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Materials and design development for bipolar/end plates in fuel cells

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Abstract

Bipolar/end plate is one of the most important and costliest components of the fuel cell stack and accounts to more than 80% of the total weight of the stack. In the present work, we focus on the development of alternative materials and design concepts for these plates. A prototype one-cell polymer electrolyte membrane (PEM) fuel cell stack made out of SS-316 bipolar/end plate was fabricated and assembled. The use of porous material in the gas flow-field of bipolar/end plates was proposed, and the performance of these was compared to the conventional channel type of design. Three different porous materials were investigated, viz. Ni–Cr metal foam (50 PPI), SS-316 metal foam (20 PPI), and the carbon cloth. It was seen that the performance of fuel cell with Ni–Cr metal foam was highest, and decreased in the order SS-316 metal foam, conventional multi-parallel flow-field channel design and carbon cloth. This trend was explained based on the effective permeability of the gas flow-field in the bipolar/end plates. The use of metal foams with low permeability values resulted in an increased pressure drop across the flow-field which enhanced the cell performance.

Keywords: Fuel cells; Bipolar; End plates; PEM

1. Introduction

The fuel cell is an electrochemical device that enables the direct and efficient conversion of chemical energy stored in the fuel along with an oxidant into electrical energy. Although discovered more than 160 years ago, fuel cells have recently attracted the attention of energy consuming devices manufacturers. This is due to the advantages that fuel cells offer over other energy consuming devices [1]. However, the widespread commercialization of the technology has not been made possible due to the high cost of the fuel cell system. The advantages that accrue with the use of fuel cells outweigh their commercialization issues. Consequently, a lot of R&D efforts are going on within virtually every major automobile and power industry and in different universities around the world. The biggest challenge to the development of polymer electrolyte membrane (PEM) fuel cell type for automotive applications is the reduction in cost of the fuel cell stack components (bipolar/end plate, catalyst and electrolyte membrane).

The final component on the outside of the fuel cell is the end (collector) plate, which contains a gas flow-field on one side and is flat on the other side. The fuel cell current is drawn from the flat side of the plate. The bipolar (separator) plate provides a separation between the individual fuel cells whose function is to provide a series of electrical connections across different cells in the fuel cell stack and to direct fuel and oxidant gas streams to individual cells. The overall efficiency of the fuel cell depends on the performance of the bipolar/end plates in the fuel cell stack. Conventionally, these plates are made out of graphite with machined gas flow-field channels. Graphite plates are good performers; however, the machining process required to make flow-field channels in these plates is quite expensive, and consequently, alternative materials and concepts are required to fabricate these plates.

Several models have been developed for optimizing the design and channel dimensions of the gas flow-field in bipolar/end plates [2–4]. These studies indicate that use of porous material in the gas flow-field will enhance the performance of these plates. The idea behind this is the reduction in the effective permeability of the gas flow-field through the use of porous materials. This is because lower permeability will result in more tortuous path parallel to the plates thereby making the flow of reactant gases towards the reaction interface from only diffusion to diffusion plus convection based. It may be noted that permeability reduction is not possible beyond a particular limit ($\sim 10^{-8}\,m^2$) in case of channel design due to restriction in machining thin channels. This paper presents experimental results with use of porous materials in the actual fuel cell stack conditions. These results will then be compared to conventional machined channel design.

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2. Experimental

In the present work, three different types of foam materials were studied, viz. Ni–Cr metal (Fe: 8% (max.), C: 2% (max), Cr: 30–54%, Ni: balance) foam with 50 PPI (pores per inch), SS-316 metal foam with 20 PPI, and carbon cloth. These materials were chosen merely because they were electrically conductive, had good mechanical properties and were easily available. It is important to note that with the use of metal/alloys systems, corrosion and membrane electrode assembly (MEA) contamination are the main issues. It is well accepted in the scientific community that corrosion of metal/alloys systems cannot be completely avoided, but can only be reduced. Several possible solutions including the use

