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Influence of pore former on electrochemical performance of fuel-electrode supported SOFCs manufactured by aqueous-based tape-casting

Juan Zhou [b, *], Qinglin Liu [b], Lan Zhang [b], Zehua Pan [a, b], Siew Hwa Chan [a, b, **]

[a] School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore
[b] Energy Research Institute at NTU (ERI@N), Nanyang Technological University, 1 CleanTech Loop #06-04, Singapore 637141, Singapore

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ABSTRACT

The microstructure of a fuel electrode has a significant influence on the whole performance of fuel-electrode supported solid oxide fuel cells (SOFCs) fabricated by aqueous-based tape casting. While in the aqueous-based tape casting process, the fuel electrode porosity, which plays a key role in the final fuel electrode microstructure, mainly comes from the pore former (potato starch in this case). Different contents of starch are added into fuel electrode slurries. When the starch content is 2.5%wt, the cells show the best performance. After one thermal cycle and discharging at a constant voltage of 0.7 V and temperature of 800 °C, the peak power density has reached ~1263 mW cm^{-2} with humidified H_2 as the fuel and air as the oxidant.

1. Introduction

Solid oxide fuel cells (SOFCs) technology is a cutting-edge technology for directly converting the chemical energy of the fuel into the electrical energy and heat by means of the electrochemical reactions [1,2]. SOFCs technology has many advantages compared with the conventional power plants, such as high efficiency, fuel flexibility, environmentally friendly, low noise level, and etc. [3–5]. SOFCs are mainly divided into four categories, namely the fuel electrode-, air electrode-, electrolyte-, and structural-supported SOFCs [6,7]. Different types of supports have different characteristics, hence exhibiting both advantages and disadvantages. However, the fuel electrode-supported SOFC is considered to be the most mature one compared to the other three [8]. The supporting fuel electrode provides the mechanical strength to the whole cell, and offers the cell with high electronic conductivity and porosity. The microstructure of the supporting fuel electrode is crucial to the performance of the entire cell [9–12] as gas permeability and reactions strongly depend on microstructural parameters such as porosity, particle size and three phase boundary length [13–15].

Porous nickel-yttria stabilized zirconia (Ni-YSZ) is currently the most common fuel electrode material for SOFCs [16–18]. During the fabrication process, the starting materials of fuel electrode (NiO and YSZ mixture) are prepared by high temperature processing. Then NiO-YSZ is reduced to metallic Ni-YSZ when the fuel electrode is exposed to the fuel environment during the cell operation. In the process of reduction from NiO to Ni, the volume of particles shrunk, which creates some amount of porosity, but this amount of porosity is insufficient to meet the requirements of gas permeability, electrochemical reactions and steam removal. Hence, the pore former is added to increase the porosity. However, if the porosity is lower and higher than the optimal value, the area of the three phase boundary region would not be maximised, which infers that it is crucial to determine the best amount value of porosity with the optimized amount of pore former added into the fuel electrode slurry.

Tape casting is a well-known shaping technology for producing large area, thin, uniform and flat ceramic tapes. This technology (organic-based tape casting) is more popular in SOFCs

List of abbreviation and nomenclature: SOFCs, solid oxide fuel cells; TPB, three phase boundary; OCV, open circuit voltages; I-V, current-voltage; I-P, current-power density; SEM, scanning electron microscope; R_{Ω}, ohmic resistances; R_T, total resistances.

* Corresponding author.
** Corresponding author. School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore.
E-mail addresses: zhoujuan@ntu.edu.sg (J. Zhou), mshchan@ntu.edu.sg (S.H. Chan).

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Table 1
The formula of different fuel electrode slurries with different amounts of pore-former.

Chemicals	The ratio of the fuel electrode layer (%)
NiO	50
YSZ	50
Potato starch	1.5, 2, 2.5, 3, 3.5
Poly acrylic acid (PAA)	2
De-ionised water	75
Poly vinyl alcohol, 87–89% partially hydrolysed	10.5
Poly ethylene glycol (PEG)(Mw 380–420)	14
Glycerol	14
1-Octanol	1.2
2,4,7,9-Tetramethyl-5-decyne-4,7-diol ethoxylate	0.75

manufacturing. However, organic-based tape casting often involves the use of toxic solvents and hazardous additives, which not only increases the manufacturing cost, but is also harmful to human health and the environment. For this reason, there are increasingly more attentions paid to development of aqueous-based tape casting [19–21]. While in a stable aqueous-based tape casting slurry system, the porosity of fuel electrode is mainly determined by the amount of pore former.

There are several papers studied the effect of different pore formers on the properties of the fuel electrode [22–28], while only a handful of literature have been reported with regard to the influence of pore formers on the morphology in the aqueous tape casting [29]. The aim of this work is to study the influence of the pore former (potato starch in this paper) on the microstructure of fuel electrode and its associated electrochemical performance in the aqueous-based tape casting.

