A SINGLE TYPE COMPOSITE HYBRID BIPOLAR PLATE WITH GAS DIFFUSION LAYER FOR HIGH EFFICIENCY PEMFC

J.W. Lim, H.N. Yu, B.G. Kim, D.G. Lee*
School of Mechanical Aerospace & Systems Engineering, Korea Advanced Institute of Science and Technology, ME3221, Guseong-dong, Yuseong-gu, Daejeon 305-701, Republic of Korea
* Corresponding author(dglee@kaist.ac.kr)

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1 Introduction

Polymer Electrolyte Membrane Fuel Cell or Proton Exchange Membrane Fuel Cell (PEMFC) is an electrochemical energy converter that converts chemical energy of fuel directly into DC electricity when hydrogen and oxygen are supplied to the anode and cathode side, respectively, producing water and electricity through the electrochemical reaction without making any pollutant. Therefore, the PEM fuel cell system is a very promising power source for residential and mobile applications with their wide operating range, low operating temperature, high efficiency, high-power density and long lifetimes [1-4]. Even with these many advantages of PEM fuel cell system, commercialization has been delayed due to high manufacturing cost of bipolar plates which comprise more than 60% of the stack cost among other components of PEM fuel cells. Therefore, an efficient manufacturing process and high performance bipolar plate development is inevitable for commercialization [3, 4].

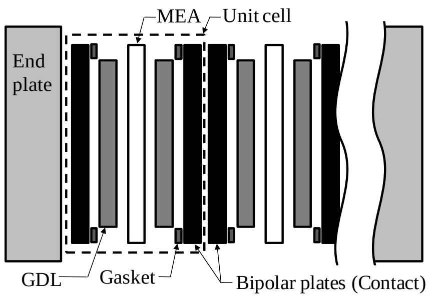


Fig. 1: Schematic drawing of the PEM fuel cell.

A fuel cell stack is composed of Membrane Electrode Assemblies (MEA), Gas Diffusion Layer (GDL), endplates and bipolar plates as shown in Fig. 1 [4-6]. In a fuel cell stack, the bipolar plates have several functions such as providing flow channels for reactant gases to maintain proper pressure distribution over the whole active area of membrane electrode assemblies, transmitting electrons from an anode to its adjacent cathode in a unit cell, transferring the reaction heat from active area to coolant and serving as coolant flow paths [5]. The functional requirements of the bipolar plate are high mechanical stiffness and strength, high chemical stability, low electrical resistance, low density, thin thickness and low gas permeability [4]. There have been many researches about development of bipolar plates using various materials such as graphite, metals and composites. Graphite bipolar plates have high void contents and brittle properties, metallic bipolar plate has corrosion problem and carbon fiber/epoxy composite bipolar plate has low electrical conductivities [7-11].

In this study, carbon composite-metal-GDL single type hybrid bipolar plate with a low electrical resistance was developed. The single type hybrid bipolar plate was designed to have an anode and cathode in one structure to form a unit cell with GDL connected by bypass. Carbon composite prepregs were coated with graphite sheet to create a soft layer so that the interfacial contact resistance between bipolar plate and GDL could be decreased. In preceded studies, the composite-metal bipolar plate with bypass which decreases the interfacial contact resistance between bipolar plates was developed and the graphite coating method which decreases the interfacial contact resistance between bipolar plate and GDL was investigated [4, 12].

In this study, the bypass concept and the graphite coating method was applied together to investigate the synergistic effect. Moreover, unlike conventional composite-metal bipolar plates, the new GDL single type concept, which is connected by the extended bypass to provide a continuous electron pass, was developed and applied. The total electrical resistance in the through-thickness direction was measured by the standard method to investigate the performance of the single type hybrid bipolar plate.

2 Experiments

2.1 The structure of hybrid bipolar plate

In a conventional PEM fuel cell stack, two bipolar plates are attached to provide flow channels for both coolants and reactants as shown in Fig. 2 (a). The total electrical resistances of the bipolar plates were observed to largely depend on the electrical contact resistance between bipolar plates, and bipolar plates and GDL [4, 13]. In this study, single type hybrid bipolar plate with GDL was fabricated, as shown in Fig. 2 (b), to reduce the total electrical resistance, moreover, the fuel cell efficiency. The equivalent electric circuits of the conventional composite bipolar plate and the single type hybrid bipolar plate are shown in Fig. 3.