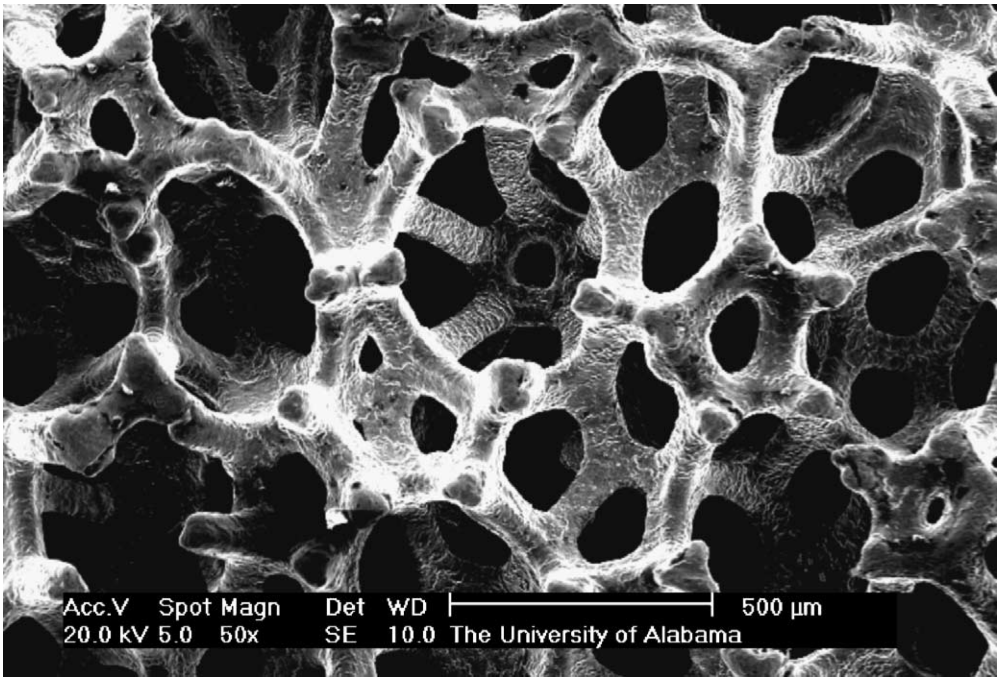

Fig. 1. SEM image of Ni-Cr metal foam with 50 PPI.

