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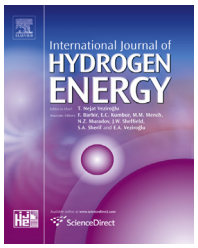

Experimental investigation of expanded graphite/phenolic resin composite bipolar plate

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ARTICLE INFO

Article history:
Received 28 January 2016
Received in revised form
25 May 2016
Accepted 29 May 2016
Available online 28 July 2016

Keywords:
Bipolar plate
Vacuum impregnation
Electrochemical impedance spectroscopy
Expanded graphite
Phenolic resin composite

ABSTRACT

A series of expanded graphite/phenolic resin composite bipolar plates with different phenolic resin contents have been prepared by resin vacuum impregnation and hot press method. The alcohol-soluble and water-soluble phenolic resins were used as polymer filler and expanded graphite plate are used as substrate carbon plate. The results indicated that the tensile strength, flexural strength, resistivity, gas permeability and corrosion current density of bipolar plate are influenced by resin solution concentration. When the solution concentration of water-soluble phenolic resin is 25%, the bipolar plate exhibits better mechanical property and resistivity. The electrochemical impedance spectroscopy (EIS) result shows that the overall resistance of homemade expanded graphite/phenolic resin composite bipolar plate is lower than that of graphite bipolar plate. The composite bipolar plates should be a promising candidate for PEMFCs and vanadium redox flow battery application.

Introduction

Proton exchange membrane fuel cells (PEMFCs) is one of the most promising candidate for new energy automobile application due to its characteristics of high efficiency and power density, low operating temperature and quick startup [1–3] et al. Bipolar plate (BP) is one of the critical component of PEMFCs. The BP has following main functions: reactant gas transportation; fuel and O_2 separation; gas leakage prevention; current collecting [4,5]. For achieving these performances, DOE has established physical and mechanical properties requirement of BP [6]. Graphite and metal were used as BP materials in previous studies, however, the graphite mechanical strength and metal corrosion resistance performances were poor [7,8]. Thus, the graphite and resin composite material can raise the corrosion resistance, but also improve the electrical conductivity, and is widely used in the preparation of the bipolar plate.

In previous composite BP studies, the carbon black (CB) [9,10], natural graphite (NG) [3,11], synthetic graphite (SG) [12], carbon fiber (CF) [9,13,14], carbon nanotubes (CNTs) [15–17], graphene (GP) [18,19] and expanded graphite (EG) [7,20–24] have been investigated. Several carbon materials were used simultaneously in one composite BP due to the target performance can not be achieved by single carbon material. EG is considered as the optimal substrate material due to its high thermal conductivity, low density, low cost and good chemical stability. Both thermosetting and thermoplastic resins were used to fabricate carbon material/

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http://dx.doi.org/10.1016/j.ijhydene.2016.05.253

polymer composite BP. Thermosetting resins, such as epoxy [21,25], phenolic [7,26] and vinyl ester [27] were investigated. Different thermoplastics, polypropylene (PP) [28], polyvinylidene fluoride (PVDF) [29], polyphenylene sulfide (PPS) [30] were also studied for BP application. Extrusion manufacture method is a convenient approach for BP fabrication. However, it is difficult to obtain the continuous graphite phase by this process, and lead to an inferior electrical conductivity BP. In this study, the continuous EG structure composite BP was fabricated by vacuum impregnation method and exhibited higher electrical conductivity and flexibility performance. The BP cost and resin curing time could be reduced by using thermosetting phenolic resin instead of epoxy.

Experiments

Preparation of graphite/phenolic resin composite bipolar plate

EG plate was used as substrate carbon plate, the thickness was 5 mm and the density was 0.2 g cm^{-3}. Alcohol-soluble and water-soluble phenolic resins (labeled as type 1 and 2 respectively) were purchased. The preparation process of EG/phenolic resin composite BP is shown in Fig. 1. The expanded graphite plate was put in a pressure-tight dipping kettle and keep the vacuum degree below −0.09 MPa for 1 h, then certain concentration of resin solution was pumped into the container and reserved for 5 h. Ethanol was used to remove the resin on the surface of plate. The plate was dried at 40 °C for 5 h, 60 °C for 5 h, and 80 °C for 5 h respectively, then hot pressed into different thicknesses at 130 °C for 1 h with plate vulcanizing machine (Changzhou No.1 Rubber & Plastic Equipment Co., Ltd., China).

