GDL cells [9,10,24–26]. In Naing's work [10], for instance, the increase in the fuel cell performance was clearly observed when the 90° GDL cell was used, but a significant $\Delta P$ difference between the 0° and 90° GDL cells was not reported in their work. It is thought that a relatively deep channel configuration in comparison with the degree of GDL intrusion might be used in their study, leading to a slight or negligible $\Delta P$ difference between the 0° and 90° GDL cells, if any. Thus, a clear presence of $\Delta P$ difference between the 0° and 90° GDL cells may be highly dependent on the specific geometry of the bipolar plate, especially the channel depth, which has not been fully explored yet.

To clarify the effects of MBP channel depth on the performance difference between 0° and 90° GDL cells, we prepared seven MBPs with different channel depths in this study. The electrochemical current–voltage (*I*–*V*) performance, high-frequency resistance (HFR), and $\Delta P$ values from inlets and outlets of hydrogen and air were measured to clarify the cause of the difference in cell performance. The cross-sectional images of GDLs upon compression were also measured to compare the degree of intrusion of both 0° and 90° GDLs.

## 2. Experimental method

### 2.1. Single fuel cell preparation

A single fuel cell consisting of the MEA, GDLs, MBPs, gaskets, and end plates was used. A typical perfluorinated sulfonic acid MEA with an active area of 25 $cm^2$ was used. Both the anode and cathode of the MEA were composed of typical Pt/C catalysts, and the Pt loadings of the anode and cathode were both 0.4 mg Pt $cm^{-2}$. To investigate closely the GDL intrusion behavior in metallic bipolar plates employing different channel depths, a carbon fiber felt-based GDL with a high anisotropy of bending stiffness was used as a model GDL. The Taber bending stiffness of the GDL was measured for five specimens at a bending angle of 15° using a Taber Industries stiffness tester (150-E V-5 model, Taber Industries, USA). The average and standard deviation of the Taber bending stiffness of the GDL in the MD and CMD were 19.49 ± 1.43 and 0.64 ± 0.06 $g_f$ cm, respectively, representing strong in-plane anisotropy of the GDL. The characteristics of the GDL used in this study are extensively described in the literature [26]. Seven MBPs with different channel depths were prepared. In all the MBPs, 316 L stainless steel (SS), which is known to be corrosion-resistant, was used as a substrate material, and a gold layer was deposited on the 316 L SS surface. A serpentine pattern and a rectangular cross-section represented the basic channel geometry design. The channel depths of the anode and cathode were varied from 0.2 to 1.0 mm to represent shallow (0.2 mm) and deep (1.0 mm) channel depth configurations. Table 1 summarizes the MBP channel depths used in this study. The land and channel widths of the anode and cathode of all the MBPs were 0.38 and 1.42 mm, respectively. The pitch width of the MBPs was fixed at 1.80 mm. To clarify the effects of the anisotropic bending stiffness of the GDLs on the performance of PEMFCs with MBPs employing different channel depths, we used MBPs with seven channel depths and GDLs with two different orientations (*i.e.*, 0° and 90° GDLs). Full schematic representations of the 0° and 90° GDL cells used in this study are given in the literature [26]. In the 0° GDL cell, the major carbon fibers in the MD of the GDL were aligned parallel to the major flow field direction of the bipolar plate at an angle of 0°. In contrast, in the 90° GDL cell, the major carbon fibers in the MD of the GDL were aligned perpendicular to the major flow field direction of the bipolar plate at an angle of 90°. Rubber-type O-rings and Teflon® gaskets were used to prevent gas leakage. Leak testing was performed after fuel cell assembly.

**Table 1**
Geometrical characteristics of the MBPs used in this study.

| MBP code | Depth configuration | Channel depth (mm) | |
|---|---|---|---|
| | | Anode | Cathode |
| MBP-1 | Symmetric | 0.2 | 0.2 |
| MBP-2 | Symmetric | 0.6 | 0.6 |
| MBP-3 | Symmetric | 1.0 | 1.0 |
| MBP-4 | Asymmetric | 0.2 | 0.6 |
| MBP-5 | Asymmetric | 1.0 | 0.6 |
| MBP-6 | Asymmetric | 0.6 | 0.2 |
| MBP-7 | Asymmetric | 0.6 | 1.0 |

### 2.2. Electrochemical measurements of the single fuel cell

The electrochemical performance of the PEMFCs was measured by a commercial tester (1 kW test station, Chino Co., Korea). To measure the operating temperature of the fuel cell, T-type thermocouples (TCs) with an uncertainty of ±0.5 °C were inserted into holes (40 mm in depth) in both the anode and cathode bipolar plates, and tube-shaped cartridge heaters were also inserted into both the anode and cathode end plates. Both the TCs and the heaters were connected to a fuel cell temperature controller (UT

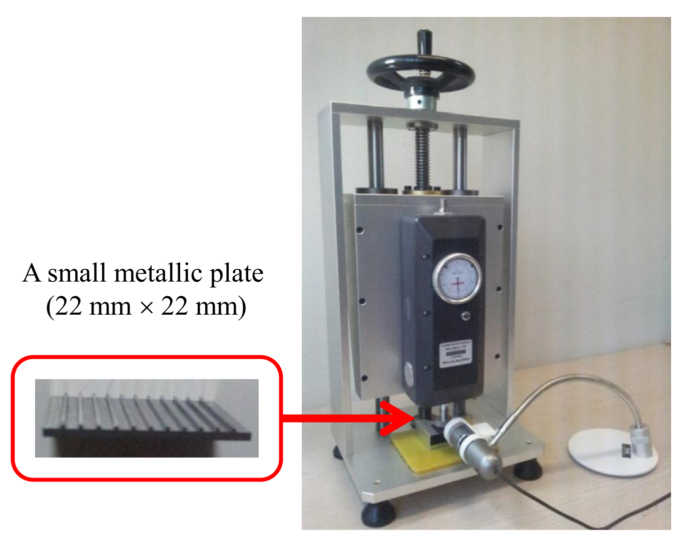


**Fig. 1.** A photo of compression equipment for a visual observation of GDLs under compression.