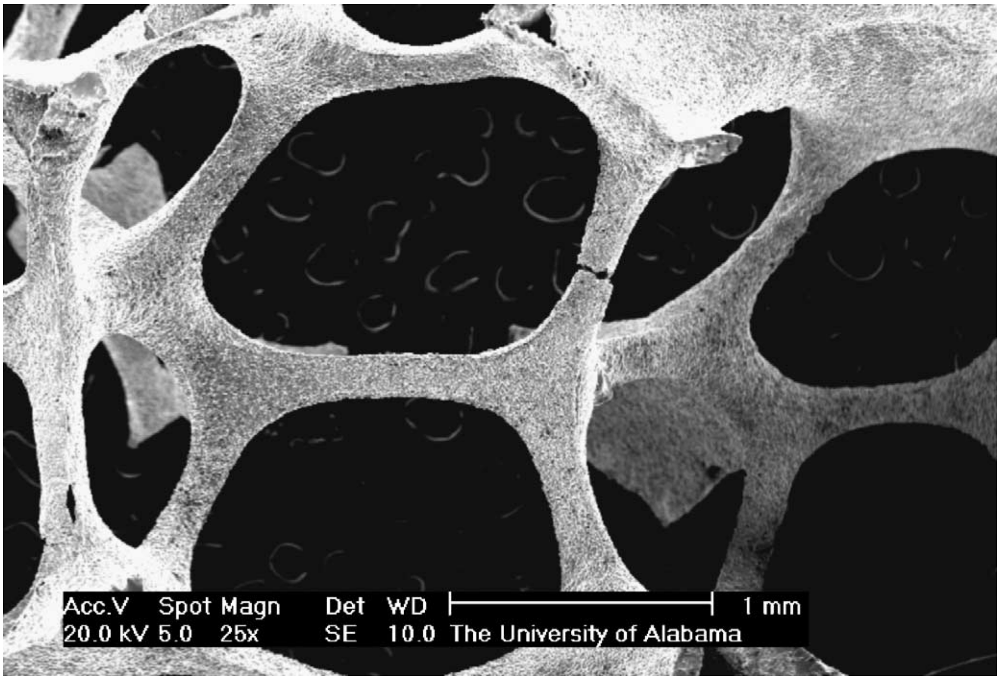

Fig. 2. SEM image of SS-316 metal foam with 20 PPI.

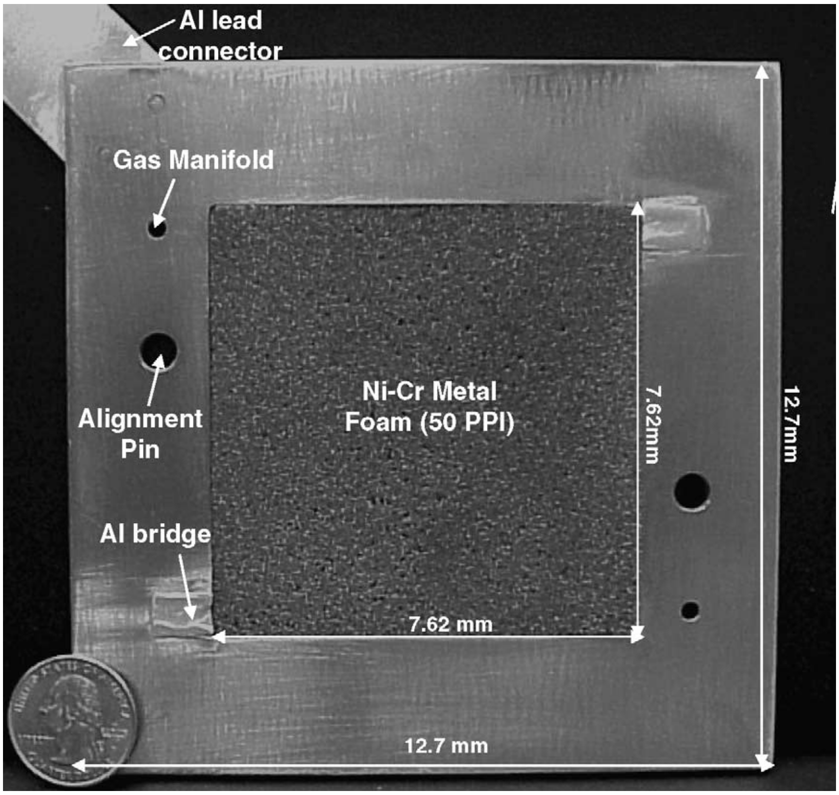

Fig. 3. Picture of Bipolar/end plate with Ni–Cr metal foam (50 PPI) in the flow-field.

of protective coatings to increase the corrosion resistance of metals/alloys systems in fuel cell environment are being studied by several researchers [5–8]. The MEA metal ion contamination can be minimized to a great extent by optimizing the fluid-flow in the metal foams, so that whatever metal ions products are formed does not stagnate in the cell stack and are exhausted along with the by-product water [9].

Metal foams are a new class of materials which until now have not been characterized properly but do posses alluring potential to be used for numerous applications including: electrodes and catalyst carriers, filters, flame arresters, heat exchangers, silencers, etc. Excellent reviews of manufacturing techniques and properties have been done by few researchers [10–12]. In the present study,

