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Effect of conductive carbon material content and structure in carbon fiber paper made from carbon felt on the performance of a proton exchange membrane fuel cell

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ABSTRACT

This study concerns the use of conductive carbon material with different content and structure to produce carbon fiber paper for use in proton exchange membrane fuel cells, and investigates how changes in the content and structure of the conductive carbon material influence fuel cell performance.

In this study, phenolic resin is used as a conductive carbon material, and is subjected to heat treatment at temperatures of 700 °C, 1000 °C, and 1400 °C, which changes its structure. Before carbon fiber paper is prepared from carbon felt, the felt is treated with phenolic resin solutions with resin content of 5, 10, 15, 20, 25, and 30 wt%. During fuel cell testing, torsion of 40, 60, 80, 100, and 120 kgf-cm is applied. The study found that when the phenolic resin content is 15 wt%, the heat treatment temperature 1400 °C, the test area 25 cm^2, and the test temperature 65 °C, a fuel cell can achieve a current density of 2020 mA cm^{-2} at 0.5 V and torque of 120 kgf-cm.

1. Introduction

A proton electrolyte membrane fuel cell (PEMFC) stack for automotive applications typically consists of membrane-electrode assemblies (MEAs), gas diffusion layers (GDLs), gaskets, and bipolar plates. The chief function of the GDL in a fuel cell is to provide a channel for fuel diffusion, conduction of electrons, and elimination of the water produced by the cell. A GDL must therefore meet four requirements: (1) Superior conductivity: electrons must be transmitted via the GDL, catalyst, and bipolar plate [1,2]. (2) Excellent air permeability: A GDL must have sufficient air permeability to facilitate the transmission of fuel [3]. (3) Appropriate hydrophobicity/hydrophilicity: While a GDL must not be flooded with water, the proton exchange membrane must also not become too dry, which would degrade fuel cell performance [4]. (4) Excellent mechanical strength: A GDL must withstand relatively high pressures when a fuel cell is assembled [5,6]. This study added a conductive carbon material to carbon felt when preparing carbon fiber paper, which was then used to produce GDLs for use in PEMFCs. The characteristics of the conductive carbon material were employed to increase the conductivity of the GDL while maintaining excellent air permeability, and the effect on fuel cell performance investigated under different pressures.

Gas diffusion layers (GDL) are typically made of carbon fiber paper or carbon fiber fabric, and the composition of a GDL can significantly affect PEMFC performance [7]. Carbon fiber fabric and carbon fiber paper are currently the most common materials used to make GDLs. Carbon fiber paper made from carbon fiber felt displays good processing properties and is considered a promising electrode material. Carbon felt is highly porous [8], which enables it to provide sufficient channels for the transmission of oxygen, hydrogen, and air. Carbon has the advantages of high conductivity and resistance to corrosion, and is well suited to the environment inside a PEMFC. While carbon fiber fabric is prone to warping and shrinking in fuel cells, carbon fiber paper offers excellent size stability. This study therefore selected carbon fiber paper as its subject.

Prior research [9] indicates that there are three key factors that can affect the thickness of carbon fiber paper produced from carbon felt: the yard weight, pressure during hot pressing, and phenolic

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resin content. Of these, prior studies have only investigated the yard weight of carbon felt, and found that fuel cell performance is best when GDL thickness is slightly greater than that of the gasket. According to Priyanka H. et al. [10], in order to increase conductivity, the application of a layer of carbon nanotubes (CNTs) to the carbon fibers when processing carbon fiber paper will increase the conductivity of the GDL and boost fuel cell performance. Subong Kim et al. [11] employed polyacrylonitrile (PAN)-based carbon fiber as a substrate, and used the wet-spinning method to produce carbon fiber paper. Serdar Celebi et al. [12] applied a layer of CNTs directly to carbon fiber paper, which was used to make PEMFC GDLs. Selective carbon nanofiber (CNF) growth on only one side of the carbon paper was required to transfer protons on the platinum catalyst sufficiently fast to avoid any proton mass-transfer losses. The current study, however, investigated the effect of changing the content of conductive carbon material (phenolic resin) in carbon fiber with a constant yard weight.

Phenolic resins have attracted much attention since their initial development by Baekeland in 1907 [13]. Phenolic resins form the most important candidate substrates for ablative composites due to their low cost, excellent ablative properties, dimensional stability, and chemical resistance [14]. Recently, more and more researchers have been focusing on the properties of carbon/phenolic composites in bipolar plates [15–17], and have reported a trend of rising conductivity with increasing carbonization temperature. Because phenolic resins possess these advantages, this study chose to use phenolic resin as a conductive carbon material, and liquid phase impregnation was employed to increase the conductivity of carbon fiber paper in the expectation that this would increase fuel cell performance. We discuss the relationship between fuel cell performance and different proportions of conductive carbon material added to carbon fiber paper GDLs, and investigate the effect of the key characteristics of thickness, resistivity, and air permeability on performance.

