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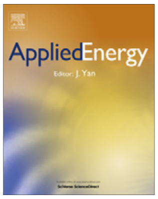

Surface roughness effect on the metallic bipolar plates of a proton exchange membrane fuel cell

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HIGHLIGHTS

- ▶ Various degrees of roughness are caused by the sandblasting method.
- ▶ An improper surface modification depletes the PEMFC performance severely.
- ▶ The AC impedance are used to assess the fuel gas transfer effect.
- ▶ The Warburg resistance form in the coarse flow channel surface.

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ABSTRACT

Proton exchange membrane fuel cells (PEMFCs) is a promising candidate as energy systems. However, the stability and lifetime of cells are still important issues. The effect of surface roughness on metallic bipolar plate is discussed in this paper. Various roughness on the bulk surface are obtained by the sandblasting method. The grain sizes of sand are selected as 50, 100 and 200 μm. The Ac impedance experiment results show that the bipolar plate roughness and carbon paper porosity are well matched when the surface roughness is within 1–2 μm. Superior condition decreases the contact resistance loss in the fuel cell. The high frequency resistance of the coarse surface was larger than that of the substrate by around 5 mΩ. Furthermore, a new arc was formed at the low frequency region. Hence, the unmatch roughness condition of the bipolar plate significantly increases the contact resistance and mass transfer resistance. This paper develops a sequential approach to study an optimum surface roughness by combining the whole performance (I–V) curve and AC impedance result. It benefits us to quantify the contact and mass transfer resistance exists in the PEMFC. The proposed surface treatment improves the surface effect and promotes the implement of potential metallic bipolar plate in near future.

1. Introduction

Hydrogen energy is considered to be an ideal alternative energy in the foreseeable future [1–4]. Hydrogen has been used as the fuel in the fuel cells [5,6]. The major advantages of proton exchange membrane fuel cells (PEMFCs) are low-temperature operation, quick starting and high energy density. Therefore, the PEMFC can be extensively applied to power generation, portable electric equipment, ship and hybrid vehicles. The bipolar plate acts as an important component in the PEMFC [7]. The bipolar plate served as a fuel gas feed, water drain and electronics transfer medium. These properties, such as corrosion resistance, electrical resistance, flow pattern, hydrophobic surface, cost and weight of the bipolar plate, were discussed extensively [8–12]. Kanezaki et al. [13] discussed the cross-leakage from the adjacent gas flow and GDL that influenced the single-cell performance. This cross-leakage was useful to reduce the concentration loss and water drain in the fuel cell. Fundamentally, this mechanism occurred frequently under the larger pressure difference and flux density of gas. However, the friction and bending loss decreased the pressure difference in the flow channel. Hence, the worse fuel cell performance was observed under large friction and the rough surface in the fuel cell. The gas concentration, diffusion coefficient, pressure, viscosity and friction involved a mass transfer reaction. Cooper and Smith [14] adopted AC impedance, current interruption and high frequency resistance technology to analyze the fuel cell performance. The ohmic resistance error by three methods was within 4.3% of each other. This high frequency resistance deviation was very small for the contact resistance physically. Lee et al. [15] manufactured graphite bipolar plates by various processes. Various pressure, temperature and graphite proportion were arranged in this experiment. The well-proportioned graphite reduced the contact resistance. Furthermore, the increasing graphite particle enhanced the hydrophobicity

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of the bipolar plate. This phenomenon proven that the surface effect was significant to the whole fuel cell performance. Kraytsberg et al. [16] attributed the attributed contact resistance to the bipolar plate and the GDL. The passivation layer and morphology of the bulk influenced the performance significantly. The morphology of the bulk was polished by various grit sizes of Emery paper. The maximum contact resistance (361 mΩ) was measured under the 1-μm grain diamond polishing. However, the opposite trend could be measured when the minimum contact resistance (22 mΩ) was measured under the 127-μm grain diamond polishing. The smooth surface acted a steep descend of the contact conductivity. Yan et al. [17] observed the 2-kW PEMFC performance by AC impedance technology. Fundamentally, the gas mass transfer effect was measured under the small gas stoichiometry. The electronic transfer effect was observed under low relative humidity. The mass transfer effect to the cell stack was more important than in the single cell. Hence, the AC impedance technology could provide reliable fuel cell information for the cell preliminary design. The AC impedance technique was adopted to evaluate the PEMFC performance in many papers [18–20]. Barber et al. [21] discussed the contact surface area between the bipolar plate and the collector by the mathematical model. Three main operating factors, bulk surface roughness, compact force and the coating thickness of the collector, affected the total contact surface area significantly. Moreover, the minimum porosity of the bipolar graphite led to the maximum contact surface with the collector. Avasarala et al. [22] discussed the relation of the roughness over the complex bipolar plate and the contact resistance. The artificial roughness was polished by various grit sizes of sandpapers (#80–1000). The minimum contact resistance caused by the #600 sandpapers and the roughness was approximately 0.9 μm. Contrary to common belief, maximum contact resistance was caused by the #1000 sandpapers. Antoni et al. [23] discussed the contact resistance under various passivation layers and surface roughness. The stainless steel 316 and SS 904 were selected as the substrates. The roughness of the bipolar plate was polished by various sandpapers. The value of the contact resistance increased gradually when the roughness was modified within 1–2 μm. The contact resistance increased sharply when the surface roughness was less than the 0.5 μm. Furthermore, this experiment was set at a potentiostatic mode of 800 mV and 500 mV in the cathodic condition. The SS 316 also possessed superior performance under the polarization test. Shoyama et al. [24] discussed the relation of the hydrophobicity and water management in the bipolar plate and GDL. The roughness involved the hydrophobicity in the flow channel significantly. It was observed that the coarse surface enhanced the surface tension. Furthermore, the abundant PTFE in the GDL would enhance the hydrophobicity. A better single-cell performance curve was measured when the hydrophobic GDL accompanied with the hydrophilic bipolar plate was set in high relative humidity.