Mechanical property measurement

The tensile and flexural strength of BP were measured by materials testing machines Z005 (Zwick Roell Group, Germany) based on ISO 527 and GB/T 13465.2-2002 standard. For the tensile strength test, the sample dimension was 150 mm × 20 mm × 1 mm, the test speed was 10 mm min^{-1} and the initial distance between fixtures was maintained at 100 mm. A rectangular plate with dimension of 120 mm × 20 mm × 1 mm was used to measure the flexural strength. The punch speed for each test was kept at 5 mm min^{-1} and the span length was maintained at 60 mm. Each presented data was the average of five tested samples.

Resistivity measurement

The resistivity was measured by 4-Point Probes Resistivity Measurement System (4 Probes Tech, China) using four probe method. The resistivity (ρ) of the bipolar plate was obtained from the following equation:

$$\rho = \frac{V}{I} \times C\ \Omega\ \text{cm} \quad (1)$$

where V (mV) is the measured voltage, I (mA) is the applied current, C (cm) is the probe coefficient, the value is 6.28.

Gas permeability measurement

Gas permeability measurement was performed using a test device, as shown in Fig. 2. Square sample was assembled between two chambers and 0.2 MPa hydrogen was applied to the specimen at room temperature. The effective dimension of the sample was 50 mm × 50 mm, and the test was performed for 2 h. SP-3420 Gas Chromatography (Beijing Beifen-Ruili Analytical Instrument (Group) Co., Ltd., China) was used as an analytical facility.

Corrosion current density measurement

The corrosion current density of the BP was measured using potentiodynamic polarization in a simulated PEMFC environment. Three-electrode electrochemical cell was used in the electrochemical measurements. BP was used as a working electrode with 1 cm^2 effective area. The Ag/AgCl was used as a reference electrode, and the platinum sheet was used as a counter electrode. The experiment was conducted using 1 M H_2SO_4 solution at 80 °C. The potentiodynamic potential curve was swiped at a scan rate of 1 mV s^{-1} from −0.3 V to 0.4 V with the help of CHI 760E Electrochemical Workstation (CH Instruments, Inc., China).

Single cell test

A 6.25 cm^2 activation area membrane electrode assembly (MEA) was used for single cell. Carbon paper (SGL Group, Germany) was used as gas diffusion layer, Nafion 211 was selected as proton exchange membrane. Catalyst slurry was sprayed onto the membrane with a spray gun. Anode and cathode catalyst layers were prepared with a platinum loading of 1.0 mg Pt·cm^{-2}. The MEA was sandwiched between two similar BPs. I–V and EIS curves were measured by KFM2150 FC IMPENDANCE METER (KIKUSUI, Japan). The scan rate for I–V test was 0.2 A min^{-1}. The frequency scanning range was 20 KHz–10 mHz, and AC interference signal amplitude was 5% for EIS test. The composite BP thickness was 2 mm. Hydrogen

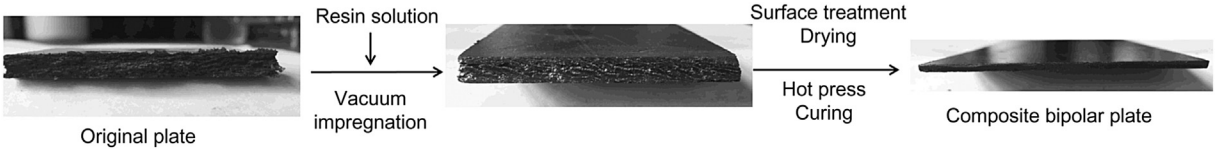

Fig. 1 – The preparation process of EG/phenolic resin composite BP.