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The effect of compression molding parameters on the electrical and physical properties of polymer composite bipolar plates

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ABSTRACT

The performance of polymer electrolyte membrane fuel cell (PEMFC) greatly depends on the properties of the components. Bipolar plate is one of the key components of PEMFC and the properties of the plates on fuel cell performance are critical. Electrical conductivity and surface roughness of the bipolar plate appear very important properties to minimize ohmic resistance and optimize water management, respectively. The composite bipolar plates having conductive fillers and thermosetting resin binder are produced by compression molding. Response Surface Methodology (RSM) has been applied to optimize the production conditions of bipolar plate. Electrical conductivity, physical appearance and roughness are chosen as response parameters and molding temperature, pressure and time are chosen as independent parameters. The main challenges of this study are observation of the individual and combined effects of these parameters on bipolar plate properties by RSM. The optimization of the production conditions of polymer composite plate is carried out by aiming maximum electrical conductivity and minimum time. The maximum electrical conductivity of 107.4 Scm^{-1} is obtained at temperature of 187 °C, pressure of 119 bar and time of 5 min. It is found that the polymer composite plates produced by the compression molding process at minimum time satisfied the electrical conductivity target of Department of Energy (DoE).

Introduction

The proton exchange membrane fuel cell (PEMFC) is an electrochemical device, which converts chemical energy into electrical energy. PEMFC has advantages of high power density, low operating temperature, relatively quick start-up, and rapid response to varying loads. These features make PEMFCs the most promising and attractive power technology in the near future for a wide variety of power applications from portable to large scale stationary power systems. PEMFC consists of many unit cells which are composed of anode-electrolyte/membrane-cathode (membrane electrode assembly, MEA), gas diffusion layer (GDL) and bipolar plate (Fig. 1). The bipolar plate has several functions such as collecting and conducting of the current from the anode to the cathode of the next cell, connecting and separating the individual cells in series to form a fuel cell stack with required voltage, distributing of fuel gas and oxygen over the whole active surface area as uniform, facilitating water management within the cell, managing of heat and supporting MEA [1–7]. A significant part of the PEMFC fuel cell stack is the bipolar plates, which

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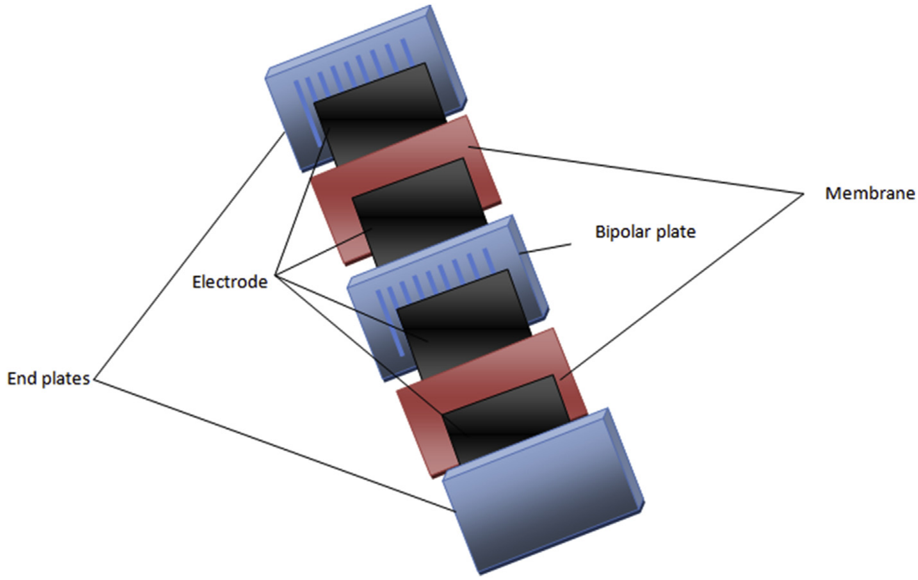

Fig. 1 – Simplified structure of a PEMFC stack.

account for about 80% of total weight and 45% of total stack cost depending on their producing technology [5,8–10].

Conventionally, bipolar plates are produced from pure graphite, metal and polymer composite. Since graphite has a good electrical conductivity and excellent corrosion resistance, it is the most commonly used material for a bipolar plate. On the other hand, pure graphite bipolar plates contribute significantly to the cost, weight and volume of PEM fuel cell stacks. Also machining of graphite plates is difficult and expensive because it lacks mechanical strength due to its brittleness [10–12]. Several metals have good electrical conductivity, gas impermeability, thin thickness and ease of mass production. Since the metallic bipolar plates are thinner than the graphite bipolar plates, the stacks having metallic plates provide weight and volume advantages [13]. However, metals such as stainless steel and metal alloys are not preferable, because of corrosion problem that can degrade the output power of the PEMFC. Polymer composite is less expensive and lighter weight alternative to pure graphite and metal [10–12]. Since the efforts have been made in recent years to reduce the cost as well as the weight and volume of the fuel cell, the polymer composites for the production of bipolar plates are studied [11–14]. Chemical, thermal and mechanical long-term stability of bipolar plates is also crucial for long-term operation of the fuel cell [5]. Polymer composites mainly consist of polymer binder such as thermoplastic and thermoset polymer and conductive fillers such as graphite, carbon black, carbon nanotube and carbon fiber. Both thermoplastic and thermosetting resins have been considered for development of composite bipolar plates. The resins are strong, corrosion resistant, easily mass produced, and relatively impermeable to hydrogen gas. The production conditions and addition of additives can improve the properties of the composite material without significantly increasing its overall cost [5,10,15–19].

Bipolar plates require several properties to achieve the desired fuel cell stack performance that are electrical conductivity, gas tightness, chemical stability, lightweight and mechanical strength to withstand clamping forces [20]. The specific requirements of bipolar plate are based on the Department of Energy (DoE) target values [10,20–24]. On the other hand, the most relevant properties are the electrical conductivity and the mechanical properties. Bin et al. [11] fabricated the polymer composite by compression molding technique using polyvinylidene fluoride as a binder and titanium silicon carbide as conductive filler. The effects of content and particle size of silicon carbide, he mold pressure and mold pressing time on the electrical conductivity and the flexural strength of the conductive composite are discussed. Lee et al. [2] fabricated the composites made of graphite particles and epoxy resin by hot press method. The electrical and mechanical properties of composite were evaluated and moldability was tested with design of experiments. They found that the electric conductivity of the composite was improved by increasing the mixing ratio of graphite particles, processing pressure and temperature. Kakati et al. [21] studied the composite bipolar plates for fuel cell by compression molding technique using novolac type phenol formaldehyde resin as a binder and natural graphite, carbon black and carbon fiber as reinforcements. Their results showed that the carbon black and carbon fiber content above 5% significantly reduced the electrical conductivities of the bipolar plates. The flexural strength of the bipolar plate for optimum composition (novolac:30%; natural graphite:60%; carbon black:5%; carbon fiber:5%) was 55.28 MPa, while the in-plane and through-plane electrical conductivities were 286 Scm^{-1} and 92 Scm^{-1}, respectively. Ghosh et al. [22] investigated the effect of carbon fiber length and graphene on carbon-polymer composite bipolar plate. The optimum carbon fiber length and graphene content are found to be 1 mm and 1.5%, respectively. Kang et al. [23] designed and fabricated ultralight and thin composite bipolar plates using epoxy-carbon fiber prepregs. The optimum conditions for composite layer were obtained with 20 μm flake like natural graphite particles and epoxy resin