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Composite endplates with pre-curvature for PEMFC (polymer electrolyte membrane fuel cell)

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A B S T R A C T

A conventional PEMFC (polymer electrolyte membrane fuel cell) stack is composed of multiple stack composed of GDL (gas diffusion layer), MEA (membrane electrode assemblies), and bipolar plates sandwiched in between two thick metallic endplates tightened by bands or tie-bolts as to maintain proper contact pressure on its active area and gasket interface. The proper contact pressure distribution in a stack offers low contact resistance for high energy efficiency and fluid leakage prevention as well. For which, the endplates should have proper structural stiffness.

This work presents a new design of asymmetric composite sandwich endplates which are made of carbon fiber reinforced composite and glass fiber reinforced composite with a pre-curvature generated by the residual thermal deformation, which will yield the required pressure distribution in the stack when the endplates are fastened by the clamping device. Clamping tests were performed with respect to amount of pre-curvature of composite sandwich endplates and the pressure distribution on the stack surface was measured using pressure sensitive films.

1. Introduction

Polymer electrolyte membrane fuel cell is an electrochemical energy converter that converts chemical energy of fuel directly into DC electricity. PEM fuel cells are a serious candidate for automotive applications, but also for small-scale candidate stationary power generation, and for portable power applications as well [1,2]. The components of a fuel cell stack such as MEAs (membrane electrode assemblies), GDL (gas diffusion layer), and bipolar plates of a polymer electrolyte membrane fuel cell or proton exchange membrane fuel cell (PEMFC) as shown in Fig. 1, should be held together with sufficient contact pressure to prevent the side leakage of reactants and to minimize the contact resistance between adjacent unit cells in the stack [3], which has been accomplished by employing two thick steel endplates to maintain proper pressure distribution through the cells. Too much pressure may squeeze the gas diffusion layer and change its porosity ratio, which may choke the fuel cell by making the flow of gases and migration of water difficult. On the other hand, too little pressure may result in a high contact resistance between gas diffusion backing and the bipolar plates, which would lower the fuel cell performance as well. Therefore, the endplate should have high flexural stiffness to resist the high clamping force applied to its sides by bands or bolts, which have been used to give a proper contact pressure distribution in the stack. The low flexural stiffness of endplate may yield a non-uniform pressure distribution in the fuel cell stack as shown in Fig. 2 [1–3]. However, the weight of endplate should be also reduced as much as possible for the passenger car application to obtain high mileage to fuel rate, which is difficult to accomplish with conventional metallic structures.

Although there are many research works to improve fuel cell performance, very little scientific research has been focused on the endplates and the pressure distribution between the fuel cell stacks. Wang et al. tried to make the pressure distribution uniform by using the hydraulic piston [4]. However, it is difficult to apply the hydraulic piston in the case of PEMFC which is used as the portable fuel cell for automobiles since a lot of equipment should be needed to use the hydraulic piston.

In this work, the endplate composed of the carbon fiber reinforced composite and the glass fiber reinforced composite with pre-curvature was designed for PEM fuel cell. The deformation of the composite plate due to the thermal residual stresses after fabrication was analyzed using FEM with respect to stacking sequence and compared to the experimental results [5–7]. The effect of thermal residual stress on the pressure distribution of the fuel cell stacks was measured using the pressure sensitive films.

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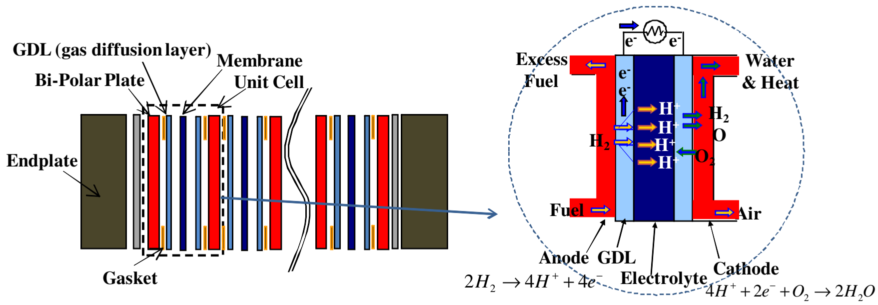

Fig. 1. Schematic drawing of stack for PEMFC.