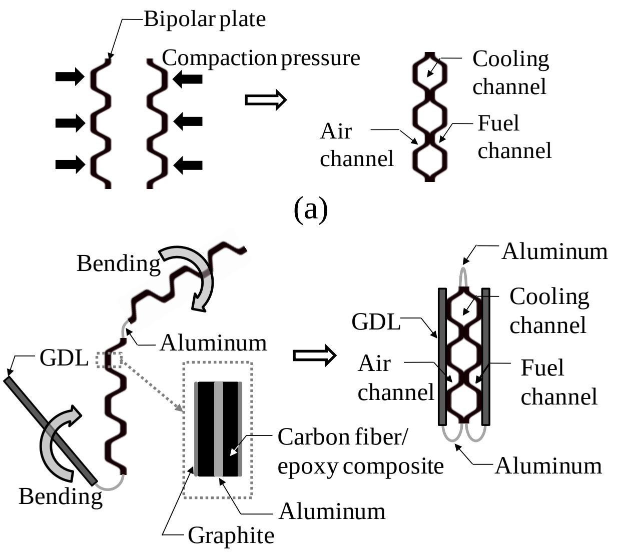


Fig. 2: Schematic drawing of hybrid bipolar plate with bypass connected GDL.

It can be observed that the electrical conduction through the continuous aluminum bypass significantly decreased the total electrical resistance of the bipolar plates in comparison with that through the interfacial contact resistance in through-thickness direction. One side of the single type bipolar plate was used as an anode, where the other was used as a cathode for the closed-loop electric circuit of the PEM fuel cell. Moreover, the applied graphite coating method decreased the interfacial contact resistance between the bipolar plate and GDL. Aluminum foils were used as the bypass due to its high failure strain and electrical conductivity, which is suitable for flexible electron bypass in the single type hybrid structure. The aluminum membrane was co-cured with a carbon fiber/epoxy composite and connected further to the GDL to obtain the continuous electron pass to reduce the total electrical resistance effectively.

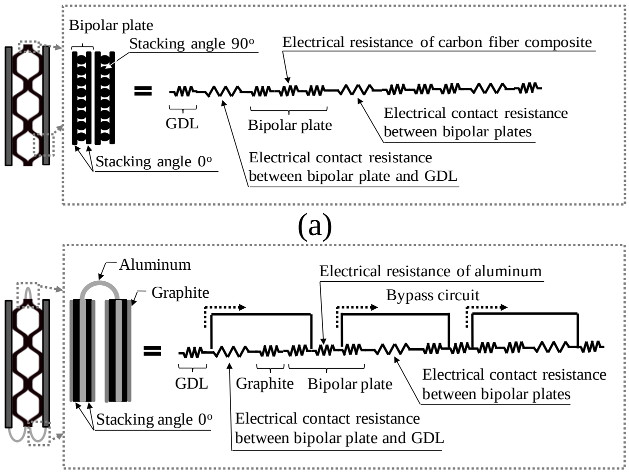


Fig. 3: Equivalent electric circuits: (a) conventional composite bipolar plate with GDL, (b) single type hybrid bipolar plate with bypass connected GDL.

Electrons should pass through the bipolar plates and GDL in the through thickness direction to the adjacent unit cells to generate the voltage where the efficiency of the PEMFC is largely dependent on the total electrical resistance in the through-thickness direction of the unit cells. The developed single type hybrid bipolar plate with GDL effectively decreased the total electrical resistance in the through-thickness direction via continuously connecting the unit cell components such as two bipolar plates and GDL with electron bypass.

2.2 Fabrication of the hybrid bipolar plate

In the first step, the aluminum surface is modified by a mechanical abrading technique and then cleaned with acetone. In the second step, the stacked composite prepregs were coated with the graphite sheet and the prepregs and the aluminum sheet was pre-formed to follow the channels, and stacked. In the third step, the aluminum and carbon fiber/epoxy composites are co-cure bonded using a hot press. In the final fourth step, GDL is connected to the aluminum bypass and the bypasses are bent by approximately 180^o to provide continuous electrical conducting pass.

