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Current density and catalyst-coated membrane resistance distribution of hydro-formed metallic bipolar plate fuel cell short stack with 250 cm^2 active area

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HIGHLIGHTS

- Current and temperature distribution for a fuel cell short stack of up to 600 A.
- Determination of the current distribution in the catalyst-coated membrane.
- Evaluation of the current distribution impact of 75-μm, stainless-steel bipolar plate.
- Evaluation of anisotropic bipolar plate conductivity as the result of hydro forming.
- Invention of methodology evaluating current distribution of metal bipolar plate stack.

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ABSTRACT

An automotive fuel cell with an active area of 250 cm^2 is investigated in a 4-cell short stack with a current and temperature distribution device next to the bipolar plate with 560 current and 140 temperature segments. The electrical conductivities of the bipolar plate and gas diffusion layer assembly are determined ex-situ with this current scan shunt module. The applied fuel cell consists of bipolar plates constructed of 75-μm-thick, welded stainless-steel foils and a graphitic coating. The electrical conductivities of the bipolar plate and gas diffusion layer assembly are determined ex-situ with this module with a 6% deviation in in-plane conductivity. The current density distribution is evaluated up to 2.4 A cm^{-2}. The entire cell's investigated volumetric power density is 4.7 kW l^{-1}, and its gravimetric power density is 4.3 kW kg^{-1} at an average cell voltage of 0.5 V. The current density distribution is determined without influencing the operating cell. In addition, the current density distribution in the catalyst-coated membrane and its effective resistivity distribution with a finite volume discretisation of Ohm's law are evaluated. The deviation between the current density distributions in the catalyst-coated membrane and the bipolar plate is determined.

1. Introduction

Fuel cells (FC), especially proton exchange membrane (PEM) FC, are regarded as a promising energy-conversion system for zero-emission vehicles. The fuel cell converts hydrogen and oxygen to electric energy and heat. The electric energy can be used to operate a vehicle's electric motor. The high efficiency of fuel cell systems (50–65%), and the high gravimetric energy density of hydrogen are two of this technology's notable properties for the commercialization of fuel cell vehicles. For a highly efficient system, the fuel cell stack with its cells must operate as homogeneously as possible. To achieve this goal, materials, geometrical properties and operating conditions need to be optimized. Therefore, the fluid distribution and thermal management must be locally determined.

Various flow fields are experimentally investigated and compared in Refs. [1–6]. Numerical investigations are described in Refs. [7,8]. The primary impact of the flow field on cell performance is caused by fluid distribution inside the active areas that arise out of the individual channel design. This distribution also depends on the fluid flow both in front of and behind the active area. A method for the ex-situ determination of flow behavior in fuel cells is evaluated in Ref. [9]. The effect of the fluid and temperature distribution

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can be evaluated using segmented cells. Various approaches are described in the literature. The general methods for various flow fields are discussed in Refs. [10–13]. Temperature distributions and their impact on overall cell performance are shown in Ref. [14]. To further characterize these approaches, the work of [15] uses electrochemical impedance spectroscopy (EIS) separately for each fuel cell segment. Spatial high-resolving results for current distributions are shown in Ref. [16]. The differences in current density between the channel and land areas of the bipolar plate are precisely shown. The impact of different operating conditions on the local current density distributions is shown in Refs. [17,18]. Furthermore, those conditions' effect on temperature and relative humidity in both the anode and the cathode flow fields is discussed. Comparisons of the experimental and numerically evaluated results of current distribution are shown in Refs. [19,20]. In addition, reference [20] shows the electric potential variation in various regions of the stack in galvanostatic operation mode. The work of [21] determines the current distribution of a graphitic meander flow field bipolar plate with an active area of 240 cm^2. In Refs. [22], the current distribution of a large area fuel cell compared to computational-fluid-dynamic (CFD) simulation results is shown. In Refs. [23], the applied model interprets the experimental results of local evaluated current densities to determine numerically the relative humidity of the two gases and the water content inside the membrane of the membrane electrode assembly (MEA).

In this work, the current density distribution and the temperature distribution are measured in a fuel cell short stack with 4 cells and an active area of 250 cm^2 using the commercially available current scan shunt (CSS) module adapted to the cell geometry and fabricated by S++ Simulation Services. This principle has already been described in Ref. [24]. The results are applied to evaluate the current density distribution of the catalyst-coated membrane (CCM) as part of the MEA by taking the high in-plane electrical conductivity of the non-segmented metallic bipolar plates and gas diffusion layers (GDL) into account. Based on the measured currents in the CSS, we calculate the current densities in the CCM using a finite volume computation of the volumetric current distribution implemented in Matlab. This numerical model is based on a finite volume framework, which has been described in Refs. [25,26] and applied on different applications therein. Thus, we obtain an approach by which we can determine the current density distribution not only in the bipolar plates but also in the CCM of a fuel cell stack. The outlet pressures of the gases are regulated according to a best efficiency curve of a compressor, an example of which is shown in Ref. [27].