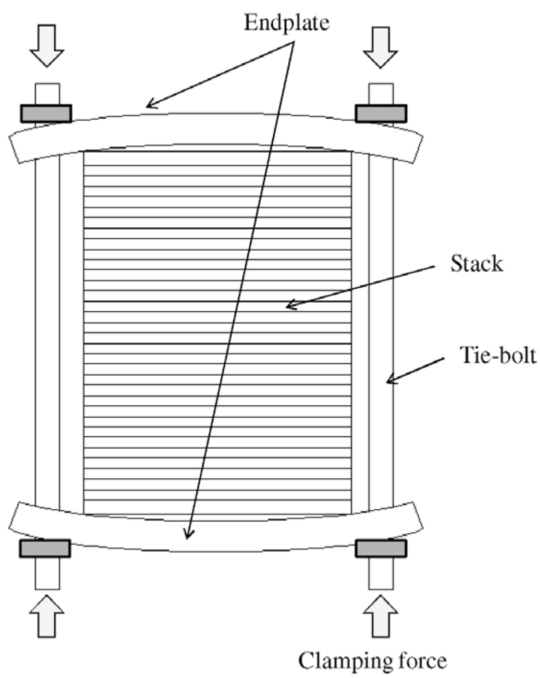

Fig. 2. Deflection of endplates of PEMFC by the clamping force.

2. Materials and design method for endplates

The main idea of the design for endplates is to give a pre-curvature to the composite plate so that it can apply a uniform pressure to the fuel cell stack. The endplate with low flexural stiffness will be deformed creating low pressure in the middle area of stacks as shown in Fig. 3a, while the endplate with pre-curvature could be flat after clamping as shown in Fig. 3b. In this work, the pre-curvature of the endplates generated by the thermal residual stress due to the difference of coefficients of thermal expansion between the composite prepregs was used to make the endplate flat after clamping of stacks [8,9]. Since the glass/epoxy composite has a larger coefficient of thermal expansion (CTE) than that of the carbon/epoxy composite, the composite plate could be bent as shown in Fig. 4, where a and b represent the thickness of glass epoxy and carbon epoxy composite, respectively. The material for composite endplates was unidirectional carbon/epoxy prepreg (URN 300, SK Chemical, Korea) and glass/epoxy prepreg (UGN 150, SK Chemical, Korea) whose cured properties were listed in Table 1 [10,11]. Using the material properties of Table 1, in this work, the hybrid composite endplates was designed with proper stacking sequence to make the composite plates yield a uniform pressure to the fuel cell stack.

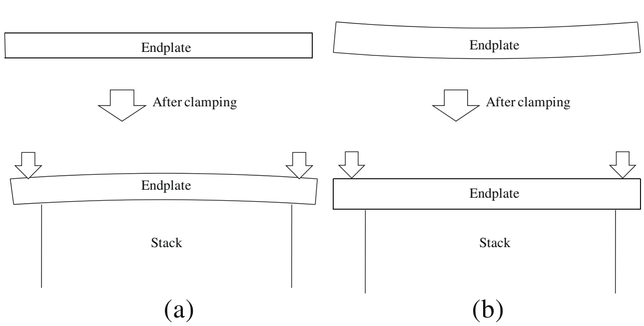

Fig. 3. Deflection of (a) the conventional endplates and (b) the composite endplates with pre-curvature.

3. Analysis of thermal deformation of the asymmetric composite plate

The flexural stiffnesses of composite endplate with pre-curvature were designed with respect to the stiffness of the endplate of the stainless steel of 10 mm, which has been used in automobile. The total thickness of the composite endplates is limited to 15 mm because of space limitation in the passenger car application. The area of the endplate was selected as 100 mm × 200 mm, which was also dimensions of the current PEMFC. Using the material properties in Table 1, the curvature of the hybrid composite plates generated by the fabrication thermal residual stress was calculated by the classical laminated plate theory (CLPT) program [8] with respect to the thickness of the carbon/epoxy composites. The temperature change of the composite plate was 100 °C, equal to the difference between the curing temperature (125 °C) and the room temperature (25 °C). Several different stacking sequences for the composite plates were tried to compare the thermal deformation of each case as listed in Table 2, where 0 and 90 correspond to the x- and y-directions of the specimen dimensions of endplates, respectively as shown in Fig. 5. Also, Fig. 6 shows the thermal deformations and the flexural stiffness of the composite plates with respect to the thickness of carbon/epoxy composites. As the thickness of the carbon/epoxy composite is increased, the flexural stiffness increases. However, the thermal deformation increases up to a certain value, followed by a small decrease with respect to plate thickness. When the thickness of the carbon/epoxy layer is 4.5 mm, the pre-curvature effect has a maximum value.

The composite endplates with pre-curvature and the conventional endplates were also analyzed under the stack clamping condition by finite element method using ABAQUS 6.7 (ABAQUS Inc., RI, USA), a commercial software package. Fig. 7 shows the finite element mesh used in the numerical calculations. The 3-dimensional 8-node linear elements of ABAQUS were used to model the composite plate with the pre-curvature. The clamping force was about 20 kN and the elastic foundation condition was 20 MN/m as shown in Fig. 8. The deflections due to the clamping force were calculated