Development and Performance Evaluation of Carbon-Polymer Composite Bipolar Plate for Proton Exchange Membrane Fuel Cell

Submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

by

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March, 2011

Abstract

Bipolar plate is a key component of low temperature fuel cells, which may contribute up to 80% of the total weight of the proton exchange membrane fuel cell (PEMFC) stack. Different type of materials like metal, coated metal, graphite, composites etc. are under investigation to develop bipolar plates with high electrical and thermal conductivity, mechanical strength, flexibility, corrosion resistance, and low hydrogen permeability. Moreover, the bipolar plates must be thermally stable in the fuel cell operating temperature. Pure graphite bipolar plate is a good candidate for fuel cell application, owing to its high electrical conductivity and good corrosion resistance. However, low formability, high gas permeability, low mechanical strength, low flexibility, and cumbersome machining of complex flow-field limit the application of pure graphite bipolar plates. Similarly, corrosion of metal and uneven expansion of coated metal limit the applicability of metal based bipolar plate. Therefore, scientists and researchers are giving attention towards the development of carbon-polymer composite bipolar plate due to its low density, good corrosion resistance, light weight, good flexibility, and ease in machining or in-situ molding of flow fields during processing. The aim of this research is to develop a carbon-polymer composite bipolar plate with low density, high electrical and thermal conductivity, high flexural strength, high hardness, less hydrogen permeability and good corrosion resistance.

Monolayer graphene was developed by thermochemical reduction of NG. The synthesized graphene was characterized by SEM, EDX, XRD, HRTEM, ED, AFM, FTIR and BET. The absence of graphite 002 and 004 peaks in the diffractogram shows that monolayer graphite formed. The yield of monolayer graphene was also confirmed by SEM, HRTEM, ED, and XRD analyses. The AFM analysis of the graphene showed that the thickness was around 1 Å. The developed graphene was used as reinforcement along with natural graphite (NG), carbon black (CB), and carbon fiber (CF) to develop carbon-polymer composite bipolar plate. Similarly, three types of thermoset polymer, viz., resol-phenol formaldehyde (resol-PF), novolac-phenol formaldehyde (novolac-PF), and vinyl ester resin (VER), were used for compression molding of the composite bipolar plates. The NG/resin composite bipolar plates were developed and characterized to find out the optimum molding temperature. Similarly, the effects of NG, CB, and CF content on the properties of the composite bipolar plates were also studied. The developed bipolar plates were characterized thoroughly for electrical conductivity, thermal conductivity, flexural strength, shore hardness, corrosion resistance, hydrogen permeability, and morphological analysis. The in-plane electrical conductivities of the NG/CB/CF/resin composite bipolar plates, for the optimum compositions, were recorded as 415.05, 285.54, and 355.05 $S \cdot cm^{-1}$, respectively for resol-PF, novolac-PF, and VER. Similarly, the through-plane electrical conductivities of those composite bipolar plates were 99.70, 91.79, and 95.95 $S \cdot cm^{-1}$, respectively. Therefore, the through-plane electrical conductivities of the bipolar plates were edge behind the target value of 100 $S \cdot cm^{-1}$. The flexural strengths of the NG/CB/CF/resin composite bipolar plates, at the optimum compositions, were 54.23, 55.28, and 53.50 MPa, respectively. The thermal conductivity of those composites were 145.3, 128.26, and 132.4 $W \cdot m^{-1} \cdot K^{-1}$, respectively. The corrosion analysis of the bipolar plates was carried out in simulated rigorous PEMFC and AFC environment. The corrosion current density of the NG/CB/CF/resin composite bipolar plates, at the optimum compositions were well below the target of 1 $\mu A \cdot cm^{-2}$. Similarly, the hydrogen permeabilities of the bipolar plates were in the order of 10^{-9} $cm^3 \cdot cm^{-1} \cdot s^{-1}$ at 50°C. The optimum compositions of the NG/CB/CF/resin bipolar plates were further reinforced with 1% graphene, at the expense of NG, to improve the electrical conductivities. The in-plane electrical conductivities of the graphene reinforced composites were recorded as 435.31, 311.33, and 376.03 $S \cdot cm^{-1}$, respectively for resol-PF, novolac-PF, and VER resins. The through-plane electrical conductivities of those composites were 130.17, 123.5, and 129.79 $S \cdot cm^{-1}$, respectively. The reinforcement with 1% graphene also improved the mechanical strength of the composite marginally. The corrosion current density of the composite in simulated rigorous PEMFC environment was still in the order of 1 μA·cm^{-2}. Similarly, the hydrogen permeability of the composite was also in the order of 10^{-9} cm^3·cm^{-1}·s^{-1} at 50°C. The overall properties of the graphene reinforced composites were well above the target values of the bipolar plates for PEMFC.

A PEMFC set-up was developed to study the performance of the developed bipolar plates in real fuel cell. The use of graphene in the composite bipolar plates also showed around 10% improvement in the power density of the PEMFC. The peak power density of the PEMFC with the optimum composition of the NG/CB/CF/resol-PF composite bipolar plates was 397 mW·cm^{-2} at a current density of 752 mA·cm^{-2}. The reinforcement with 1% graphene to the above composite bipolar plates increased the peak power density of the PEMFC to 437 mW·cm^{-2} at a current density of 827 mA·cm^{-2}.

Keywords: Bipolar plate; Composite; Electrical conductivity; Fuel cell; Graphene; Reinforcement