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Study on metallic bipolar plate for proton exchange membrane fuel cell

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Abstract

Cost reduction is the most critical issue for ensuring the practical use of proton exchange membrane fuel cells (PEMFC). In current designs, the bipolar plate is the most expensive part in the repeating-parts of the PEMFC. To address this issue, bipolar plates made of several kinds of materials are being developed by various companies. Above all, a metallic bipolar plate is said to have a highest potential for achieving the cost target. However, in order to implement metallic bipolar plates, several issues must be addressed, including corrosion of the metal, electric contact between cell parts, press forming and so on. In this paper, the electric contact between a *metallic* bipolar plate and another cell part was evaluated by a structural analysis with a finite element method and a compression test. Then, power generation tests were conducted on single cells in which metallic bipolar plates were mounted.

Keywords: Proton exchange membrane fuel cell; Metal; Bipolar plate; Structural analysis; Finite element method

1. Introduction

In recent years, global warming due to greenhouse gases, such as carbon dioxide, has been a worldwide problem. In order to decrease carbon dioxide levels, advancements in vehicles that use lower amounts of fossil fuels and efficiency improvements to power stations are essential. For such a purpose, electric vehicles and residential co-generation, in which proton exchange membrane fuel cells (PEMFC) are used as power sources, have received considerable attention. However, the application of PEMFCs still requires the attention to numerous issues. For realistic vehicle use, both the size and cost of the PEMFC must be reduced. In current designs, the most costly component in a PEMFC is the bipolar plate that is currently machined from a bulk of carbon or hot-molded from a composite carbon and resin [1]. The application of metallic bipolar plates has potential for fulfilling these requirements [2]. However, whether metal is used as the base bipolar plate material, the bipolar plates must be able to accomplish numerous functions in a corrosive environment: to supply fuel and oxidant to the anode and cathode, respectively, to act a gas manifold, to seal gas, and to collect electricity from the electrodes. Therefore, many additional improvements must be implemented before metallic bipolar plates can be used in practical environments. In particular, the metallic bipolar plates should be formed with a cold-press to reduce production costs. However, press formation may lead to poor planarity or high contact resistance, which is likely to lower cell voltage.

This study evaluates the contact of a metallic bipolar plate sandwiched between gas diffusion layers (GDL) by performing a structural analysis with a finite element method (FEM) using the general-purpose analysis software “ABAQUS.” The software was used to analyze a stainless steel bipolar plate, which is the most likely base material that will be applied to practical metallic bipolar plates. In addition, metallic bipolar plate prototypes were fabricated and used to evaluate the structural contact in both an ex-situ and in-situ cell test. Finally, power generation tests were conducted on the single cells with the metallic bipolar plates.

2. Structural analysis of the metallic bipolar plate and GDL

2.1. Compression characteristics of the GDL

In order to perform the structural analysis, the compression characteristics of the GDL were experimentally evaluated in a compression test. In this experiment, a 20 wt.% PTFE waterproofed carbon paper (Toray, TGP-H-090, 280 μm thick) was

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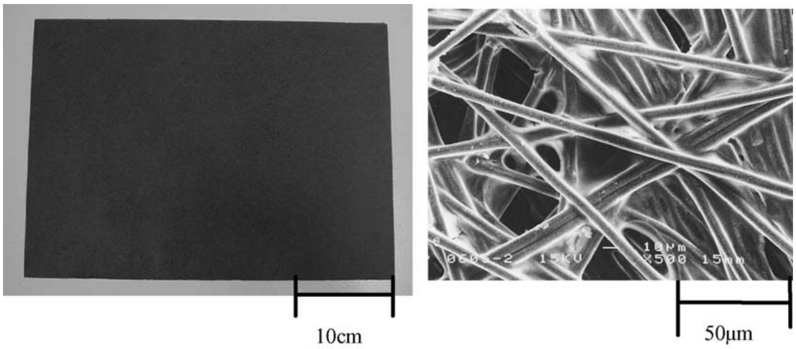


(a) Appearance photograph

(b) Scanning electron microscope photograph

Fig. 1. Photograph of gas diffusion layer.

used as the GDL. Pt loading of both the electrodes was ca. 0.4 mg cm^{-2}. Photographs displaying the overall appearance and the scanning electron microscope image of the GDL used in the compression test are shown in Fig. 1(a) and (b), respectively. As shown in Fig. 1(b), the GDL is a porous medium comprised of carbon fiber with a diameter around 50 μm.