2. Experiment

2.1. Preparation of the conductive carbon material

The conductive carbon material consisted of phenolic resin, which was used at 100 wt% to prepare test pieces with dimensions of 3 cm (L), 5 cm (W), and 3 cm (H). These pieces were kept in an oven at 70 °C overnight, and then placed in a nitrogen environment, where they were either left uncarbonized or subjected to temperatures of 700 °C, 1000 °C, and 1400 °C. Structural changes in the phenolic resin were then examined.

2.2. Preparation of the carbon fiber paper

This study used oxidized fiber felt (from the Kuo Tung Felt Co., Ltd.) and phenolic resin (from the Chang Chun Plastics Co., Ltd.) as raw materials. The yard weight of the oxidized fiber felt was 90 g m^{-2}. The oxidized fiber felt was carbonized at a temperature of 1800 °C to produce carbon fiber felt. Phenolic resin was chosen as the conductive carbon material, and used in impregnation. The phenolic resin was mixed so as to constitute 5, 10, 15, 20, 25 and 30 wt% of the impregnation solution (diluted with an organic solvent), and the resulting solutions were designated GPR5, GPR10, GPR15, GPR20, GPR25, and GPR30. The carbon fiber felt was impregnated with the phenolic resin mixture, placed in an oven, and baked at a temperature of 70 °C for 15 min. Hot pressing at a temperature of 170 °C and pressure of 50 kg cm^{-2} was then performed to change the composite material to carbon fiber paper (see Fig. 1), and the carbon fiber paper was carbonized again, which changed the structure of the phenolic resin. Apart from material left untreated, the second carbonization was performed at temperatures of 700 °C, 1000 °C, and 1400 °C, and the resulting material was designated −X (untreated), −700, −1000 and −1400. For example, carbon fiber paper prepared using 5 wt% phenolic resin and subjected to a second carbonization temperature of 700 °C was designated GRP5-700. The carbon fiber paper resulting from the foregoing processing steps is referred to in this paper as the “GDL”.

2.3. Characterization of carbon fiber paper

A Teclock SM-114 thickness tester was used to measure the thickness of the carbon fiber paper, and the thickness was determined from the average of measurements taken at five random points. A Loresta GP MCP-T600 m was used to measure volume resistivity, and testing and analysis of surface resistivity was performed in accordance with JIS K 7194 regulations. Through-plane resistivity was measured via the two-point method, using copper plates 10 mm apart. Measurements were made at a minimum of five points on each piece of carbon fiber paper at different

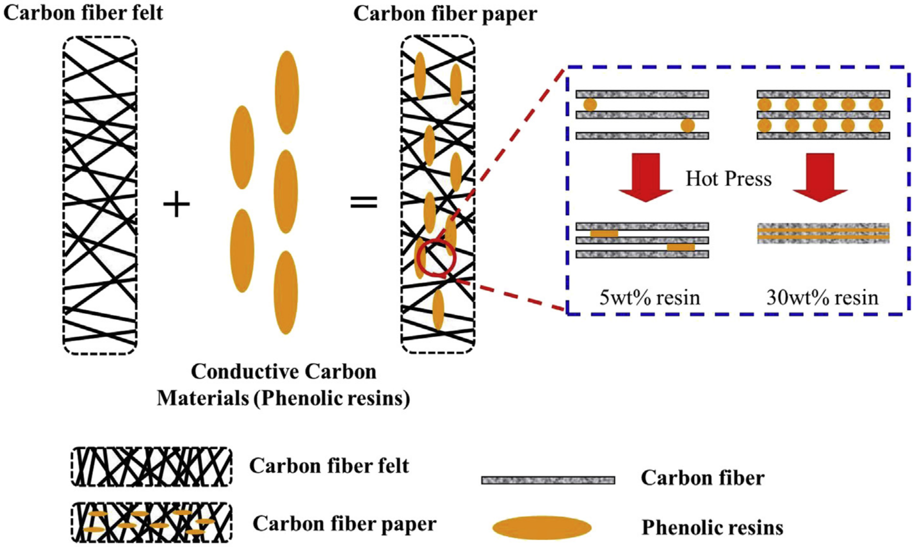

Fig. 1. Schematic diagram of carbon fiber paper production.