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New lightweight bipolar plate system for polymer electrolyte membrane fuel cells

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Abstract

The use of metal based bipolar plates in polymer electrolyte membrane (PEM) fuel cells, with an active coating on titanium to reduce voltage losses due to the formation of passive layers has been demonstrated. Lifetime data in excess of 8000 h has been achieved and power densities in excess of 1.8 kW dm^{-3} and 1 kW kg^{-1} are predicted. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

A key prerequisite for many power applications is the production of compact and lightweight polymer electrolyte membrane fuel cell (PEM FC) stacks. With bipolar plates accounting for the bulk of the stack, it is desirable to produce plates with the smallest possible dimensions permissible. Traditionally, carbon based materials have been chosen, as these are chemically stable in a fuel cell environment and produce the highest electrochemical power output. However, the lack of mechanical strength inherent with carbon limits the size and hence the volumetric power density. Other materials are being evaluated by a number of academic and industrial research groups, with the aim of producing low voltage drop, long lifetime materials. The alternatives to graphite fall into three categories: carbon–carbon composites [1], carbon–polymer composites [2] and metals [3]. It is likely that only carbon–polymer composites and metal systems will meet the long term cost requirements for fuel cell technology. For portable PEM systems, both the mass and volume of the stack are key considerations and the present thickness of polymer composite bipolar plates [4] results in stacks with low volumetric power densities (as measured on kW dm^{-3} basis).

Consequently, work at Loughborough University has focused primarily on stainless steel and titanium plate technology, which enables thin bipolar plates to be used and, in the case of titanium, plates with low mass. Unfortunately, although the passive films on the surface of these metals protect them from corrosion, it also acts in part as an electrical insulator and thus reduces cell performance due to ohmic losses. To reduce this parasitic loss, the plate surface has to be modified.

Coating systems for metal plates have been investigated by many workers in the field (e.g. [3]), but little data has been presented on the long term performance of suitably coated metal bipolar plates. This paper describes the short and long term performance of coated metal plates, with particular emphasis on the coating designated FC5 and developed by ICI's Electrochemical Technology Business.

2. Experimental

Screening tests for the performance of the coating comprise: contact resistance, corrosion testing, short term polarisation performance and long term durability data. The experimental conditions for the measurement of contact resistance, short term polarisation performance and the long term performance evaluation have been described earlier [5].

Corrosion testing was performed using a series of potentiodynamic sweeps in a mixture of sulphuric and hydrofluoric acids at elevated temperature. Observations of the magnitude of the corrosion currents and changes in contact resistance before and after exposure to the acidic environment of the corrosion test were made.

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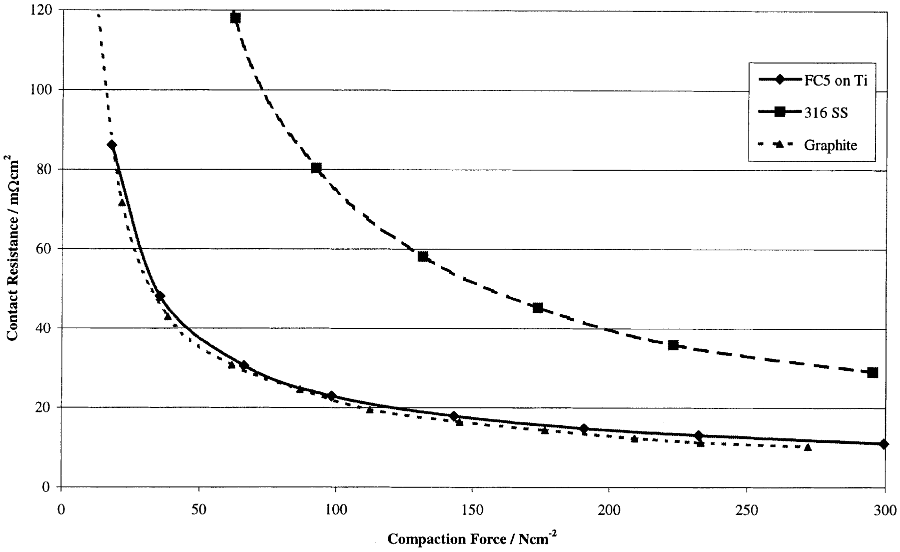

Fig. 1. Contact resistance of different materials as a function of compaction force.