The surface morphology of the aluminum component of the hybrid bipolar plate was one of the most important factors for the successful adhesive bonding, which substantially influences both electrical resistance and bonding strength. Mesh number 320 of sandpaper was used to create the grooves to maximize the carbon fiber contacting area, which resulted in an average R_a of 2.1 μm on the aluminum sheet to reduce the electrical resistance [4].

In the second step, the carbon fiber/epoxy composites prepregs (USN 020, SK chemical, Korea) were stacked with the stacking sequence of [0_6]. The stacked prepregs were coated with a thin graphite layer to create the soft surface to increase the contact area with GDL which ultimately decreases the interfacial contact resistance. Fig. 4 shows the process of the graphite coating method, where a sticky backup film was used to remove a thin layer of graphite from a graphite foil (BD-100, Samjung CNG, Korea). The backup film with a thin graphite layer was attached to the stacked prepregs and laminated under 80^{o}C with the feeding rate of 7 mm/s. This transfers the thin layer of the graphite on the prepregs [14].

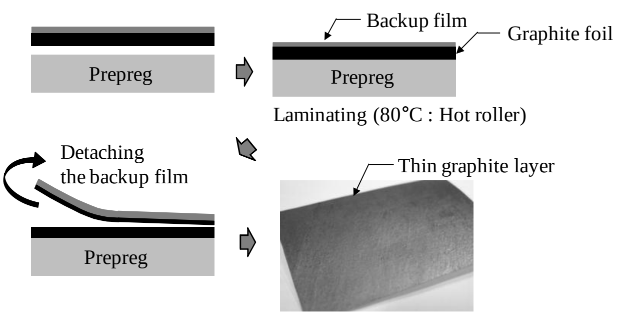


Fig. 4: Graphite coating process of the composite prepreg.

The aluminum sheet of 50 μm thickness was prepared 10 mm longer than the prepregs for further bypass connection to the GDL. The prepregs and the aluminum sheet were pre-formed with channeled roller and mold while stacking as shown in Fig. 5. The fiber direction of the carbon fiber/epoxy composite was set parallel to the direction of the channels. This pre-forming method reduces the residual stress after curing and provides the uniform electron pass by preventing tearing of the aluminum sheet and breakage of the fibers [13].

In the third step, the pre-formed carbon composite/aluminum/carbon composite sandwich sheet was co-cured in a hot press under the curing pressure of 20 MPa. The dwelling temperature was maintained at 80^{o}C for 1 hour, and the full cure of the carbon fiber/epoxy composite prepreg was completed at 125^{o}C for 1 hour. The thickness of the cured bipolar plate was 0.2 mm.

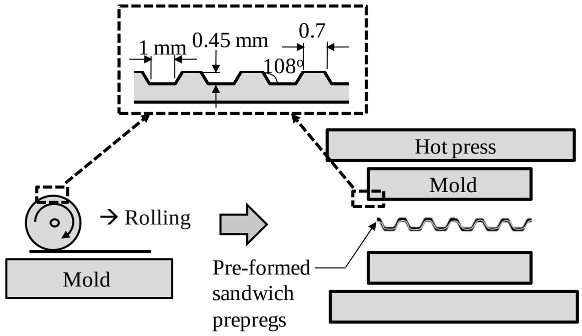


Fig. 5: Pre-forming process.

In the final step of fabrication, the GDL is cut to the size of bipolar plate and then placed on the both sides of the bipolar plate. The 10 mm extra tip of the aluminum sheet was bent by approximately 180^o to overlap the edge of the GDL to provide a bypass. Polyimide tape was used to attach the aluminum bypass and GDL together as well as to electrically insulate as shown in Fig. 6.