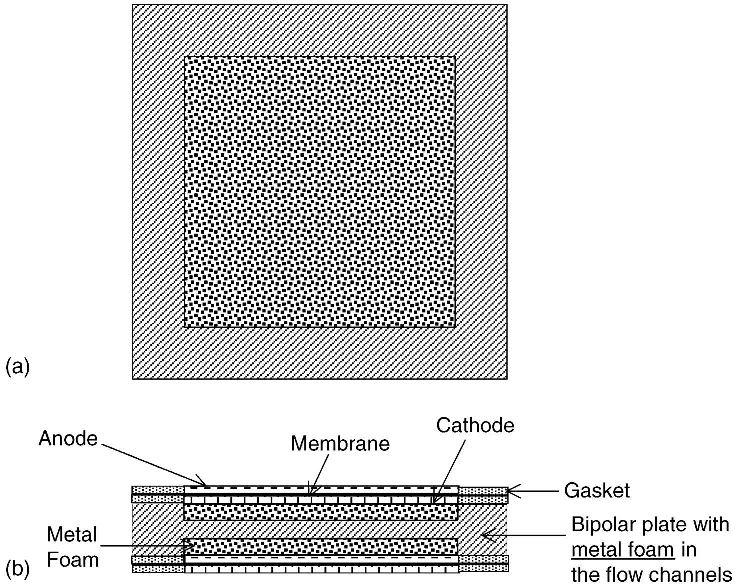

Fig. 4. Schematic showing (a) bipolar/end plate with metal foam in the gas flow-field; and (b) cell configuration with bipolar/end plate shown in (a).

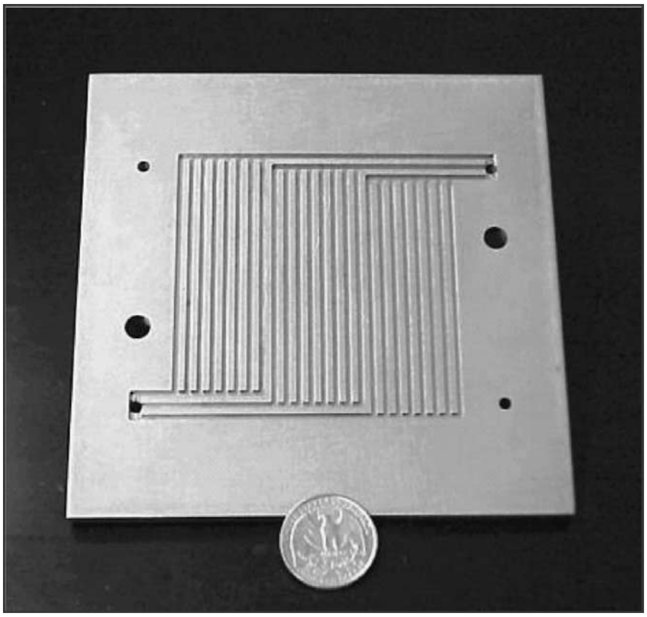

Fig. 5. SS-316 bipolar/end plate with machined multi-parallel channel gas flow-field design designed and developed at University of Alabama [9].

we present one more potential application of these foam materials.

Figs. 1 and 2 shows the SEM pictures of open pore structure of Ni–Cr and SS-316 metal foams, respectively. Fig. 3 shows the picture of the actual end plate with one of the foam materials (Ni–Cr) as used in experiments. Fig. 4 shows the cell schematic with metal foams in the gas flow-field of bipolar/end plates. The results from these foam materials would be compared with our previously developed SS-316 bipolar/end plate with machined multi-parallel channel gas flow-field design (Fig. 5) [9].

A one-cell prototype PEM fuel cell stack with SS-316 base bipolar/end plates and Al 3003 support plates was fabricated and assembled using the facilities at the University of Alabama (Fig. 6). It may be noted that one-cell stack will consist of only two end plates. As discussed earlier, porous material was used the gas flow-field of these plates. The dimensions of the end plates were: 12.7 cm × 12.7 cm × 0.5 cm and that of the gas flow-field were 7.62 cm × 7.62 cm × 0.15875 cm. An Al metal bridge was placed near the gas manifold to avoid silicon rubber gasket deformation in these regions. Al lead connectors were bolted to these end plates.

