Development of New Solid Oxide Fuel Cells with Honeycomb Structure

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Abstract: Various types of cell designs have been proposed, and among them, a honeycomb-type solid oxide fuel cell (SOFC) is suitable for compact SOFC modules since it has large surface area of electrodes per a unit volume. The objective of this study is to develop fabricating process of honeycomb SOFC accumulated with multi micro-cells. So far, we have successfully fabricated a LSM cathode supported honeycomb SOFC via the fabrication processes of extrusion of LSM honeycomb monolith and coating of inner walls of multi micro channels using electrolyte and anode slurries. The prepared honeycomb SOFC had channel density of about 1000cpsi (channels per square inch), wall thickness of about 160μm, the dense electrolyte layer about 10μm, and anode layer about 20μm. The effective electrode area of the honeycomb is estimated to be 40 cm² per 1cc. In this study, the effects of geometry and electrode configuration on the performance of the honeycomb-type SOFC were investigated by simulation using various equivalent electronic circuits. Current collecting loss due to the resistance of electrodes was also estimated and will be presented.

Keywords: SOFC, Simulation, Honeycomb support, Cells accumulation, Coating

1. INTRODUCTION

Recently, SOFCs have received much attention around the world because of high energy efficiency and environmentally harmless. So far, various types of cell designs have been proposed and SOFC based on honeycomb support was shown to be one of the most compact SOFCs due to its structural characteristics with large electrode area per a unit volume, which is attractive for space saving, cost reduction and thermal control. For honeycomb SOFCs, however, there are only a few reports on electrolyte-supported type with millimeter sized channels [1, 2]. Electrolyte honeycomb support has some advantages such as ease of electrolyte (honeycomb body) densification and high mechanical strength of electrolyte honeycomb body. However, electrochemical performance of the electrolyte-supported types is difficult to improve due to large ohmic resistance of thick electrolyte. In addition, alternative configuration of air and fuel electrodes halves the electrode area per a unit volume. In contrast, there are no reports for electrode-supported type either on fabrication process of thin and dense electrolyte layer on the channel surface or its electrical properties.

The objective of this study is to design and fabricate the most efficient SOFC with honeycomb structure. In this study, the effects of material configurations and honeycomb channel number on the performance of SOFC...
were investigated using the simulation of equivalent electrical circuit.

2. CALCULATION

2.1. Material Configurations of Honeycomb SOFCs

Three types of honeycomb structures with various material configurations are shown in Fig. 1. Figures (a) and (b) are electrolyte-supported types, and Fig. 1 (c) is electrode-supported type. For electrolyte-supported types, air and fuel electrodes are formed as thin films (about 20 μm) alternatively on the electrolyte honeycomb channel surfaces. In contrast, in the case of electrode-supported types, an electrolyte and the other electrode layers are formed as thin films on all of the channel surfaces in electrode support. The alternative configuration of air and fuel electrodes for electrolyte-supported types halves the electrode area per a unit volume compared to that of electrode-supported type, in which air (or fuel) is passed through all of channels.

For electrolyte-supported types, air/fuel gases can be supplied alternatively through honeycomb channels. In contrast, in the case of electrode-supported types, all of channels can be used as only air (or fuel) supplying pass by using porous honeycomb body as a pass of the other gas (for example, body for air and channels for fuel). From preliminary data on gas permeability for porous substrate, sufficient gas supply for electrochemical reactions could be estimated.

2.2. Electrical Simulations

First, we calculated the current flow at 0.5 V for the electrolyte- and electrode-supported honeycomb SOFCs aligned with 2×2 square channels. The current flow was calculated using electrical circuit simulation tool (PSpice 10.5). The equivalent circuit was built up by connecting the sliced honeycomb units with 1 mm thickness in Z-axis direction, which composed of material ohmic resistances and cell (electrochemical) resistance. The parameters used in this calculation are listed in Table 1.

