Requirements and testing methods for surfaces of metallic bipolar plates for low-temperature PEM fuel cells

P Jendras, K Lötsch and T von Unwerth

Department of Advanced Powertrains, Institute for Automotive Research, Technical University of Chemnitz, 09126 Chemnitz, Germany

Abstract. To reduce emissions and to substitute combustion engines automotive manufacturers, legislature and first users aspire hydrogen fuel cell vehicles. Up to now the focus of research was set on ensuring functionality and increasing durability of fuel cell components. Therefore, expensive materials were used. Contemporary research and development try to substitute these substances by more cost-effective material combinations. The bipolar plate is a key component with the greatest influence on volume and mass of a fuel cell stack and they have to meet complex requirements. They support bending sensitive components of stack, spread reactants over active cell area and form the electrical contact to another cell. Furthermore, bipolar plates dissipate heat of reaction and separate one cell gastight from the other. Consequently, they need a low interfacial contact resistance (ICR) to the gas diffusion layer, high flexural strength, good thermal conductivity and a high durability. To reduce costs stainless steel is a favoured material for bipolar plates in automotive applications. Steel is characterized by good electrical and thermal conductivity but the acid environment requires a high chemical durability against corrosion as well. On the other hand formation of a passivating oxide layer increasing ICR should be inhibited. On the other hand pitting corrosion leading to increased permeation rate may not occur. Therefore, a suitable substrate lamination combination is wanted. In this study material testing methods for bipolar plates are considered.

1. Introduction

Low temperature polymer electrolyte fuel cells (PEM FC) transform hydrogen into electrical current, thermal heat and water vapour as waste product, by an oxidation reaction with oxygen in the air. A single fuel cell consists of a proton conducting membrane with an electrode on each side (MEA), a porous gas diffusion layer (GDL) and adjoining current collectors. By stacking multiple cells the current collectors of two neighbouring cells act as bipolar plates. They fulfil the following main functions in the fuel cell stack [1]:

- Conduct current between neighbouring cells,
- Provide channels for reactant gases and for removing reaction products,
- Facilitate water through the cell,
- Thermal management through the cell and
- Isolation of the individual cells.

Bipolar plates can be graphite plates, polymer composite plates with carbon black particles or metallic sheets. Because of their high strength, metallic bipolar plates can be made of very thin sheets with a thickness of 0.1 mm or less. This enables a high power density, which is necessary for automotive fuel cell systems. Furthermore, sheet metals can be stamped, cut and welded in very short cycle times,
which is suitable for the needed mass production in the automotive industry. On the downside, base metals form a passive layer which increases the interfacial contact resistance to the GDL and corrode in acidic environments. Therefore, they have to be made of noble metal sheets or coated with a protective and conductive layer. Due to a lack of mass quality insurance methods and a need of a high operation safety in automotive applications, actual fuel cell stacks contain metallic bipolar plates made of expensive materials [2].

The objective of this paper is to describe the examination of the high requirements and their testing methods with the goal of reducing material costs and production costs by a specification of local functions and requirements and by avoiding too high technical efforts. Furthermore, the authors give a general overview of available testing methods and define local and measurable requirements.

2. Requirements

The general requirements for fuel cells and bipolar plates are described by the United States Department of Energy (DOE). The main requirements of the surface of the active area of metallic bipolar plates are low interfacial contact resistance (ICR) between the GDL and the bipolar plate and a good corrosion resistance against the acidic environment [3]. As shown in figure 1, the active area contains the flow field in the center of the bipolar plate, where the chemical reactions take place. The remaining parts of the bipolar plate are known as passive area. The common ratio between active and passive area ranges between 1/1 and 3/1 [2].

An additional requirement is the surface roughness of metallic bipolar plates that has an effect on the achievable ICR and the corrosion properties. The size ratio between a carbon fiber and a polished or a rough surface is illustrated in figure 2. The diameter of the carbon fiber in the GDL is slightly larger than the roughness peaks. Different roughnesses result in different amounts of contact points between GDL and bipolar plate, as well as a different pressure at the contact points since pressure equals force divided by area. Tawfik, Hung and Mahajan have described these effects accurately and depicted a range of average roughness [4]. Table 1 summarizes the exact values of ICR, corrosion resistance and surface roughness.
Table 1. General requirements for surfaces of metallic bipolar plates [3, 4].