Experiments were carried out using the fuel cell test station facilities at the University of Alabama. The facilities include: (a) CompuCell GT® gas controller unit for precise control of the mass flow of reactants as well as humidification, temperature, and back pressure on both fuel and oxidant sides; (b) Scribner Associates 890B fuel cell test load for precisely drawing desired amount of current from the cell stack; (c) FuelCell™ software for precise computer control and monitoring of operating parameters.

Pure hydrogen and oxygen were used as reactant gases on the anode and cathode sides, respectively. Nitrogen was used as a purging gas. The reactant gases were externally humidified by passing them through a humidification chamber in the gas controller unit. The operating conditions for both anode and cathode sides were $T = 80\,^{\circ}\mathrm{C}$; $P = 207\,\mathrm{kPa}$ (back pressure); anode flow rate, $Q_a = 150\mathrm{cc/min} + \mathrm{LBF}$ (Load Based Flow); and cathode flow rate, $Q_c = 80\mathrm{cc/min}+\mathrm{LBF}$.

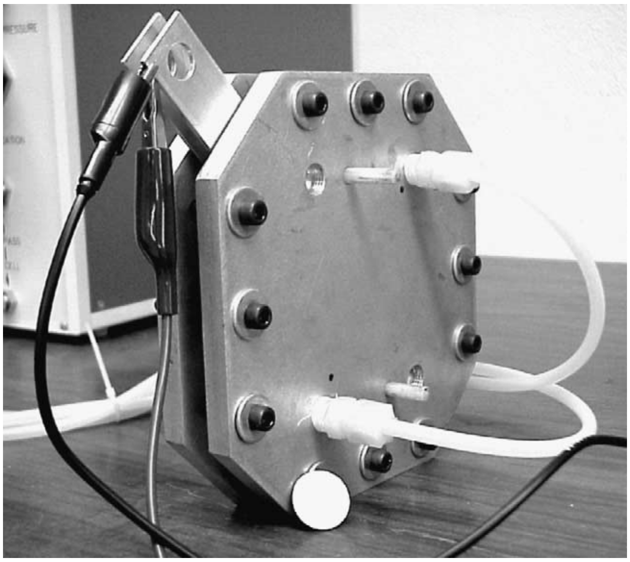

Fig. 6. Prototype one-cell PEM fuel cell stack with metal foam in the gas flow-field on bipolar/end plates.

3. Results and discussion

The aim of this study was to establish the feasibility of use of metal foams in the gas flow-field of bipolar/end plates in the PEM fuel cell stack. Consequently, issues such as membrane electrode assembly metal ion contamination due to the use of metallic components which have been reported by researchers have not been addressed here in detail [5–9]. Solutions have been proposed to the above problems, and similar approaches can be applied to metal foam systems.

Polarization studies are typical for any electrochemical system to evaluate its performance. Fig. 7 shows the polarization curves for the one-cell PEM fuel cell stack with different bipolar/end plate concepts. These curves were obtained by increasing the load level (scan rate: 2 mA/s) from the cell and monitoring the cell voltage. As is typical of any electrochemical system, the curve shows a continuous decrease in voltage as the load level is increased. This is due to the polarization losses (activation, ohmic and concentration), the magnitude of which depends on the amount of current drawn from the cell. Activation polarization is predominant at low current densities, ohmic polarization at intermediate current densities while concentration polarization at high current densities. Furthermore, it can be seen from Fig. 7 that the performance of Ni–Cr metal foam was highest followed by SS-316 metal foam and conventional multi-parallel

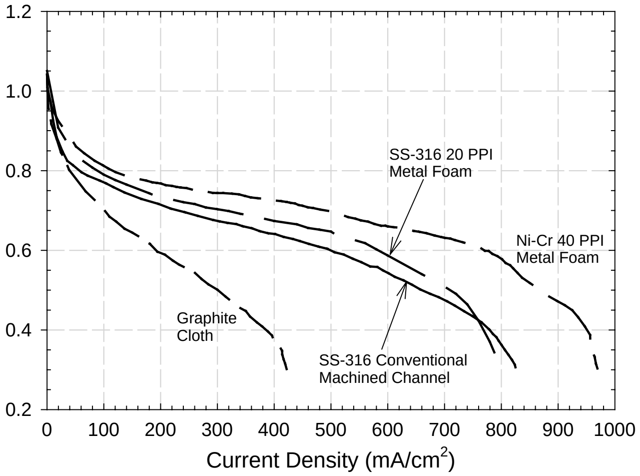

Fig. 7. Polarization curves for different bipolar/end plate concepts.