It was mentioned that the roughness of the bipolar plate affected the fuel cell significantly. The contact resistance involving the bipolar plate roughness and GDL porosity was discussed in many papers. There are few papers depicting the bipolar plate roughness involved in the fuel gas transfer mechanics. However, the stability of the fuel cell should be improved before it is fully developed. Therefore, the fuel gas transfer resistance and bipolar plate roughness are discussed in this paper.

2. Experiment

2.1. Surface roughness on the bipolar plate

A single serpentine gas flow bipolar plate with an active area of 25 cm^2 was manufactured from an Al alloy 5052 and machined as shown in Fig. 1. The flow channel was machined as 0.9 mm in both depth and width. The smooth surface was clearly observed on the substrate ($R_a = 0.2131$ μm) in the inset. Roughness variations on the bulk surface were caused by the sandblasting method. The sand grain sizes were selected as 50, 100, and 200 μm. Furthermore, the bipolar plate after sandblasting with medium sand was immersed in sulfuric acid for 30 min in order to analyze the characteristic of the surface roughness after the corrosion. Various sandblasting methods involved not only the contact resistance effects but also the mass transfer mechanism. The relationship between the surface roughness and the sandblasting method is listed in Table 1.

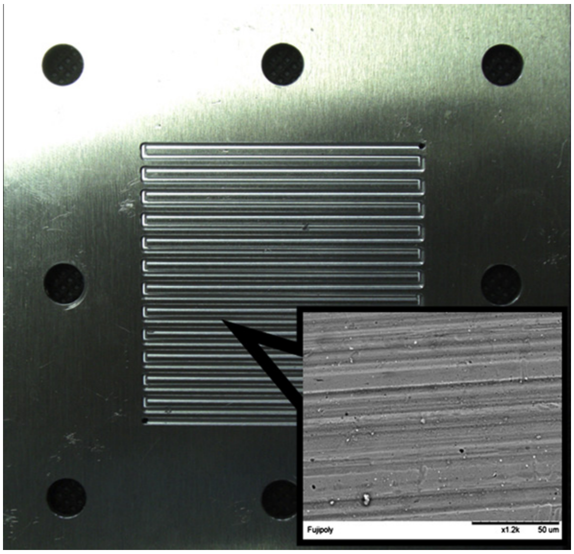

Fig. 1. The morphology of 5052 Al-alloy bipolar plate.

2.2. Fuel cell configurations

The manufactured PEMFC used in this experiment was assembled with commercial membranes (Nafion-112), sandblasted metallic bipolar plates, and Toray carbon paper (E-Tek). 180-μm-thick gas diffusion layers were used as the base material in this study. The active area of the Nafion 112 membrane was 25 cm^2 (5 cm × 5 cm). The schematic diagram and photo of PEMFC apparatus were shown in Fig. 2. In the fuel cell experiments, the compaction force imparted on a cell was loaded as 200 N/cm^2.

2.3. Electrochemical measurements

The fuel gas was supplied with oxygen (140 sccm) in the cathode and hydrogen gas (210 sccm) in the anode. The temperature of the fully humid flow gas and cell were set at 60 °C. The range of the electric load was 0.85–0.1 V (voltage scan rate was 0.1 V/h), and the limit current was set at 25 A. The fuel cell performance

Table 1
Change in the roughness of the bipolar plate with various degrees of sand.

Part no.	Name of part	Sizes of sand (μm)	Roughness (R_a) (μm)	Etching
1	Substrate		0.213	
2	Fine sand	50	1.521	
3	Medium sand	100	1.892	
4	Coarse sand	200	2.932	
5	Medium sand with etching	100	1.2920	30 min