Energy Conversion and Management 169 (2018) 334–344

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Contact resistance prediction of proton exchange membrane fuel cell considering fabrication characteristics of metallic bipolar plates

Peng Liang[a], Diankai Qiu[a], Linfa Peng[a], Peiyun Yi[a], Xinmin Lai[a,b,*], Jun Ni[c]

[a] State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, Shanghai 200240, PR China
[b] Shanghai Key Laboratory of Digital Manufacture for Thin-walled Structures, Shanghai Jiao Tong University, Shanghai 200240, PR China
[c] Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI 48109-2125, USA

ARTICLE INFO

Keywords:
Proton exchange membrane fuel cell
Contact resistance
Coating
Weld
Dimensional error

ABSTRACT

This study offers an efficient method to improve manufacturing technique of metallic bipolar plates (BPPs) so as to simultaneously reduce contact resistance (CR) and maximize power density in proton exchange membrane fuel cell (PEMFC). CR plays an important role in the energy conversion in the cell and can be normally reduced by coating on the BPP surface. Nevertheless, the effect of fabrication process on the CR has not been revealed, especially for the welding and forming characteristics. In this paper, a comprehensive three-dimensional finite element model of BPP/gas diffusion layer (GDL) assembly was established to investigate the influences of coating, weld and dimensional error on the CR, which are produced during the fabrication process of metallic BPPs. Experiments were carried out to validate the accuracy of the model. The results indicate that direction and distribution of the current in the cell change significantly with altering the weld path of metallic BPPs, which are different from graphite BPPs. 47% CR reduction is observed for the case of dense weld arrangement. For the coating process, it is found that the necessity of coating on both sides of single BPP is quite low if channel number is less than 20. Statistic simulation was conducted to investigate the effect of dimensional error on CR. Specially, 14.5% increment in CR is found when the dimensional error exceeds 30 μm. The methodology developed is beneficial to the fabrication management of metallic BPPs and the efficiency improvement of PEMFC.

1. Introduction

Proton exchange membrane fuel cell (PEMFC) has been actively researched for a number of years because of its advantages such as low-temperature operation, rapid start-up and high power density [1–3]. PEMFC is approximately 50% efficient at the conversion of hydrogen fuel chemical potential to electrical power, with the remainder of the hydrogen energy converted to heat through activation, mass transport and ohmic loss [4,5], the latter which is mainly caused by contact resistance (CR) in PEMFC. Specially, CR between gas diffusion layer (GDL) and bipolar plate (BPP) plays a dominant role in the performance of PEMFC [6,7]. It is a complexed issue determined by many factors, such as the material property, surface topography, clamping pressure and fabricated features of components [8].

In order to reduce ohmic loss, lots of achievements have been obtained in current studies. Jia et al. [9] investigated the effect of special operating conditions on CR. The results indicated that temperature and humidity affected the CR obviously. Zhou et al.'s [10] results showed that CR had high dependence on clamping force. Avasarala and Haldar [11] studied the effect of surface roughness of composite BPP on the CR. To reduce CR, coating on the BPP has been demonstrated to be a useful method by many researchers [12–14]. On the other hand, numerical methods have been adopted to predict the CR. A mechanical-electrical finite element (FE) model has been proposed to investigate the influence of equipotential assumption on the contact surface in our previous study [15]. Meantime, mathematics models were also developed to predict CR based on micro contact analysis [5,8,16,17]. These models were beneficial in understanding the contact behavior and predicting CR between BPP and GDL.

Nevertheless, the effect on CR resulting from fabrication process has not been revealed, especially for the metallic BPP fuel cell. As is well known, stainless steel has emerged as the most used material for BPP due to the possibility of mass producing extremely thin plates and low cost [9,15,18,19]. Generally, metallic BPP is stamped from thin stainless steel plate and joined by two plates to satisfy important requirements such as effective sealing and sufficient strength. Further coating on the BPP surface is necessary to reduce CR and increase corrosion resistance [20–22]. However, several issues in the fabrication processes are still needed to be considered in order to improve the fuel cell performance. During the stamping process of metallic BPP, springback

* Corresponding author at: State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, Shanghai 200240, PR China.
E-mail addresses: namelp@sjtu.edu.cn (P. Liang), xmlai@sjtu.edu.cn (X. Lai).

https://doi.org/10.1016/j.enconman.2018.05.069
Received 11 February 2018; Received in revised form 30 April 2018; Accepted 19 May 2018