| Surface characteristic         | 2020 Targets                                                                 |
|-------------------------------|-----------------------------------------------------------------------------|
| Interfacial contact resistance (ICR) | < 10 mΩ cm² at 140 MPa                                                      |
| Corrosion resistance          | < 1 μA/cm², with corrosion current at -0.1 V and H₂ purge                   |
|                               | < 1 μA/cm², with corrosion current at 0.6 V and Air purge                   |
| Average roughness Rₐ          | 0.2 … 3 μm                                                                  |

3. Testing methods

3.1 Planar interfacial contact resistance measurement

In order to achieve a high current density in the fuel cell, the electrical resistance of a cell must be as low as possible. Primarily, the contact resistance between the individual components of the gas diffusion layer and the bipolar plate influences the entire electrical resistance of a cell. The internal ohmic resistance is significantly smaller. Therefore, there is a lower priority on it. The measuring arrangement is shown in figure 3. The press simulates the surface pressure in the fuel cell stack. In between are two gold-plated copper plates. Copper is used as plate material due to its high electrical conductivity and the gold coating reduces the contact resistance to the actual measuring object. Gold does not form a passivating corrosion layer. In the center, the layer-like structure consists of two gas diffusion layers on both bipolar plate sides. The sample has an area of 1 cm². It is not converted since the resistance per area (mΩ / cm²) is always given for the comparison [4].

A constant current of 1 A is applied and the voltage drop across the measuring arrangement is measured. With the area of 1 cm² and one ampere, a similar current density results as in a PEM fuel cell. The resistance can then be determined by using Ohm's law. Surface pressures between 10 N/mm² and 300 N/mm² are specified in order to obtain a spectrum around the value of N/mm² applied in the fuel cell stack [4].

At first, an arrangement is measured with only one gas diffusion layer and no bipolar plate (see figure 3 – left side). This results in the sum of the contact resistance between the GDL and the gold-coated copper electrode and the ohmic resistance of the measuring arrangement R₁. Afterwards, the actual measurement setup (see figure 3 – right side) is measured.

Figure 3. Schematic diagram of interfacial contact resistance (ICR) measurement.
The resistance $R_2$ determined in this setup is corrected with the aid of the value from the first measurement $R_1$. The division by 2 results from two contact surfaces in the construction, but only one is of particular interest [4].

$$ICR = \frac{(R_2 - R_1)}{2}$$  \hspace{1cm} (1)

The disadvantage of this measuring method, however, is that only semi-finished material and no bipolar plate can be measured. As a result, production steps cannot investigate possible influences.

### 3.2 Accelerated corrosion resistance test

The arrangement for measuring the corrosion resistance consists of a container with sulfuric acid solution. Three electrodes are attached: the counter electrode, the reference electrode and the working electrode. The counter electrode is made of conductive corrosion-resistant material such as platinum or graphite. The reference electrode is designed as a calomel electrode or a standard hydrogen electrode. The working electrode is the material sample pressed from the outside to the measuring cell. An aperture forms a connection to the electrolyte [4].

The three electrodes are connected to a potentiostat. A voltage is applied between the working electrode and counter electrode. By the reference electrode a regulation and thus a constant potential becomes possible. The voltage generates a current, namely a corrosive flow [6].

In order to simulate the conditions in a PEM fuel cell, the measurements are carried out at 80 °C. Atmospheric or hydrogen gas is passed through the electrolyte. The gases can act as reaction partners for corrosive and reducing processes. The solution of 0.5 M $\text{H}_2\text{SO}_4$ and 2 ppm $\text{F}^-$ or 2 ppm HF ensures an accelerated aging process [4].

Both potentiodynamic and potentiostatic measurements are applied. The dynamic method uses a potential between 0.5 V below and 1 V above the free corrosion potential and a sampling rate of 1 mV/s. Under static conditions, a potential of 0.6 V is applied over 8 hours. This potentiostatic test allows researchers to simulate the material behavior after a long period of use without having to build up a fuel cell and to operate it over a long period of time. The corrosion behavior is to be read from the potentiodynamic polarization curves. Kumar [5] describes the procedure in detail.

![Figure 4. Schematic diagram of corrosion test cell and potentiostat.](image)
3.3 Roughness measurement

The roughness is influenced by the production of semi-dies, the forming and further production process steps. This, in turn, has influence on contact resistance, corrosion behavior, flow behavior, etc. Hence, this characteristic of the surface is measured by the optical and tactile approach.