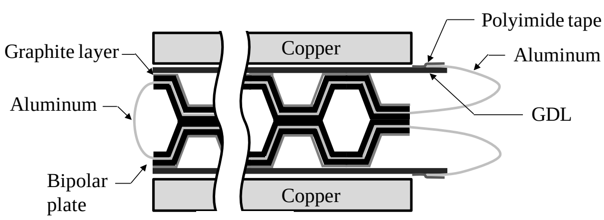


Fig. 6: Schematic drawing of the single type hybrid bipolar plate with GDL on the experiment device.

Finally, the aluminum bypass which connects two bipolar plates was bent by approximately 180^o to provide the single type hybrid bipolar plates with continuous electrical conducting pass. Due to the high mechanical strain properties only the aluminum sheet was used as a continuous electrical pass. When the carbon fiber/epoxy composite and GDL was bent by approximately 180°, the carbon fibers were broken or the GDL was torn, which made them fail the function as an electrical pass.

2.3 Measurement of the properties

Fig. 7 shows the experimental method which was used to measure the total electrical resistance [15]. Bipolar plate specimens with 40×40 mm size were placed between the gold coated copper plates which were used to connect a power supply and a voltage measurement device. The constant current (1A) was supplied under compaction pressures using an instrument (INSTRON 4469, Instron Corp., MA, USA). The specimens were compressed with pressures ranged from 0 to 2.0 MPa to investigate the total resistance in the through-thickness direction with respect to compaction pressure. The temperature of the specimens was maintained at 25°C ± 1°C.

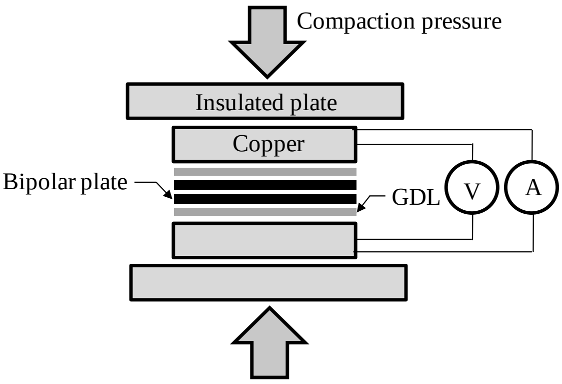


Fig. 7: Experimental method to measure the total electrical resistance in the through-thickness direction.

In a conventional PEM fuel cell, the compaction pressure is high to enhance the contact between components which could decrease the total electrical resistance. However, a high compaction pressure requires high component mechanical properties as well as if the compaction pressure decreases during the life cycle, the fuel cell efficiency decreases dramatically. Therefore, the total electrical resistance should be low at a low compaction pressure. In this study, the total electrical resistance of the developed single type hybrid bipolar plate with and without GDL connection as a function of compaction pressure was investigated. Also, the total electrical resistance of the conventional composite bipolar plates, which were composed of carbon fiber/epoxy composites (USN 020, SK chemical, Korea) with the stacking sequence of $[0_5/90_5]_S$, were compared [13].

3 Result and discussions

From the experiments, it was observed that the total electrical resistance of the single type hybrid bipolar plate without the graphite layer and GDL connection exhibited 96.8% lower than the conventional composite bipolar plate, under compaction pressure of 1.0 MPa. The GDL connected single type hybrid bipolar plate with the graphite layer exhibited 34.3% lower the total electrical resistance in comparison with the single type hybrid bipolar plate without the graphite coating and without GDL connection under compaction pressure of 1.0 MPa. It is because the soft graphite layer increases the contacting area between bipolar plate and GDL and the continuous electrical bypass among the unit cell components which leads to the decrement of the electrical contact resistance. In addition, the total electrical resistance of the GDL connected single type hybrid bipolar plate without the graphite layer and the graphite coated single type hybrid bipolar plate without GDL connection was investigated as a function of compaction pressure. Fig. 8 shows the total electrical resistance of the hybrid bipolar plates under compaction pressure of 1.0 MPa.