Fig. 2 shows the stress-strain curve obtained from a compression test conducted at room temperature for the GDL. In the experiment, 10 small 2 cm squares were cut out from the 30 cm square GDL shown in Fig. 1(a). These squares were then stacked and compressed in order to increase the precision of the strain. As shown in Fig. 2, the compression rigidity of the GDL remains constant up to 15 MPa. However, once the pores of the GDL are destroyed, the compression rigidity suddenly increases.

2.2. Method for structural analysis

Fig. 3(a) and (b) show the schematic cross-section of a single cell in which metallic bipolar plates were incorporated and the analysis model that was used to perform the structural analysis, respectively. In the present study, the same analysis model as that reported in [3] was used. As mentioned above, the gas flow fields of the metallic bipolar plate must be formed with a press to reduce production costs. Because the shape of the gas flow field formed by pressing a thin plate is limited to a corrugated shape, as shown in Fig. 3(a), a press-formed metallic bipolar plate has a large tolerance in height and high compression rigidity. Therefore, in order to achieve good contact between the metallic bipolar plate and the neighboring cell components, the compression deformation of the components needs to be jointly evaluated.

As shown in Fig. 3(b), the structural analysis of a 100 μm thick bipolar plate was conducted on a 1/2 pitch portion by taking into account the shape periodicity of the bipolar plate. The boundary conditions were set so that the X-axis displacement was fixed, and only the Y-axis displacement was considered. As shown in the figure, the displacement that was distributed uniformly in the plane at Y = constant was given along the Y-axis. The analysis was then handled as a so-called "contact problem".

2.3. Results of structural analysis

Fig. 4 shows the relationship between the compressive displacement of the bipolar plate and the compressing pressure as well as the relationship between the compressive displacement of the combined bipolar plate/GDLs and the compressing pressure. The maximum bipolar plate displacement is about 0.5 μm under a stack compressing pressure of 0.5–1.0 MPa. Thus, it is

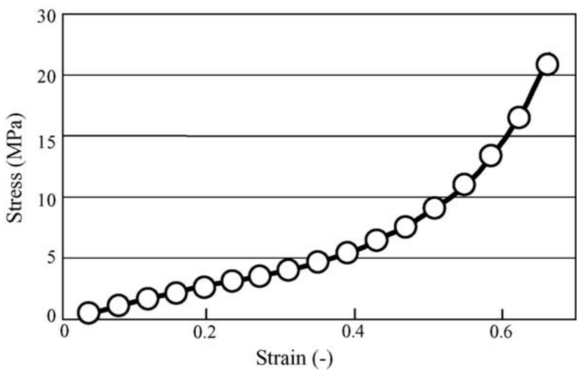


Fig. 2. Compressive stress-strain curve of gas diffusion layer.

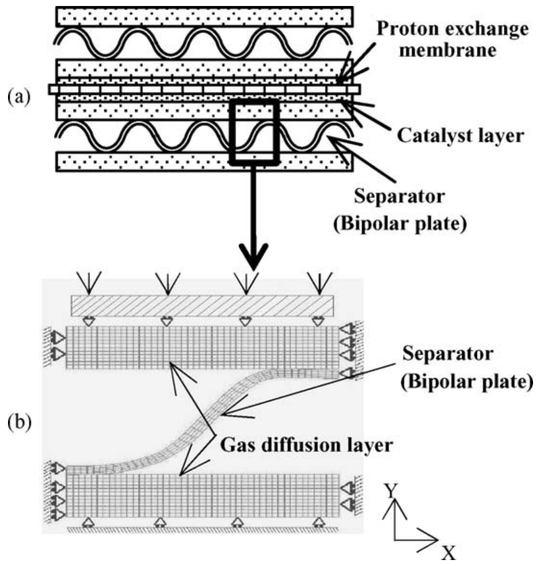


Fig. 3. Analytical model.

