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Mechanical behaviour of multi-layer half-cells of microtubular solid oxide fuel cells fabricated by the co-extrusion process

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Abstract

Multi-layer micro-tubes consisting of four anode layers of NiO and YSZ mixture, and an electrolyte layer, YSZ, were fabricated by co-extrusion. The die designed in this study is able to extrude 5 layers around a sacrificial core, which eliminates the difficulties from the use of mandrel in processing tubes. Scanning electron microscopy (SEM) results revealed that this technique can be used for the successful fabrication of multi-layer microtubes with good bonding between the layers. 3-point bending was used to evaluate the mechanical properties of these co-extruded multi-layer samples. Moreover, thermal shock resistance of the tubes was investigated by water quenching from an elevated temperature. The results were compared with those obtained for conventionally extruded single layer samples. The co-extruded samples were found to have the highest average strength and also the highest weibull modulus and reliability. It was also found that multi-layer anode can significantly improve thermal shock resistance.

Keywords: Solid oxide fuel cell; Co-extrusion; Bending test; Weibull modulus; Thermal shock resistance

1. Introduction

Solid oxide fuel cells (SOFCs) are electrochemical devices that directly convert chemical energy to the electrical energy. There are two major types of SOFC design, namely planar and tubular. Tubular design has several advantages like the ease of sealing and higher thermal stability [1–3]. SOFCs operate at high temperature, which leads to slow start-up/shut-down time and limits the usage of SOFCs to only stationary systems. Moreover, high current path decreases the produced power density of the SOFC [4,5]. To overcome these problems several remedies are suggested and micro-tubular design is the most outstanding. This type of design has also been improved by decreasing the tube diameter and the electrolyte surface area to volume ratio, leading to an increased power density for these tubes [6,7]. Moreover, decreasing the wall thickness of these tubes improves the thermal shock resistance of the cell [6,7]. These two important characteristics can significantly reduce the start-up and shut-down cycle times for SOFCs and therefore, provides the possibility of using fuel cells in moving parts [8,9].

So far, many conventional processing routes have been proposed for fabrication of micro-tubular solid oxide fuel cells, among which extrusion is one of the most important methods [10–12]. Generally, in conventional processing methods anode tube is fabricated first, as it can support the other layers, and the other layers will be introduced later. This fabrication method involves many processing steps which increases the fabrication cost. Moreover, some difficulties arise while sintering the electrolyte layer on the anode layer due to thermal mismatch between layers. Recently, co-extrusion has been introduced as a processing method for fabrication of micro-tubular SOFCs [13,14]. In this method, the processing steps are reduced since the anode and electrolyte layers can be fabricated simultaneously. Moreover, the anode layer can be fabricated with functionally graded structure, which reduces the thermal mismatch between anode and electrolyte layers.

Although many studies have been conducted on designing and performing co-extrusion process [13,14], few studies are

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devoted to the investigation of the effect of an anode multi-layer structure on the mechanical properties of half-cell tubes of SOFCs. However, besides the electrical performance and fabrication of the SOFCs, their mechanical properties are also important due to the following reasons. First, it is necessary to handle the fabricated SOFC tubes without any damage for use and also for stack formation. Moreover, these tubes must be able to withstand the thermal shocks they experience during the operation.

In this paper, the possibility of successful fabrication of multi-layer micro-tubes to be used in solid oxide fuel cell half-cell is investigated. In addition, the effect of anode functional structure on the mechanical properties of multi-layer micro-tubes is studied. Moreover, microstructural characterization of micro-tubes and also thermal shock resistance of half-cells are investigated.

2. Materials

Multi-layer micro-tubular solid oxide fuel cell is produced using the co-extrusion process. The processed micro-tube consisted of 5 layers, 4 anode layers and an electrolyte layer. Yittria-stabilized zirconia (YSZ) was used as an ion conducting material in electrolyte material. Anode layers were fabricated from mixture of nickel oxide (NiO), YSZ and activated carbon as pore former. In order to perform the extrusion process, the powders were prepared in the form of suitable pastes. Details of the technique used for paste preparation as well as the chemical composition of each layer are presented in the authors' previous paper [15].