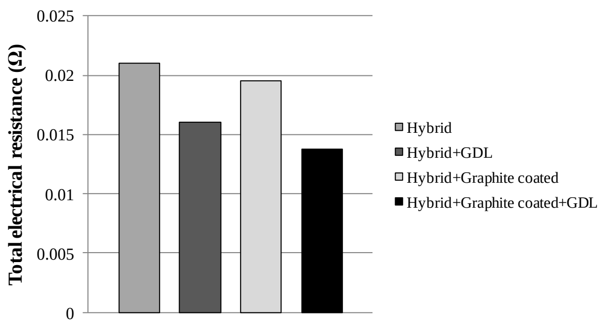
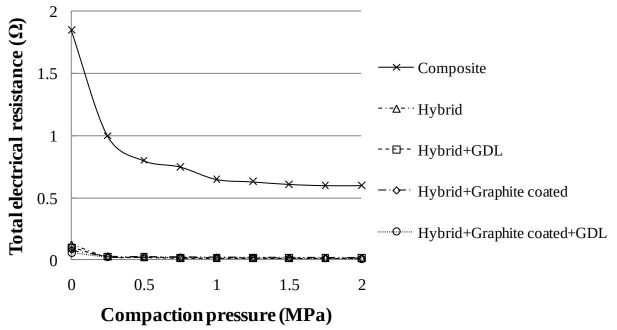


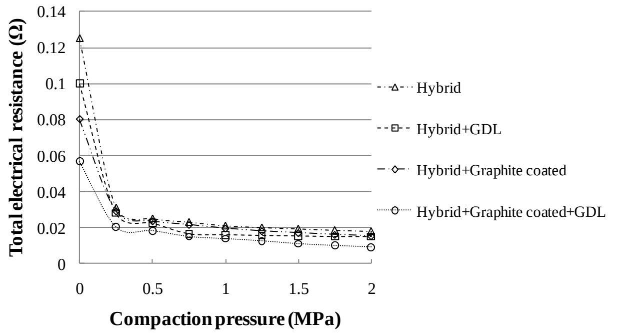
Fig. 8: Total electrical resistance hybrid bipolar plates under compaction pressure of 1.0 MPa.

From the obtained experimental results, the total electrical resistance of the bipolar plates with bypass was significantly smaller than without bypass.

It is because the single type hybrid bipolar plates have a parallel equivalent electrical circuit, as can be observed in Fig. 3, the total electrical resistance of the single type hybrid bipolar plates largely depends on the lower electrical resistance components in the parallel circuit [16]. Fig. 9 shows the total electrical resistance of the bipolar plates as a function of compaction pressures from 0 to 2.0 MPa.



(a)



(b)

Fig. 9: Total electrical resistances of the bipolar plates as a function of compaction pressure: (a) compared with the conventional composite bipolar plate, (b) without the conventional composite bipolar plate.

Therefore, the aluminum/composite single type hybrid bipolar plate with continuous GDL connection and graphite coating has 98% smaller total electrical resistance then the conventional composite bipolar plate (2% of the total electrical resistance of the conventional composite bipolar plates) and it could potentially increase the efficiency and performance of PEM fuel cells.

4 Conclusions

In this study, the single type hybrid bipolar plate with GDL for a PEM fuel cell was developed to decrease electrical resistance. An aluminum sheet and a carbon fiber/epoxy composite were co-cure bonded to provide continuous bypass for low electrical resistance. The surface of the aluminum sheet was abraded with 320 mesh sandpaper (resulting in an arithmetic aluminum sheet surface roughness, R_a, of 2.1 μm) and pre-formed to decrease the electrical resistance of the bipolar plate by increasing the aluminum-carbon fiber/epoxy composite contact area and provide the uniform electron pass. The carbon fiber/epoxy composite surface was coated with a thin graphite sheet to create a soft layer to increase the contact area with GDL. In addition, extended aluminum bypass was overlap connected to the edge of GDL and polyimide tape bonded to provide GDL-bipolar plate–bipolar plate-GDL continuous bypass. The total electrical resistances in the though-thickness direction of the bipolar plates were measured and compared. From the experiments, it was found that the single type hybrid bipolar plate with continuous GDL connection and graphite coating exhibited 98% lower the total electrical resistance than the conventional composite bipolar plate due to the continuous uniform electron bypass and the large contact area between the graphite layer on the bipolar plate and GDL. Therefore, the developed single type hybrid bipolar plate with GDL could be used for high efficiency PEM fuel cell systems.

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