Table 1 Parameters used in the electrical simulation

<table>
<thead>
<tr>
<th>Electrolyte-supported type (pattern 1 and 2)</th>
<th>Anode layer</th>
<th>Cathode layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell resistance (Ω·cm²)</td>
<td>1.3</td>
<td>1500 S/cm</td>
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<tr>
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<td>20 μm</td>
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<table>
<thead>
<tr>
<th>Anode-supported type</th>
<th>Anode honeycomb body</th>
<th>Cathode layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell resistance (Ω·cm²)</td>
<td>0.3</td>
<td>1500 S/cm</td>
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<td></td>
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<td>160 μm</td>
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<thead>
<tr>
<th>Cathode-supported type</th>
<th>Cathode honeycomb body</th>
<th>Anode layer</th>
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<td>Cell resistance (Ω·cm²)</td>
<td>1.0</td>
<td>100 S/cm</td>
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<tr>
<td></td>
<td></td>
<td>160 μm</td>
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</table>

These values were calculated by our experimental measurements using tubular single cells [3]. Next we also calculated the current flow at 0.5 V for the cathode-supported honeycomb-type SOFC aligned with 10×10 square channels. For electrical simulation, honeycomb configuration with a wall thickness of honeycomb support, a channel size and a coating film thickness are set at 160 μm, 0.64 mm and 20 μm, respectively.

3. RESULTS and DISCUSSION

3.1. Effects of Material Configurations on SOFC Performance

Figure 2 shows the current flows simulated for various honeycomb SOFCs with 2×2 square channels as a function of honeycomb length. And, Fig. 3 shows the current collecting losses of various honeycomb SOFCs calculated using ideal values under the condition, in which ohmic resistances of thin electrode layers and electrode support are ignored.

The current for both of the electrolyte-supported types were quite smaller than those for electrode-supported types regardless of honeycomb length. This is because that thick electrolyte wall (160 μm) and thin cathode layer (20 μm) in the air channels cause high ohmic resistance and alternative configuration of air/fuel channels makes net electrode area half of total channel surfaces. As shown in Fig. 3, with increasing honeycomb length, the current collecting loss became larger due to cathode resistance. This high ohmic resistance of cathode layer suppresses an enhancement of current flow.

In a range of few milli-meter honeycomb lengths, current for anode-supported type was larger than that for cathode-supported one as shown in Fig. 2. With increasing the honeycomb length up to 7 mm, however, the current for cathode-supported type became superior to anode-supported one, and then, the current for the former becomes about 1.3 times of that for the later at the honeycomb length of 10 mm. This behavior is also caused by high resistance of thin cathode layer inside the honeycomb channels of anode-supported type. The current for anode-supported type above 2 mm length deviated significantly from the ideal value calculated under the condition in which ohmic resistance of thin cathode layer was ignored, and finally the current collecting loss reaches about 80 % of ideal value at the honeycomb length of 10mm as shown in Fig. 3.

On the other hand, in the case of cathode-supported type, current can increase linearly with increasing honeycomb length without large deviations from ideal current values, because current collecting losses of cathode honeycomb body and thin anode layer are quite small (below
3.2. Effects of Channel Numbers in a Honeycomb on SOFC Performance

Figure 4 shows the current flows simulated for cathode-supported honeycomb SOFCs with 10×10 square channels in a honeycomb with length of 1 mm (sliced honeycomb unit). With increasing channel numbers, the honeycomb size becomes larger up to 8.2 mm×8.2 mm for 10×10 channels’ honeycomb than that of 1.8 mm×1.8 mm for 2×2 channels’ honeycomb.

The current increases almost linearly with channel numbers and the honeycomb with 10×10 channels can attain 1.2 A at 0.5 V. This result indicates that our designed cathode-supported honeycomb SOFC has ability to generate a power of 0.6 W in 8.2 mm×8.2 mm×1 mm honeycomb size at an operating temperature of 700 °C, at which the cell resistance of our developed cathode-supported single cell was 1Ω·cm². The current collecting loss of cathode-supported type with 10×10 channels is about 5% and can be negligible from the energy loss point of view at the performance of volumetric power density. By considering current collecting loss by honeycomb length enhancement (Fig. 3), for cathode-supported type with 10×10 channels and 10 mm length, volumetric power density of 2 W/cc at an operating temperature of 600 °C, at which the cell resistance of our developed cathode-supported single cell was 2Ω·cm², can be expected which is our targeted performance.

Currently, simulation study on total performance included gas supply, thermal distribution and electrochemical reaction is proceeded to optimize structural configuration of honeycomb SOFC.

4. CONCLUSION

In this study, the concept of the honeycomb type SOFC with integrated micro-cells was examined from the viewpoint of current collecting loss. Cathode support honeycomb type SOFC is superior to electrolyte or anode support type due to its small current collecting loss.

ACKNOWLEDGEMENT

This study was supported by the New Energy and Industrial Technology Development Organization (NEDO).

REFERENCES