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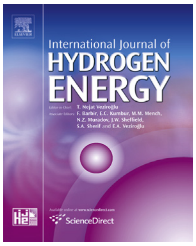

Effects of mesh and interconnector design on solid oxide fuel cell performance

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ABSTRACT

In this study, three different nickel based meshes are investigated as an anode side current collector and flow-field for solid oxide fuel cells (SOFCs) to reduce the fabrication cost. The same meshes are also tested on the conventional interconnectors with machined gas channels for comparison. Eight different short stacks are installed for this purpose. The characterizations of the short stacks are achieved via performance tests together with electrochemical impedance spectroscopy analyses. The experimental results reveal that the woven nickel mesh provides the required current collection and can act as an anode flow-field. It is also found that the spot welding of this mesh significantly improves the cell performance due to the enhanced contact between the mesh and the interconnector. Therefore, the spot welded nickel mesh can be directly employed on the anode interconnector as an effective anode current collector and flow-field without machining gas channels to reduce the SOFC cell/stack fabrication cost.

Introduction

Solid oxide fuel cells (SOFCs) have been considered to have a potential to solve the future energy problems since they provide a clean, quiet and high efficient operation. Therefore, many researches have focused to maximize the single cell (short stack)/stack performance. At stack level, there exist several factors leading to a performance loss due to the contact problems such as susceptible to failure in case of a high compressing force due to their brittle ceramic nature, the type of the current collection materials, the channel dimension and the thermal expansion mismatch of the stack components. However, the design of the flow-field is one of the most significant factors affecting the SOFC single cell/stack performance. A typical SOFC short stack includes the anode and the cathode metallic interconnector for the current collection. The current collecting meshes are also frequently employed to improve the contact for a better current collection. The gas distribution, on the other hand, is achieved by machining the flow channels on the metallic interconnectors. However, this machining process brings about an extra cost and thus increases the SOFC fabrication cost. Although, there can be found numerous experimental and theoretical studies in the literature on the conventional interconnectors with machined gas channels [1–5], there is very little done for the interconnectors without gas channels.

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Many companies and research centers have developed different cell designs to speed up the commercialization of SOFC systems. Sulzer-Hexis, for example, leaded to interconnector design studies by developing first commercial SOFC unit [6]. In the developed circular design, the fuel is distributed through the cylindrical hole at the center while exhaust gases are collected from outside of structure. However, air is also fed from outside of cylinder to the inside. 1.1 kW electrical power was obtained from the system which has a complex structure consisting of 70 cells. A similar design based on also ceramic material was used by Mitsubishi and Chubu Electric Power Company [7]. The stack, which produces 2.5 kW electrical power, has sinusoidal shape with 200 mm × 200 mm sizes and 40 cells.

The companies and research teams developing SOFC stack usually prefer metallic alloys as an interconnector material in the view points of easy machining and fast start-up. Tyssen-Krups Company has developed Crofer-APU metal alloy which has a high corrosion resistance at SOFC operating conditions [8]. The most preferred design in metallic interconnectors has been suggested by German research team Julich [8]. In this design with machined parallel gas channels, interconnectors provide both the current collection and flow field. Therefore, there should be a balance between the channel and the rib sizes.

Kornely et al. [4] numerically investigated the effect of the channel size on the cell performance. They found that the power density can be increased from 0.76 W cm^{-2} to 1.03 W cm^{-2} when the channel width is increased from 2.6 mm to 4 mm and the rib width is decreased from 2.4 mm to 1 mm. Bessler [9], who numerically investigated the effects of the channel depth on the cell performance, relates the fuel utilization to the cross-section of the flow channel. Lim et al. [10] indicated that the depth of the channel has not a significant effect when the cell is operated at low or medium current densities. On the other hand, the cell performance was found to improve with channel depth at high current densities. On the other hand, Lim et al. [10] also investigated effects of fuel and air mass flow rates on the concentration polarization measured by electrochemical impedance spectroscopy. The results indicated that the concentration polarization can be defined at especially/particularly low amplitudes. The second hemisphere occurred at low frequencies with decreasing of fuel and air mass flow rate and the length of the arc increased with also decreasing of the mass flow rate.

Providing of a uniform flow field is one of the most important parameters in stack design. If the flow field is not designed properly, a non-uniform flow possibly may occur. Moreover, there can be some dead zones where the reaction gases cannot reach. This situation causes to either a temperature gradient in the stack or less cell power due to inactive reaction zones. It also negatively affects the current density distribution. The local current density is expected to be low or high depending on the fuel or air flow rate as well as the number of the dead zones. The local hot points may be seen also at high current density regions increasing the cell resistance. Huang et al. [1] investigated the entrance and exit conditions for the fuel and air to provide a uniform flow in the stack. They found that there is no reactant in some channels when the interconnectors have one entrance and exit points because the shortest route is preferred by the reactant gases. However, it was reported that the flow properties and thus the performance of the stack can be improved by changing the gas entrance and exit locations although some death regions were still available. Different design alternatives were also tested to improve the flow characteristics. Among them, a uniform flow was achieved when the gases are distributed from two entrances and collected from one exit. But, there are some problems in the design for particularly multiple-cell stack in the view points of the complex geometry, leakage and nonhomogeneous fuel and air supplied for each cell in the stack. Huang et al. [1] also indicated that a uniform flow can be obtained by placing some manifolds on the interconnector surfaces. The improvement in the stack performance was reported to be approximately 11%.

The studies in the literature also showed that the flow direction is also as significant as the channel size and has a dramatic effect on the cell performance and the temperature distribution within the cell [11,12]. Recknagle et al. [12] numerically investigated the effects of co-, counter- and cross-flow types. Among them, the co-flow case showed the smallest temperature difference and the most uniform temperature and current density distribution. However, all cases demonstrated a similar fuel utilization and average cell temperature. Chyou et al. [11] also studied the effect of the same flow types. Their numerical investigations revealed that the counter-flow arrangement results in the highest power density and the cell temperature. It was seen that the cross-flow configurations generated a hot island near the fuel inlet and air outlet zones. Like Recknagle et al. [12], a more uniform temperature distribution was obtained with the parallel-flow configuration. Similar studies can be also found in the relevant literature [13–16].

Therefore, the main objective of present research is to investigate the effects of the mesh based anode flow-fields on the cell performance. The flow fields are created by using nickel based current collecting meshes instead of the conventional flow fields which includes machined gas channels. This design is expected to enhance not only the specific power density but also the current collection since it enables to use thinner interconnectors and the contact between the anode and the current collecting meshes is improved. In addition, a possible cost reduction can be achieved since the machining of the flow channels is not necessary for the proposed design.

Experimental

Flow-field designs

In order to investigate the effects of various nickel meshes on the cell performance, mainly two different short stacks are built. In the first short stack (Design 1), the interconnectors with machined gas channels are used for both the anode and cathode sides. However, the anode flow-field of the second short stack (Design 2) is achieved by using nickel meshes only which are placed on the un-machined interconnector surface whereas the cathode configuration is kept the same for both designs. The configurations of both short stacks are given in Fig. 1. A porous nickel mesh (160 mm × 160 mm with 0.7 mm