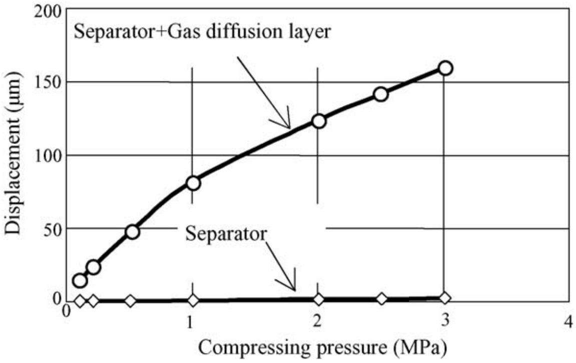


Fig. 4. Displacement of analysis model.

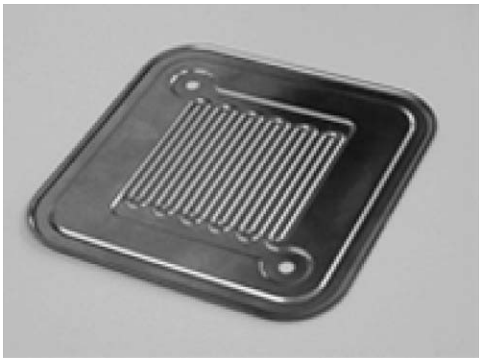


Fig. 6. Metallic separator.

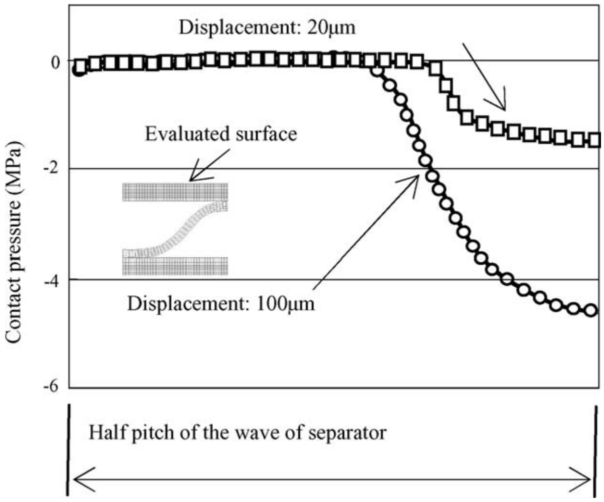


Fig. 5. Contact pressure along top surface of gas diffusion layer.

impossible to absorb a 20 μm variation in bipolar plate height that is generated by pressing. On the other hand, the displacement of the total analysis model including the GDL is nearly two orders of magnitude larger than the displacement of the bipolar plate itself. Thus, it is possible to absorb the fabrication tolerance of the bipolar plate when the bipolar plate and the GDL are combined.

Fig. 5 shows the contact pressure on the GDL side at compressive displacements of 20 and 100 μm. As shown in the figure, the larger the displacement, the larger the contact area at the contact section of the bipolar plate. However, the contact pressure between the GDL and the polymer membrane is nearly zero at the non-contact section of the bipolar plate. Thus, there is room for further contact improvement, since good contact is generally secured throughout the entire surface of the cell.

3. Compression test of metallic bipolar plate and GDL

In Section 2, the contact between the metallic bipolar plate and the GDLs was evaluated using structural analysis. As a result, it was found that a good contact was possible both when and where the GDL is deformed. However, the larger the compressive displacement, the greater the possibility that the cell components such as the bipolar plate, GDL and so on could be damaged and stop functioning as designed. Thus, in order to clarify the effects of the compressive displacement on the integrity of the cell parts experimentally, a prototype of the metallic bipolar plate was prepared by a press and compression tests were conducted on the ex-situ cell.

3.1. Compression test method

A photograph of the prototype of the metallic bipolar plate is shown in Fig. 6. This metallic bipolar plate was fabricated by molding 100 μm thick stainless steel with a 1000 ton-class press. Before molding, the stainless steel sandwiched with gold foils was previously rolled to 100 μm thick plate. As gold has more excellent ductility than stainless steel, gold on both the surfaces of stainless steel is extended to uniform thick with roller. Thus, an approximately 10 nm thick gold foil was uniformly coated on the entire surface of the stainless steel in advanced. Recently, such stainless steel coated with thin gold foil has been widely trial-used as a metallic bipolar plate for PEMFC. Flow fields were formed with six serpentine ditches that are arranged in a parallel pattern, as shown in the figure.

