Journal of Power Sources 243 (2013) 925–934

Contents lists available at SciVerse ScienceDirect

Journal of Power Sources

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

Investigation of the effects of process sequence on the contact resistance characteristics of coated metallic bipolar plates for polymer electrolyte membrane fuel cells

Cabir Turan [a,b], Ömer Necati Cora [a,c], Muammer Koç [a,d,*]

[a] NSF I/UCRC Center for Precision Forming (CPF), Richmond, VA, USA
[b] Istanbul Gas Distribution Company (IGDAS), Istanbul, Turkey
[c] Karadeniz Technical University, Trabzon, Turkey
[d] Istanbul Sehir University, Istanbul, Turkey

HIGHLIGHTS

- Effects of process sequence on ICR of bipolar plates were investigated.
- PVD coated SS316L BBPs with two different process sequence, namely formed-then-coated and coated-then-formed, were compared.
- Three different coatings (CrN, ZrN, TiN) at three different thicknesses (0.1, 0.5, 1 μm) were used.
- Coated-then-formed BPPs performed similar or even better than formed-then-coated BPPs.

ARTICLE INFO

Article history:
Received 6 March 2013
Received in revised form
29 May 2013
Accepted 31 May 2013
Available online 20 June 2013

Keywords:
Fuel cells
Metallic bipolar plate
Contact resistance
Coating
Manufacturing
Process sequence

ABSTRACT

In this study, results of an investigation on the effects of manufacturing and coating process sequence on the contact resistance (ICR) of metallic bipolar plates (BPP) for polymer electrolyte membrane fuel cells (PEMFCs) are presented. Firstly, uncoated stainless steel 316L blanks were formed into BPP through hydroforming and stamping processes. Then, these formed BPP samples were coated with three different PVD coatings (CrN, TiN and ZrN) at three different thicknesses (0.1, 0.5 and 1 μm). Secondly, blanks of the same alloy were coated first with the same coatings, thickness and technique; then, they were formed into BPPs of the same shape and dimensions using the manufacturing methods as in the first group. Finally, these two groups of BPP samples were tested for their ICR to reveal the effect of process sequence. ICR tests were also conducted on the BPP plates both before and after exposure to corrosion to disclose the effect of corrosion on ICR. Coated-then-formed BPP samples exhibited similar or even better ICR performance than formed-then-coated BPP samples. Thus, manufacturing of coated blanks can be concluded to be more favorable and worth further investigation in quest of making cost effective BPPs for mass production of PEMFC.

1. Introduction

Due to the increasing concerns about the depletion of fossil fuel resources, global warming and air pollution, fuel cell technologies have received an increasing interest in recent decades, owing to their high efficiency and low emission. Among various types of fuel cells, polymer electrolyte fuel cells (PEMFC) are considered as promising candidates for next generation power sources in transportation vehicles and other portable applications. Their advantages include low operating temperature, high power density and easy scale-up. In spite of such benefits, high cost and low durability of PEMFC stacks postpone their widespread commercialization [1].

Bipolar plates (BPPs) are one of the main components of the PEMFC, and they significantly contribute to the strength, cost, weight and volume of the overall system. U.S. Department of Energy (DOE) established a set of goals on required properties of BPPs as listed in Table 1 [2]. Variety of materials has been proposed for BPPs, however; thus far, no material meets all the requirements concurrently [3–9]. Because of good electrical conductivity, low material cost, well-established manufacturing processes and superior mechanical properties, metallic BPPs have been considered as a promising choice. Various grades of stainless steels have been

* Corresponding author. NSF I/UCRC Center for Precision Forming (CPF), Richmond, VA, USA. Tel.: +1 804 859 0835.
E-mail addresses: cabirturan@yahoo.com (C. Turan), koc.muammer@gmail.com (M. Koç).

0378-7753/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jpowsour.2013.05.182

Table 1
DOE's Performance requirements for PEM fuel cell bipolar plates [2].

Characteristic	Unit	2017 Target
Cost	$/kW	3
Hydrogen permeability (ASTM D1434)	$cm^3\ (cm^2\ s)^{-1}$	$<1.3 \times 10^{-14}$
Corrosion at anode, cathode	$\mu A\ cm^{-2}$	<1
Electrical conductivity	$S\ cm^{-1}$	>100
Contact resistance	$m\Omega\ cm^2$	<20
Flexural strength (ASTM D790-10)	MPa	>25
Forming elongation (ASTM E8M-01)	%	40

Table 2
Chemical composition of SS316L (Browns Metals Co., Rancho Cucamonga, CA, USA).

C	Mn	P	S	Si	Cr	Ni	Mo	Cu	N	Fe
0.021	1.48	0.033	0.001	0.43	16.20	10.03	2.06	0.43	0.04	Bal

put forward as BPP material candidates due to their higher formability and higher corrosion resistance than many other metallic materials. However, corrosive environment of harsh PEMFC working conditions and high interfacial contact resistance (ICR) are the main concerns about stainless steel BPPs [10–29]. Thus, in order to improve corrosion resistance and contact conductivity at reasonable cost, protective coatings on stainless steel BPPs have been extensively studied [16,18,19,30–35].