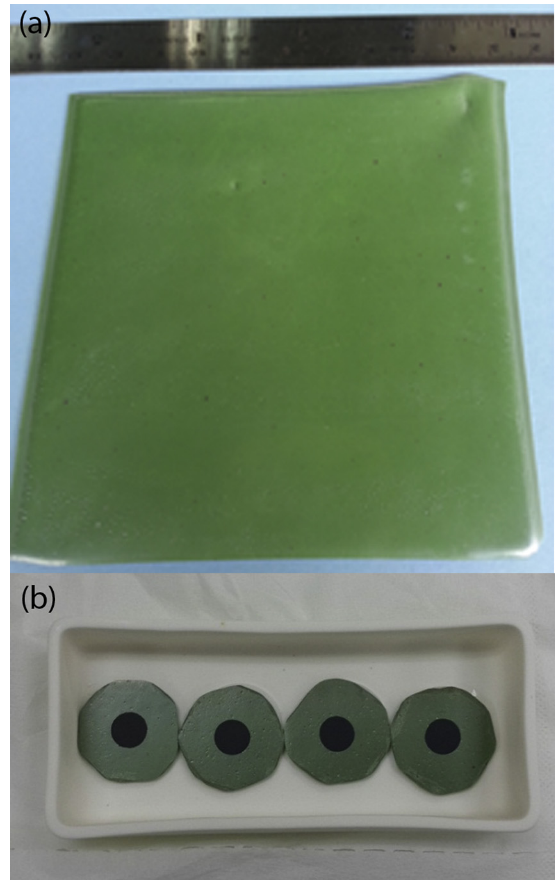

Fig. 2. The picture of (a) 10 cm × 10 cm half cell and (b) the button cell.

2. Experimental

2.1. Fabrication

Firstly, the aqueous co-tape casting and co-sintering were used to fabricate fuel-electrode supported half cells. Commercial NiO (J. T. Baker, US) and $Zr_{0.92}Y_{0.08}O_{2-\delta}$ (YSZ, TOSOH, Japan) were used for preparing the fuel-electrode layer, and the YSZ powder was used to prepare the electrolyte layer. In the aqueous-based tape casting process, potato starch powder (pore former), polyacrylic acid (disperse agent), ammonia (electrostatic dispersant), hydrolysed polyvinyl alcohol (the binder), glycerol and polyethylene glycol (plasticizer), 1-octanol (de-foamer) and 2,4,7,9-tetramethyl-5-decyne-4,7-diol ethoxylate (surfactant) were added. Details of the fabrication process can be found in our previous paper [30]. After the NiO + YSZ/YSZ half-cell was gotten, the $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3+\delta}$(LSCF)/$Ce_{0.9}Gd_{0.1}O_{2+\delta}$ (CGO) composite air-electrode with a weight ratio of 1:1 was screen printed on it.

To get a stable slurry system, the disperse agent, the electrostatic dispersant, the binder, the plasticizer, the de-foamer and the surfactant need to be in a fixed formula, even though each they can affect the porosity separately, while pore former can be more flexible. Hence, it is much easier to study the influence of the electrode microstructure by changing the amount of pore-former. Table 1 shows different amounts of pore-former used in the fuel electrode slurries with the weight ratio of 1.5, 2, 2.5, 3, 3.5%, respectively. Finally, the 10 cm by 10 cm single cells were fabricated. Fig. 1 shows the cross-section micrographs of the cell with

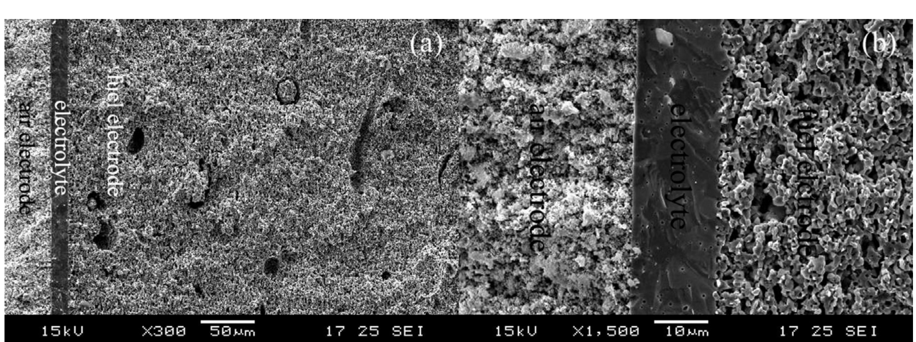

Fig. 1. The microstructure of single cell with the weight ratio of 2.5%: (a) the low magnification, and (b) high magnification SEM micrograph of the cell's cross-sectional view.