Fig. 7 shows a conceptual cross-section diagram of a metallic bipolar plate sample set in the compression tester. In the test, the metallic bipolar plate was set between two GDLs that were 20 wt.% PTFE water-proofed carbon paper (Toray TGP-H-090,280 μm thick). The GDLs were sandwiched between copper plates. The compression test was carried out with the small tester. For this occasion, copper wires were connected to both copper plates and the electrical resistance between the copper plates was measured with a resistance measure (Tsuruga, Model 3566, Japan).

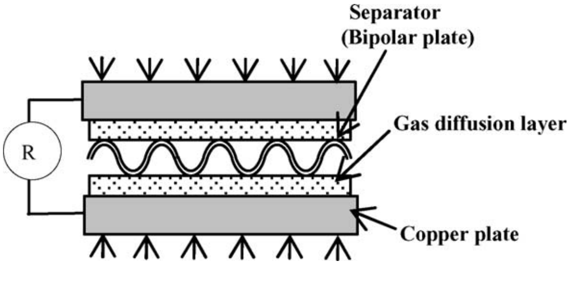


Fig. 7. Composition of press test.

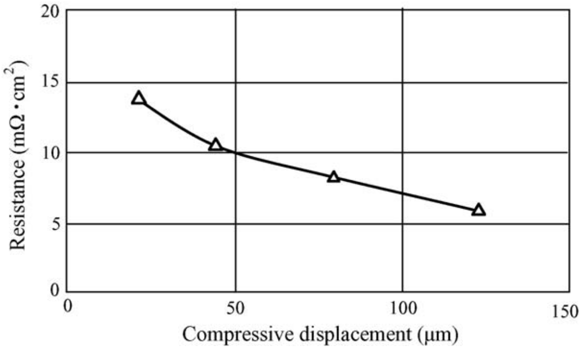


Fig. 8. Result of compression test.

3.2. Compression test results

The results of the compression test shown in Fig. 8 display the relationship between the electrical resistance and the compressive displacement between the copper plates. The figure indicates that the larger the compressive displacement, the smaller the electrical resistance. This suggests that the larger the compressive displacement, the larger the contact area. This corresponds well with the results of the structural analysis. Normally, a PEMFC is operated at a current density in the range of 0.1–1 A cm^{-2}. In this case, the cell voltage is 800–600 mV. If the cell is operated at 1 A cm^{-2}, the voltage loss by the electrical resistance, which is shown in Fig. 8, is around 15 mV at a compressive displacement of 20 μm and around 7 mV at a compressive displacement of 100 μm. The loss in cell voltage is around 1–2% of the usual cell voltage, which is relatively small.

Scanning electron microscope images of the GDL at the contact plane with the bipolar plate are shown in Fig. 9(a) and (b) for compressive displacements of 20 and 120 μm, respectively. No noticeable damage was evident on the GDL when the compressive displacement was 20 μm. However, it was confirmed that carbon fibers in the GDL were broken when the compressive displacement was 120 μm. The results in Figs. 8 and 9 indicate that a compressive displacement of around 20 μm is sufficient for securing electrical contact between the cell parts without inflicting damage. A compressive displacement of more than 100 μm is not recommended because the cell parts can be damaged.

On the other hand, the appearance of the bipolar plate was hardly changed through a compression test, except the limb part of the bipolar plate became slightly uneven.

4. Power generation test

The contact between a metallic bipolar plate and the GDLs was evaluated by the structural analysis and the compression test in Section 3. As a result, it was confirmed that the contact between the metallic bipolar plates and GDLs could be secured by a compressive displacement in the tens of μm. In order to confirm these results in an actual cell, prototypes of the metallic bipolar plates prepared in Section 3 were incorporated in a small single cell. A power generation test was then conducted for cells with compressive displacements of 20 and 100 μm.