flow-field channel design. The low performance with use of carbon cloth is due to the high contact pressure in the cell stack which resulted in pressing of the cloth and consequently blocking the pores in the carbon cloth. Consequently, the use of carbon cloth was ruled out completely.

The relative performance for metal foams and conventional channel design can be explained based on our previously developed model [2]. As predicted by our model, the current density level from the cell increases at constant voltage when the permeability of the flow-field is decreased. This is due to increased pressure drop across the flow-field as the permeability is decreased. Assuming, hydrogen as the fluid, the permeability values for Ni–Cr metal foam (50 PPI) and SS-316 metal foam (20 PPI) are in the order of 10^{-9} and $10^{-8}\,\mathrm{m}^2$, respectively. The term equivalent permeability (α) was defined for channel type of gas flow-field design, and is given as [3]:

$$\alpha = \frac{N_c (z_c/2)^2 x_c}{L} \times \left[\frac{1}{3} - \left(\frac{64}{\pi^5}\right)\frac{z_c}{x_c}\sum_{\mathrm{odd}^n}^{\infty}\frac{1}{n^5}\tanh\left(\frac{n\pi x_c}{2 z_c}\right)\right] \tag{1}$$

where N_c is the number of channels, z_c the thickness of the channels, x_c the channel width, and L is the length of the channel. For the multi-parallel gas flow-field design considered here, the equivalent permeability is in the order of $10^{-8}\,\mathrm{m}^2$. As already stated, permeability reduction is not possible beyond an order of $10^{-8}\,\mathrm{m}^2$ in case of machined gas flow-field channels due to restriction in machining thin channels.

The use of metal foams, apart from increased performance, will result in low weight of the cell stack. The result discussed here uses a thick (5 mm) base bipolar plate where a slot of dimensions 7.62 cm × 7.62 cm × 0.15875 cm was made and metal foam was placed in the slot. An improvement over this design can be made by brazing metal foams with a thin metal sheet (∼0.5 mm) to form bipolar/end plates. Such sandwich panels are already being used for structural applications in automobiles [12]. In such a scenario, the weight of the bipolar/end plate with metal foams can be reduced by around 30–50% of the weight of currently used graphite plates.

It may be noted that this work is still at an embryonic stage. The performance with use of these metal foams can still be further enhanced by carefully selecting the pore size, shape and distribution in the metal foams. Furthermore, these metal foams can be used as catalyst support for the electrochemical reactions in the fuel cell [12]. Metal foams have a highly porous structure, and catalyst can be effectively deposited onto them. In such a scenario, the metal foam in the bipolar/end plates will act as gas flow-field distributor, electrodes and catalyst support, thereby reducing the number of components in the fuel cell stack.

4. Conclusions

In the present work, the use of porous materials in the gas flow-field of the bipolar/end plate was demonstrated. Three different types of porous material were considered: Ni–Cr metal foam (50 PPI), SS-316 metal foam (20 PPI), and carbon cloth. It was seen that the use of carbon cloth was not feasible due to high contact pressures which resulted in the blockage of pores, and consequently, lowest performance was observed. In general, metal foams performed better than the conventional channel design flow-field. Furthermore, it was seen that with a decrease in the permeability of the metal foam, the cell performance increases. The performance can be further increased by carefully tailoring the size, shape and distribution of the pores in the metal foam. An additional advantage will accrue as these metal foams can be possibly used for catalyst support for the electrochemical reactions in the fuel cell, thereby eliminating the need to use carbon electrodes. These studies are in progress at University of Alabama.

Acknowledgements

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