2.1. Preparation of multi-layer micro-tubes

As mentioned before, co-extrusion was used as a fabrication method in preparation of multi-layer micro-tubes. The co-extrusion die set-up designed in this study is capable of producing multi-layer extruded rods with five outer layers. During the extrusion process, a suitable carbon paste was also extruded at the same time. The core material was subsequently burned out by firing the extruded sample, resulting in multi-layer tube. This strategy, using the sacrificial core, can significantly reduce many difficulties in processing tubular sample by eliminating the need for mandrel which is normally an inevitable part of the extrusion dies. To fabricate a multi-layer tube, the corresponding paste for each layer was fed from 4 separate barrels into the feeding cone and subsequently to a concentric annulus structure. The co-extruder die and flow fields of the pastes are schematically illustrated in Fig. 1. It

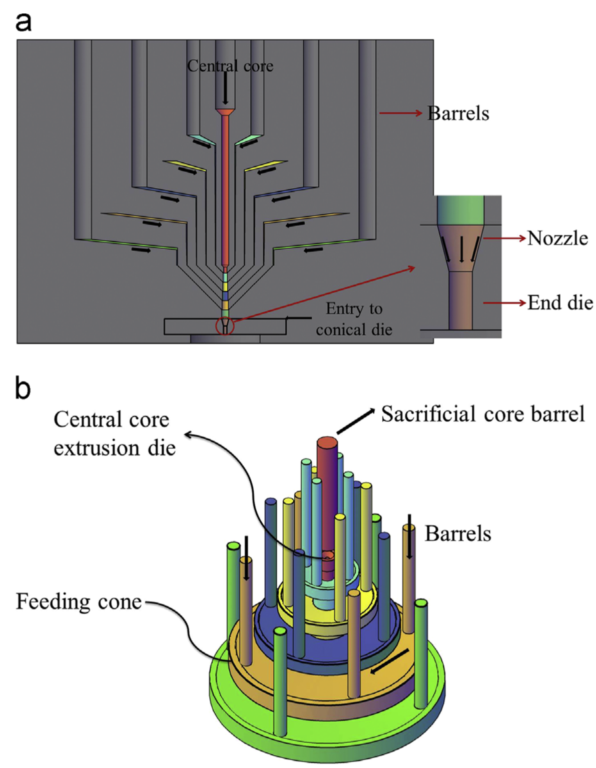

Fig. 1. Co-extrusion die, (a) cross-section view of the co-extruder die, (b) Flow fields and disks of different layers paste. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

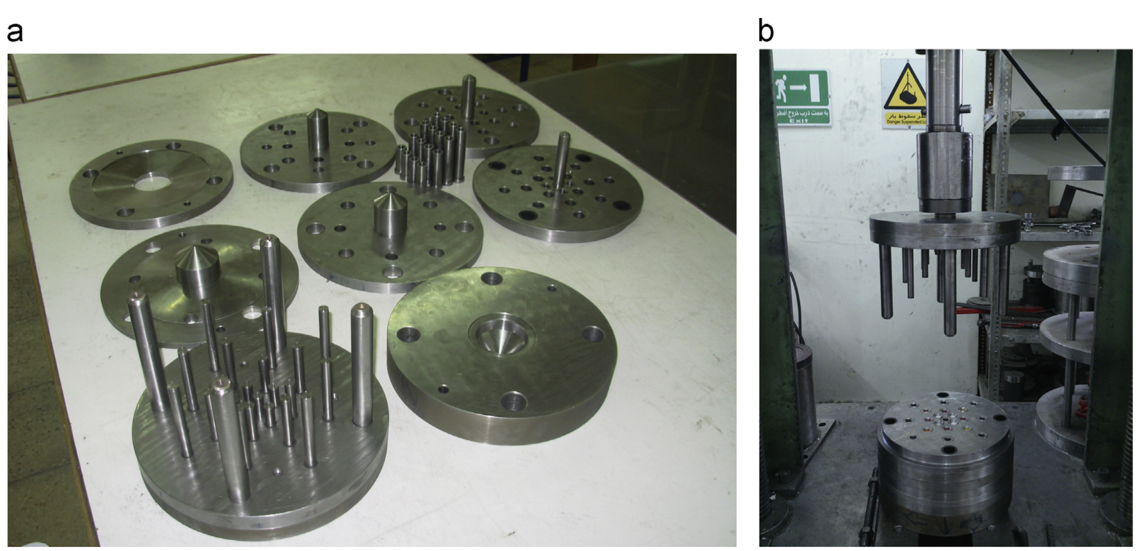

Fig. 2. Constructed co-extruder, (a) disassembled parts of the constructed die, (b) assembled die on the pressing machine.