Nomenclature

$R_{GDL/BPP}$	contact resistance between gas diffusion layer and bipolar plate, mΩ
$R_{GDL/SPP}$	contact resistance between gas diffusion layer and single polar plate, mΩ
$R_{SPP/SPP}$	contact resistance between two single polar plates, mΩ
R_a	total resistance between two cooper plates in step one (Fig. 3(a))
R_b	total resistance between two cooper plates in step two (Fig. 3(a))
R	total resistance between gas diffusion layer and bipolar plate, mΩ
R_{GDL}	bulk resistance of gas diffusion layer, mΩ
R_{BPP}	bulk resistance of bipolar plate, mΩ
ρ_{nom}	nominal contact resistivity between gas diffusion layer and bipolar plate, mΩ·cm^2
S_{nom}	nominal contact area between gas diffusion layer and bipolar plate, cm^2
H_g	thickness of gas diffusion layer, mm
H_B	thickness of single polar plate, mm
w_s	weld width, mm
T_w	weld period
n	channel number
W_B	width of channel bottom, mm
T	channel period, mm
H_{BPP}	channel height, mm
θ	channel angle, °
$R_{CO/GDL}$	contact resistance between gas diffusion layer and collector plate, mΩ
R_{CO}	bulk resistance of collector plate, mΩ
ρ	contact resistivity, mΩ·cm^2
$R_{GDL/steel}$	contact resistance between gas diffusion layer and stainless steel plate, mΩ
S	contact area between gas diffusion layer and stainless steel plate, cm^2
I	uniform current, A
U	isopotential, mV
ΔU	voltage on the upper plane of the simulation model, mV
R_w	contact resistance between two single polar plates on weld, mΩ
R_i	contact resistance between two single polar plates on channel i, mΩ
H_{BPP}^n	nominal height of channel, mm
H_{BPP}^r	real height of channel, mm
Δh	dimensional error of bipolar plate, mm
σ	standard deviation of dimensional error, mm
$\mu_{\rho nom}$	mean of nominal contact resistivity, mΩ·cm^2
$\sigma_{\rho nom}$	standard deviation of nominal contact resistivity, mΩ·cm^2
ρ_{nomi}	nominal contact resistivity of sample i, mΩ·cm^2
N	amount of samples for Monte Carlo simulation

[23,24] always occurs due to the elastic recovery. The desired channel geometry is difficult to achieve and dimensional error of channel height is inevitable. Effect of dimensional error on CR has not been explored yet. Currently, the metallic BPP is just welded at the edge of BPP (Fig. 1) to achieve the sealing and segregation of H_2, O_2 and water [25]. The effect of weld on CR has not been concerned. The necessity of weld in the middle area of BPP (Fig. 1(a)) is still needed to confirm. In addition, current studies about coating on BPP mainly focused on the outer surface of BPP (Fig. 1(b)). To the authors' best knowledge, there has not been any research work dedicated to coating effect of inner surface on CR. There is no conclusion that whether the inner surface of BPP should be coated. Hence, in order to solve these problems, not only the CR $R_{GDL/SPP}$ between GDL and single polar plates (SPP) should be improved, but also the CR $R_{SPP/SPP}$ between two SPPs in single BPP should be considered in the prediction of CR.

Therefore, the aim of this study is to investigate the effects of fabrication characteristics of metallic BPP, including coating, weld distribution and dimensional error, on CR between BPP and GDL. The CR between two SPPs in single BPP is included in our prediction model. Therefore, CR $R_{GDL/BPP}$ between BPP and GDL consists of $R_{SPP/SPP}$ and $R_{GDL/SPP}$. Firstly, a FE model of BPP/GDL assembly was developed considering the actual contact properties and structure parameters to study the CR and current flow behavior. Then, a series of experiments were systematically conducted to validate the accuracy of this FE model. At last, based on the FE model, influences of the fabrication characteristics of metallic BPP, including coating, weld distribution and dimensional error, on CR were studied in detail.

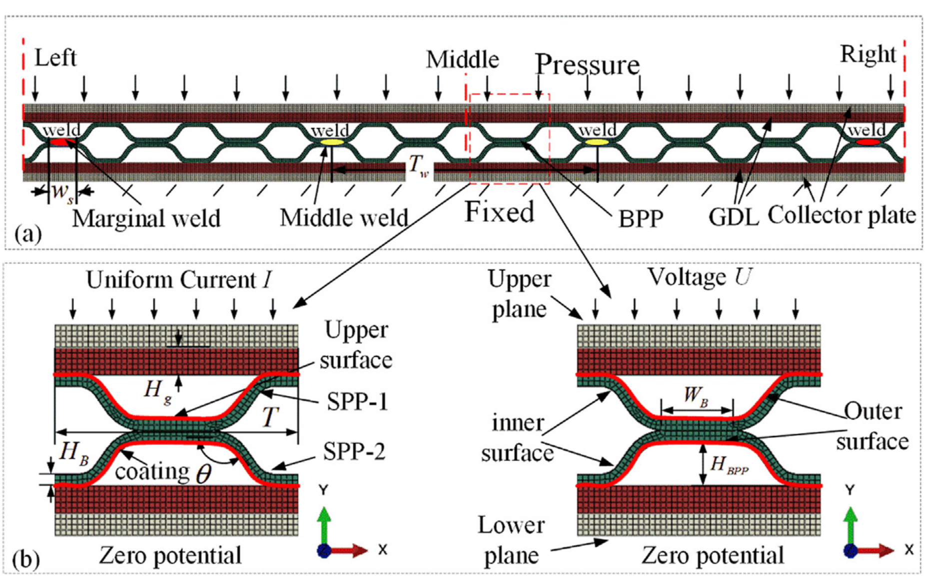

Fig. 1. Diagram of modeling: (a) the FE simulation model and (b) two loading models.