3.3.1 Tactile scanning of roughness

During tactile measurement, the surface is tracked over a distance of 4 cm. The probe is provided with a diamond tip, which is only a few nanometers thick and is able to measure surface topographies of this magnitude. The exact procedure is described in DIN EN 4287. The recorded measurement signal is cleaned from general noise and surface deviations of a different magnitude, such as ripples, are calculated. The disadvantage is that the entire surface of a bipolar plate cannot be examined due to the size of the measuring probe. Only overlying sections, such as webs, can be measured.

3.3.2 Optical roughness measurement

In the case of optical methods, the surface is scanned by means of a laser. The reflection is recorded by a sensor and converted into an image for evaluation. In a following step, the roughness is deduced from this. This method allows scanning of the entire surface. However, the approach is less accurate since unwanted surface reflections can lead to results, which do not result from the low absorption coefficient of the metallic surface instead of the topography.

4. Locally different requirements

The bipolar plate is a component with many different tasks, resulting in a complex requirement spectrum. Therefore, different properties are required locally. The following chapter examines the proper point of property and the measurable variables. Two linked and reshaped sheets form a bipolar plate. Hence, the surface at the attachments must be suitable. This suitability depends mainly on the mating method used. Soldering requires sufficient soldering.

The adjacent gas diffusion layer is located on the web surfaces. Between this component and the bipolar plate, a contact resistance should provide as small as possible. Consequently, the formation of a passive layer has to be prevented. Since it also lacks the corrosion-protective effect of such a layer, it is performed by an actively applied layer system.

The contact resistance in the flowfield channel towards the GDL is not needed. The focus there is on adequate corrosion protection. On the one hand, the corrosion rate must remain low to ensure that the permeation rate of hydrogen through the bipolar plate stays within the limits of the DOE over the entire lifetime (5000 hours in the vehicle). In combination with corrosion, the smallest possible discharge of ions is required, since this effect accelerates membrane degradation. Other effects constraining the design regarding hydrophobicity play a role inside the flow field channel, e.g. low
flow resistance is desired in ducts. In the cooling water channels it is also required to minimize the pressure drop. Furthermore, the requirements of the deionized water have to be fulfilled with respect to corrosion.

The requirements for the inactive area are slightly lower. Although corrosion protection requirements as in the ducts are similar to the gas feeds to the cell. However, the contact resistance does not play any role here.

5. Conclusions and future work
The complex requirements for the bipolar plate lead to great efforts to ensure functionality over the required lifetime of the vehicle. Consequently, methods are required to measure the physical quantities. The described methods according to the prior art are limited to the verification of the requirements on the semi-finished product.

Various properties are required at different points of the bipolar plate. A distinction is made between active and passive surfaces. More precise specification means viewing the cooling channel, the flow field channel, the contact surface to the GDL and the joining surface. Not all properties need to be checked. At present, there are still insufficient possibilities for an exact surface test for bipolar plates.

The trend in fuel cell development for vehicles is to use complex 3D structures, which are provided with a functionalizing coating. Therefore, it is necessary to develop measurement methods, which can investigate corrosion resistance, contact resistance and roughness on the filigree structures of the bipolar plate at the desired locations.

Acknowledgements
The authors would like to thank the Saxon Ministry for Economic Affairs and Labour (SMWA), the European Social Fund (ESF) and the Development Bank of Saxony (SAB) for financially supporting the project HZwo:BIP - Bipolarplatten aus Sachsen.

References
[1] Kurzweil P 2013 Brennstoffzellentechnik (Wiesbaden: Springer Vieweg)
[2] Vielstich W, Lamm A and Gasteiger H A 2003 Handbook of Fuel Cells: Fundamentals, Technology, Applications (New York: Wiley)
[3] DOE Fuel Cell Technologies Office 2016 Multi-Year Research, Development and Demonstration Plan - 3.4 Fuel Cells p 22
[4] Tawfik H, Hung Y and Mahajan D 2016 Bipolar Plate Durability and Challenges Polymer electrolyte fuel cell degradation ed M M Mench et al (Oxford: Academic Press) pp 249–291
[5] Kumar A, Ricketts M and Hirano S 2010 Ex situ evaluation of nanometer range gold coating on stainless steel substrate for automotive polymer electrolyte membrane fuel cell bipolar plate J. Power Sources 195 1401–7
[6] Asri N F, Husaini T, Sulong A B, Majlan E H and Daud W R W 2016 Coating of stainless steel and titanium bipolar plates for anticorrosion in PEMFC: A review Int. J. Hydrogen Energy