INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 6029–6035

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Anisotropic electrical resistance of proton exchange membrane fuel cell transport layers as a function of cyclic strain

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ARTICLE INFO

Article history:
Received 9 December 2015
Received in revised form
26 February 2016
Accepted 29 February 2016
Available online 17 March 2016

Keywords:
Anisotropy
Electrical resistivity
Electrical conductivity
Cyclic load
Fuel cell
Transport layer

ABSTRACT

We report on the three-dimensional electronic resistance of proton exchange membrane fuel cell porous transport layers (PTLs) as a function of cyclic mechanical compression. Through-plane data are reported as total area resistance (i.e. inclusive of contact resistance contributions), whereas in-plane data are reported as resistivity measurements with resolved anisotropy. In-plane resistivities are acquired via a square four-point-probe arrangement (4PP), which unlike linear 4PP arrangements, can resolve the anisotropy. Results are presented for SGL Sigracet 25 BA. Both through-plane and in-plane data exhibit unique profiles for the initial compressive loading. These are followed by consistent trajectories for subsequent loading cycles, which is in correspondence to material plastic deformation. Plastic deformation damage to PTLs may occur during cell manufacture; to the possible detriment of deployed stack performance. We outline means by which our method can be adapted for on-line monitoring of PTLs as part of a manufacturing quality assurance programme.

Introduction

Fuel cells are a competitive solution to global energy needs, notably for the automotive industry. In particular, proton exchange membrane (PEM) fuel cells are attractive due to their low operating temperatures and high power density. However, in spite of efforts to improve commercial viability, high cost and limited durability present challenges. Ohmic resistance is detrimental to performance as power needs to be transmitted to the electrical load as efficiently as possible. Minimising Ohmic losses is necessary to realize the benefits of optimized catalyst design and higher power densities. While the resistance of the ionomer is well documented and is significant to overall cell resistance, resistance of the porous transport layers (PTLs) is less understood and presents an optimization opportunity.

Paper PTL material is used in many contemporary PEM fuel cells; because carbon fibres make up this type PTL, preferential fibre directions may exist which result in anisotropic material resistance. Furthermore, these materials are sensitive to plastic deformation under mechanical compression. Such compression may be imposed statically or cyclically during the component's lifecycle. In manufacturing, intended

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http://dx.doi.org/10.1016/j.ijhydene.2016.02.111

PTL compression may occur during calendaring processes; but unintended compression may also occur during membrane electrode assembly (MEA) subcomponent assembly or in roll-to-roll material handling. During stack assembly, excursions might occur during stack compression and fastening. After PEM fuel cell module deployment, thermal or humidity transients may impart stresses beyond the limits of fastening hardware compliancy.

There is an urgent demand from fuel cell assembler and sub-component manufacturers for material standards and characterization tools. Appropriate controls are needed to detect and prevent failures; in manufacturing and in interpretation of end-of-life data. Understanding the effect that cyclic loading may have on the PTL is requisite for an effective quality assurance programme.

We report on new methods and apparatus to determine the three-dimensional anisotropic electrical resistance as a function of cyclic mechanical load. Example data are presented for commercial PTL material representing the contemporary standard. Both through-plane and in-plane directions are examined, where full PTL anisotropy is determined by resolving the principal resistivities within in-plane. Anisotropic treatment of resistance is forced by the fibre-based structure of contemporary PTLs; where fibre alignment distributions determine connectivity in different directions (e.g.: through-plane, in-plane along fibres, and in-plane across fibres). The examination of resistances as functions of cyclic compression in the through-plane direction addresses the role of material plastic deformation and underscores the need to consider material history – from layer manufacture to deployed stack. We report hypotheses for the mechanisms altering resistance with mechanical compression. We propose and demonstrate electronic resistance methods to evaluate the quality and history of PEM fuel cell materials. Finally, we suggest that such facile tests may be formulated into otherwise unavailable industrial standards.

Background

We have previously reviewed the literature addressing ex-situ electrical resistance characterization of PEM fuel cell transport layers in Ref. [1]. The number of studies which consider the cyclic loading effects in general for the transport layers is limited. Escribano et al. presented mechanical data, stress and thickness, for only two compression cycles [2]; plastic deformation was observed in the materials studied. Mathias et al. produced a study also limited to mechanical data [3]. In these efforts, the residual strains in PTLs cycled between approximately 0 and 2.5 MPa increased from 0 to 25% over ten cycles; most of the change occurred within the first loading. Sadeghi et al. examined thermal conductivity as a function of cyclic loading [4]. After the fifth cycle, no further hysteresis was observed from their Toray PTL material. Kleemann et al. acquired a single mechanical load/unload cycle with electrical resistance [5]; but the data was processed for modelling contact resistance and not actually reported. Kim et al. reported qualitative electrical properties, but in the context of thermal cycling [6]; they speculated that thermal cycling produced plastic deformations of the PTL via ice formation and thermal expansion.

Our previous work examined PEM fuel cell PTL electrical properties as functions of static mechanical compression [1]. Through-plane resistivity analysis techniques from the literature were methodically evaluated, and a novel method was developed for in-plane resistivity measurement. The present study is distinguished from the literature by addressing the electrical characteristics as a function of cyclic compression, and by extending the applicability of our methods to material diagnostics. Our objectives and those of the aforementioned studies are summarized in Table 1.

The present study targets intrinsic material behaviour. Cell modelling studies seeking to apply our results must first determine the strain conditions of the PTL within their system via a mechanical model; this should incorporate inhomogeneous bipolar plate contact. Resistance data may be subsequently used for an average PTL value(s), or for greater fidelity, represented as an inhomogeneous property (e.g. varying from land to channel regions due to localized strains).

Method

Fig. 1 illustrates the coordinate system describing the three-dimensional directional material properties of a PTL. It captures the important directions where: *x* and *y* are in-plane and aligned to a cut sample; *z* is perpendicular to the plane (through-plane); and machine (MD), cross-machine (CD), fibre-aligned (FAD) and fibre-cross (FXD) directions are defined as illustrated. We define MD and CD based on the edges of supplied material; this may not coincide with the true MD and CD, as oversight over manufacturing extending to initial layer formation is unavailable. Regardless, FAD and FXD do not necessarily correspond to MD and CD (ours or the true) [1,7,8]. Because of the MD-FAD misalignment, when measuring the in-plane components of PTL resistivity, the principal directions must be determined from measurements in more-than-two non-parallel directions or known a-priori.

SGL Sigracet 25 BA is evaluated in the present study. This is a commercial fibre-based PTL featuring: 190 μm nominal thickness, 5% PTFE hydrophobic treatment, and no micro-porous layer. All samples are extracted from the same sheet of material. In-plane samples are cut in alignment with respect to principal directions of in-plane resistivity, following the procedure described in Ref. [1].

The fundamental measurement apparatus and methods are reported in Refs. [1]; these have been improved upon for the present work and are described in the following paragraphs. Fig. 2 presents schematics of the apparatus.

Through-plane measurement is acquired using a linear four-point probe (4PP) electrode arrangement affixed to planar anvils which engage and compress the PTL sample. An Agilent 34420A micro-ohm meter measures the resistance. The resolution afforded by our system negates the need for measuring stacks of discrete PTL samples; which introduce indeterminate inter-sample contact resistances, and do not confer any capability to resolve resistivity. For the singular PTL sample with one top and one bottom PTL-anvil interface, through-plane data are reported as total area resistances