4.1. Power generation test method

The configuration of the small single cell in which metallic bipolar plates are incorporated is shown in Fig. 10. A catalyst-coated membrane (CCM) is located at the cell's center, and is sandwiched between GDLs and metallic bipolar plates. They are tightened with end plates through electric collectors and insulation plates. Fig. 11 provides an actual photograph of the single cell shown in Fig. 10. The reactive area of the present cell is 5 cm × 6 cm.

The conditions for power generation are shown in Table 1. The power generation test was conducted on the single cell shown in Fig. 11 at a cell temperature of 80 °C under atmo-

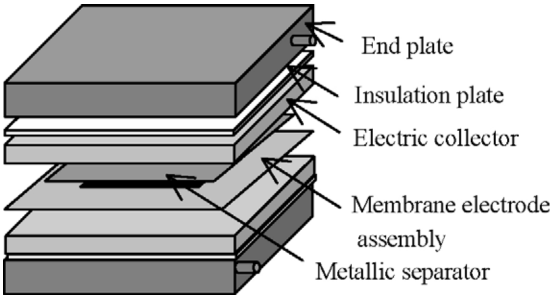
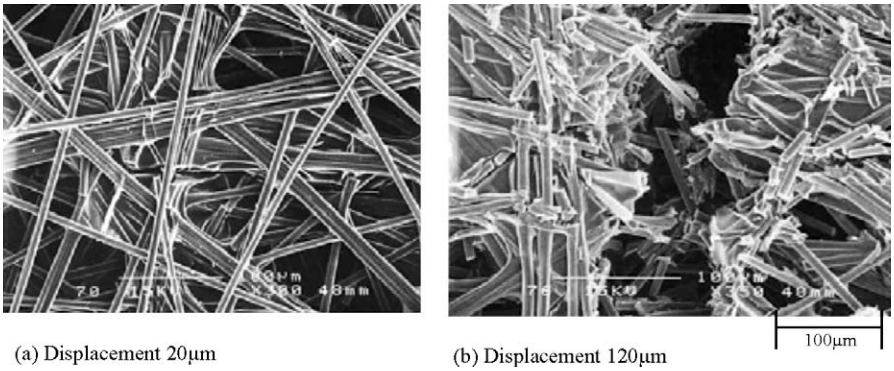


Fig. 10. Configuration of the single cell with metallic separator.


(a) Displacement 20μm

(b) Displacement 120μm

Fig. 9. Scanning electron microscope photograph of gas diffusion layer after its compression test.

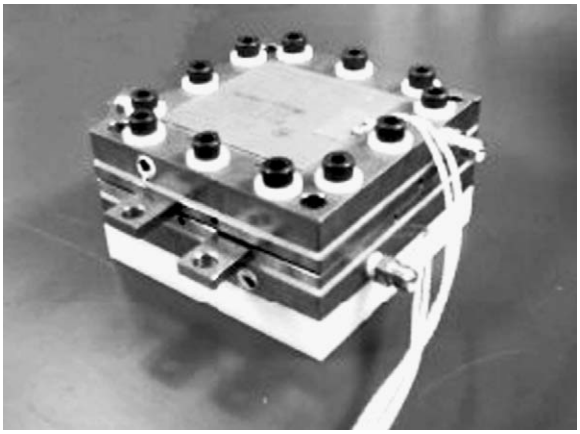


Fig. 11. Photograph of actual cell.

Table 1
Conditions of power generation test

Cell temperature		80 °C
Operation pressure		Ambient
Humidification temperature	Fuel	70 °C
	Oxidant	70 °C
Utilization ratio	Fuel	35%
	Oxidant	20%

spheric pressure. Hydrogen fuel and oxidant air, which were both pre-humidified to a dew point of 70 °C, were fed into the cell. The change of cell voltage with time was observed during power generation.

4.2. Power generation test results

Fig. 12 shows the *I–V* characteristics for the cells in which the compressive displacement was 20 and 100 μm. For comparison, the result of a cell with carbon bipolar plate is shown in the figure. The compressive displacement is less than 1/5 for the cell with 20 μm displacement compared with the cell with 100 μm displacement; almost identical *I–V* characteristics were obtained. Thus, even when the displacement is around 20 μm, it is evident that the bipolar plate contact is sufficient. And the performance of the cells with press-formed bipolar plates is not inferior to that of the cell with machined carbon bipolar plate.