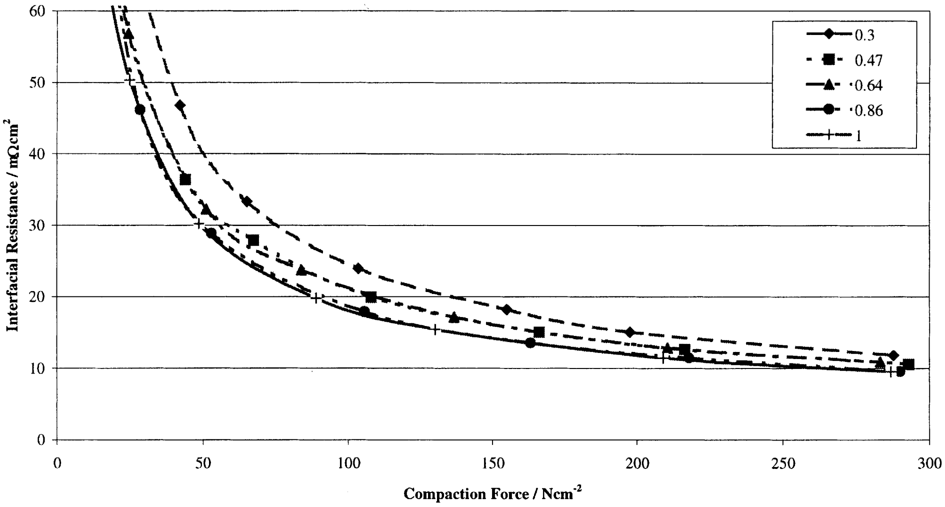

Fig. 2. Effect of coating thickness on contact resistance. The legend indicates the fraction of coating applied compared to that deposited on plates to generate the data in Fig. 1.

The coating of FC5 onto titanium was performed using proprietary methods. The coating method can be used for any structure of bipolar plate and does not significantly affect the dimensions of the flow channels.

3. Results and discussion

The contact resistance of the FC5 system compared to Poco™ graphite and stainless steel is shown in Fig. 1. It can be clearly seen that the contact resistance of the FC5 coated titanium approaches that of the graphite and is far superior to that of uncoated 316 stainless steel. Interestingly, the contact

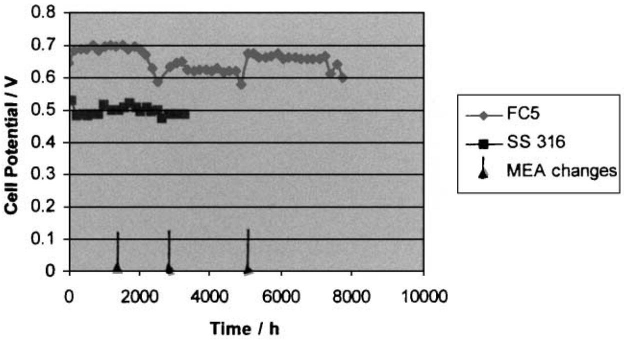

Fig. 3. Durability with time of operation data for FC5 coated titanium plates and 316 SS, in operation of a single laboratory cell.

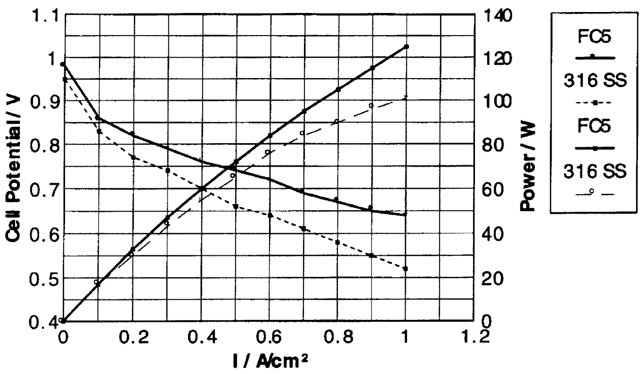

Fig. 4. Polarisation data from a 200 cm^2 APS cell design for FC5 coated titanium plates and 316 SS.

resistance varies with thickness of the coating layer (Fig. 2), suggesting a minimum amount of coating is required to avoid formation of passive layers.

No affect on the contact resistance from potentiodynamic sweeps in mixtures of sulphuric and hydrofluoric acids, was observed. No measurable metal corrosion took place under the same potentiodynamic conditions.

The most significant data is that of the longer term performance of the FC5/Ti system, as shown in Fig. 3. Also shown in Fig. 3 is comparative data for 316 SS taken from [5]. Fig. 3 not only shows the long term performance data of the two materials, but also the much higher voltage output of the cell with the FC5 coated plates, compared to the 316 SS plates. Membrane/electrode assembly (MEA) changes are indicated in Fig. 4, and it can be seen that in the FC5 case, cell performance declines to a point where the MEA has to be changed, but that the cell performance comes back to that expected after changing the MEA. Analysis of the MEA for metal ion impurities revealed no contamination and it is thought that problems with the cell design led to the decrease in MEA performance (the same voltage profile has been observed with other plate materials, including non-metallics). Periodic ex situ assessment of the plate contact resistance revealed no change with time from the FC5 coated plate.

Larger scale experiments to assess the performance of FC5 and 316 SS in a 200 cm^2 plate were performed and the data generated is shown in Fig. 4. The increase in voltage and power output at any given current density for FC5 over 316 SS can be clearly seen. Previously reported data indicate that the volumetric and gravimetric power densities using a proprietary APS plate design are 1.8 kW dm^{-3} and 0.6 kW kg^{-1}, respectively. Using the FC5 coated titanium plate design, power densities of 1.8 kW dm^{-3} and >1 kW kg^{-1} can be estimated from the single cell data.

4. Conclusions

Titanium can be employed to produce fuel cells with very high volumetric and gravimetric power densities, ideal for portable applications. Lifetime of the FC5 plate system has also been shown to be very high. Stack performance is now to be evaluated.

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