Physical vapor deposition (PVD) nitrides are widely researched to improve corrosion resistance and contact conductivity of metallic BPPs [36–40]. Several studies reported performance evaluation of different coatings such as TiN Refs. [32–35,41–43], CrN [38,40,44–50] and ZrN [51,52] on stainless steel substrate materials. In previous studies by authors, effect of manufacturing process type and conditions on corrosion and contact resistance CrN, TiN and ZrN coated BPPs were investigated [53,54].

When coated metallic materials are needed for BPP, order of process sequence (coating and forming) would be important. Coating of BPPs after forming would be a reasonable path since one can expect that forming of coated blanks may deteriorate the surface due to possible deformation of coatings with brittle characteristics. On the other hand, forming of pre-coated metallic material can increase manufacturing speed of BPPs, and consequently reduces the cost. "Finish first, fabricate later" is a growing trend in sheet metal manufacturing due to promise of simpler workflows, reduced stock, easier environmental compliance and lower overall costs [55,56]. Although the literature is abundant for investigations on the effect of forming process on coating failures [57–60], to the best knowledge of the authors, there is no dedicated study focusing on the effect of manufacturing processes sequence on ICR behavior of coated metallic BPP. The aim of this study is to understand and disclose the effect of process sequence (e.g., coating before forming vs. coating after forming) on the contact resistance of the coated metallic BPPs.

2. Experimental methodology and conditions

To this aim, in this study, two groups of coated metallic BPPs were investigated in terms of process sequence on ICR between BPPs and gas diffusion layer (GDL) in this study. The first group of samples was 'formed-then-coated' while the second group of 'coated-then-formed' samples was coated as blank sheets; then, formed with the same forming methods (stamping and hydroformed). Three different PVD metal nitride coatings, namely titanium nitride (TiN), chromium nitride (CrN), zirconium nitride (ZrN), at three different coating thicknesses, 0.1, 0.5 and 1 μm, were used as performed by Tanury Industries Co. (Lincoln, RI, USA). Table 2 shows chemical composition of SS316L, used in experiments and Table 3 shows PVD process parameters provided by this supplier.

Two different die geometries were employed to obtain different micro-channel arrays on BPP samples. Forming dies were named according to their channel heights as 250 and 750 μm, throughout the study. Forming parameters were selected as 40 MPa pressure with a pressure rate of 1 MPa s^{-1} in hydroforming and 200 kN force with a punch speed of 1 mm s^{-1} in stamping based on the previous studies of authors [29], in which detailed description of the forming processes employed and test setup used were presented.

Surfaces of bipolar plates were examined using Hitachi SU-70 scanning electron microscope (SEM) fitted with EDAX energy dispersive X-ray spectroscopy system (EDS) and HIROX KH-7700 (HIROX-USA, NJ, USA) digital microscope. Wyko NT1100 optical profiler (Veeco Instruments Inc., Tucson, AZ, USA) was also used for surface roughness measurements.

Interfacial contact resistance (ICR) values between samples and carbon paper GDL (Toray TGP-H 60, Toray Corp., Tokyo, Japan) were measured through the method developed by Wang as reported in Ref. [17]. The detailed information about the methodology and experimental setup were explained in previous publications [6,29]. ICR tests were conducted before and after corrosion tests in order to reveal the effect of PEMFC condition (i.e. corrosive) exposure on ICR values. Potentiodynamic electrochemical corrosion test with O_2 bubbling was chosen to simulate cathodic conditions of PEMFC. Potential range was changed between −1.2 V and 0.8 V with respect to standard hydrogen electrode (SHE) at a 1 mV s^{-1} rate in potentiodynamic experiments. Detailed explanation of the corrosion test procedure can be found in an earlier work [5].

Coated-after-forming samples underwent to ICR test as received whereas coated-before-forming BPP samples were subjected to ultrasonic cleaning in an acetone bath prior to ICR tests. Post corrosion test samples were also cleaned by acetone to remove the acidic solution residue.

Table 3
Coating conditions (provided by Tanury Industries, Lincoln, RI).

Run#	Coating	Thickness (μm)	Temperature (°C)	Deposition time (min)	Deposition current (A)	Bias voltage (V)	Nitrogen flow rate (sccm)	Argon flow rate (sccm)	Pressure (m Torr)
1	TiN	0.1	60	6	450	75	500	800	5
2	TiN	0.5	60	38	450	75	500	800	5
3	TiN	1	60	75	450	75	500	800	5
4	CrN	0.1	60	2	450	75	500	800	5
5	CrN	0.5	60	4	450	75	500	800	5
6	CrN	1	60	8	450	75	500	800	5
7	ZrN	0.1	60	2	450	75	500	800	5
8	ZrN	0.5	60	8	450	75	500	800	5
9	ZrN	1	60	16	450	75	500	800	5