Fig. 13 shows the open-circuit voltage and the cell voltage at 0.2 A cm^{-2} versus time for the cells in which the compressive displacement was 20 and 100 μm. Cell voltage data were acquired every five hours, and the data for the open-circuit voltage were taken every 24 h. As shown in the figure, the open-circuit voltage for the cell with the compressive displacement of 100 μm significantly decreased during the very early stage. This decrease in the open-circuit voltage can be attributed to a short-circuiting of the electrolyte membrane or a crossover of reactant gas, especially hydrogen gas, due to the damage of to electrolyte membrane. In the present case, however, the crossover of the electrolyte membrane is likely to be the primary cause. On the other hand, both the open-circuit voltage and the cell voltage at 0.2 A cm^{-2} were relatively stable with respect to time for the cell with a compressive displacement of 20 μm. Thus, no noticeable decrease was recognized. As described above, the cell with the compressive displacement of 20 μm experienced less damage to the cell parts and exhibited more stable cell characteristics than the cell tightened to a displacement of 100 μm to ensure secure contact.

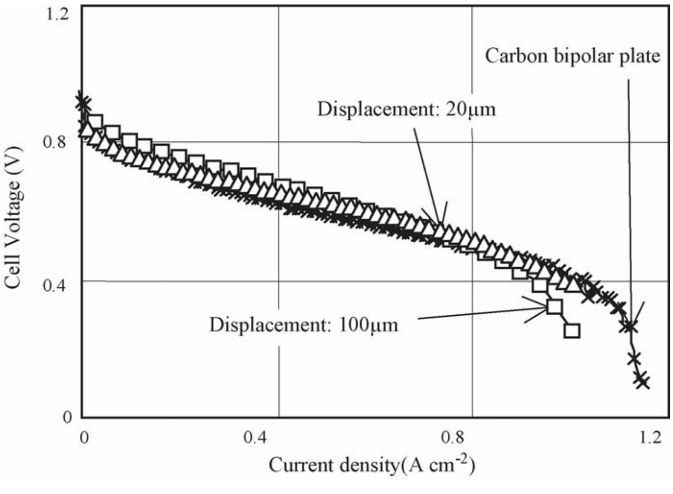


Fig. 12. *I–V* characteristics of the single cell with metallic separator.

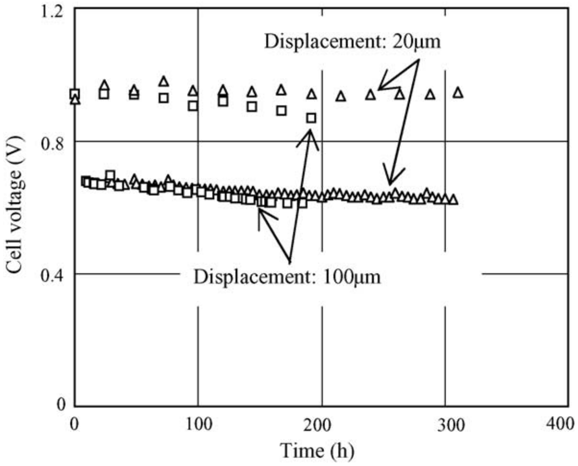


Fig. 13. Time tend of the cell performance.

5. Conclusion

This study evaluated the contact of a metallic bipolar plate in both ex-situ and in-situ cells. It was found that sufficient contact was obtained between the metallic bipolar plate and its neighboring parts, which allow for a moderate amount of compressive deformation. However, the contact may induce serious damage depending upon the degree of the contact.

References

[1] T. Besmann, J. Henry, J. Klett, Development of a carbon composite bipolar plate, Proc. Fuel Cell Seminar (2003) 61–64.

[2] T. Armstrong, M. Brady, P. Tortorelli, Thermally nitrided metallic bipolar plates for PEM fuel cell, Proc. Fuel Cell Seminar (2003) 251–254.

[3] M. Hori, Journal of Japanese society of tribologists (Fuel cell), Japanese Society Tribologists 49 (5) (2004–2006) 10–16.