2. Cell design

For automotive applications, a cell design is chosen with an active area of 250 cm^2. The manifolds are located on the bottom and top because of drainage effects at startup and shutdown. The bipolar plate in the top view is shown in Fig. 1, showing the cathode side. The sealing between the bipolar plate and the subframe is the blue colored structure in the picture. Between the two half-plates, gas tightness is achieved with welding lines. The total welding-line length on each bipolar plate is approximately 2 m. The active area is point-welded at 4800 spots with a diameter of 0.3 mm each. The material in use is 0.075-mm-thick stainless-steel foil of type 316L. The plates are designed with the computer-aided-design (CAD) software Catia V5 by Dassault Systèmes and formed via hydroforming technology. The coating of the bipolar plate is a chromic base layer with a carbon top coating that is in contact with the GDLs. The bipolar plate assembly is coated after the laser welding process and therefore, it not coated between the two assembled and welded plates. The flow from the media ports to the active area

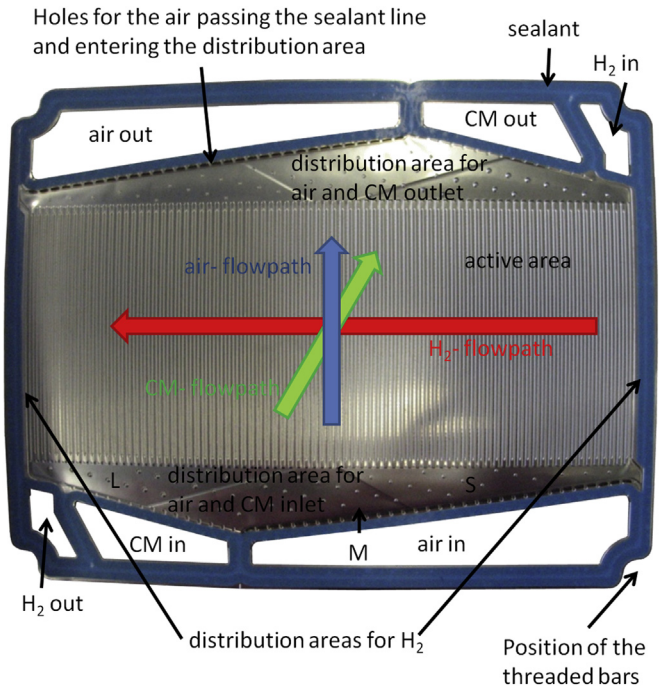

Fig. 1. Stainless-steel, carbon-coated, welded and sealed bipolar plate. View from the cathode side with the channels from bottom to top. The sealing contour is shown in blue. The main flow directions are indicated by arrows; the hydrogen pathway is red, the air pathway is blue and the coolant's medium pathway is green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

via the distribution area crosses the sealant contour. In these areas, the gases pass between the two half-plates through holes from the port side to their corresponding reaction side of the bipolar plate. For the coolant side, the coolant medium (CM) is guided through in between the two welded plates by entering the space directly in the port areas. The active area is shown by narrow channels in the middle of the plate. The distribution areas are located to the left and right for the hydrogen and the top and bottom for the air and the CM. For hydrogen, the distribution occurs behind the thicker sealant line to the left and right of the active area. This distribution consists of a channel with a width of 4 mm and a depth of 0.7 mm. The bipolar plate on the anode side is flat at the distribution areas for the air and the CM. The bipolar plate on the cathode side is leveled in three steps in this area. In Fig. 1, the levels are marked with the letters S, M and L. The heights in these three parts of the distribution areas, which determine the cross-section of the flow, are for air 288 μm, 388 μm and 588 μm for S, M and L, respectively. For the coolant medium, the heights in the distribution areas are 622 μm, 522 μm and 322 μm for S, M and L, respectively. Small pins, which are formed by the bipolar plate on the cathode side, are integrated both for forming stability and as distance elements to the subframe. The plate is designed to obtain a cross-flow of hydrogen and air and a co-flow of CM and air. At the four edges, small areas are excluded from the four threaded bars for applying the force over the pressure plates to the overall geometry of the cells.

In Fig. 2, the channel geometries in cross-sections are shown for the anode and cathode. Fig. 2(a) shows the channels of the anode. The width of the channels is 1.0 mm and the depth is 0.2 mm. The channel cross-sections are of a trapezoidal shape based on the formability of the plates. The chosen wall angle, indicated by α, is 45°. The land width of the contact area between the GDL and the bipolar plate is 0.6 mm next to each channel. The formed radii of 0.1 mm for the inner radii of the metallic foil further reduce the