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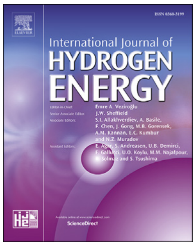

Thermal stress analysis of a planar anode-supported solid oxide fuel cell: Effects of anode porosity

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ABSTRACT

A Fuel cell is a highly efficient device for converting chemical energy in fuels to electrical energy and the electrical efficiency is strongly affected by the porosity in electrodes due to its close couplings with mass transfer and active sites for the electrochemical reactions, which will also cause changes in distribution of thermal stresses inside the electrodes. A three-dimensional computational fluid dynamics (CFD) approach based on the finite element method (FEM) is used to investigate the effects of porosity on polarizations, temperatures and thermal stresses by coupling equations for gas-phase species, heat, momentum, ion and electron transport. It was found that the porosity in the anode remarkably affected the exchange current density and electrical current density, but it had an opposite effect on the anodic activation polarization compared to that in cathode. The first principle stress was enhanced from 0 to 2 MPa to 6–8 MPa by an increased anode porosity from 25% to 40%, and the increased porosity resulted in a decrease of the von mises stress along the main flow direction as well. The conclusions could be used to lay foundations for an improved performance and stabilization by optimizing electrode microstructures and by eliminating the stresses in electrodes.

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Introduction

The solid oxide fuel cell (SOFC) is a device that can efficiently and environment-friendly convert chemical energy in fuel to electrical energy via electrochemical reactions instead of combustion [1,2]. The research on SOFCs has extended from materials design [3] and fabrications [4] to basic analysis of electrochemical reactions [5], enhancement of power density [6], poisoning effects due to various impurities in fuel [7] and thermal stress distribution [8], which is intimately related to its stability and lifetime [9].

The thermal stress could detrimentally affect the lifetime of single cells and short stacks due to the formation of cracks and has attracted increasing attentions in the SOFC research community recently [10]. The experimental techniques are used to examine the effect of the operating parameters on the thermal stress behavior and performance of SOFCs, but it takes much longer time and more investments compared to modeling work.

Compared with the experimental conduction, the easier and time-saving modeling works has gained more attention because of its comprehensive thermal stress evaluation, multiscale studies, as well as low cost [11–13]. Min et al. [8] performed FEM simulations to investigate the thermal stress distribution when the fixed constrained was included and the results showed that the fixed constraint would exacerbate the thermal stress. Lin et al. [11]analyzed the thermal stress distribution in an SOFC stack at various support conditions and different stages of operation. Selimovic et al. [12] investigated the cell's structural response to diverse design parameters and presented the relationships between maximum principle stress and working voltage, fuel utilization. The thermal stress was also utilized as a criterion to optimize the structure of SOFC interconnects [10]. The thermal stress decreased when the width of interconnects' ribs had a graded structure.

The thermal stress could mainly be attributed to the prominent gradient of temperature distribution and the mismatches of mechanic properties of various components within the cell [14]. Besides, it was proved that the performance was affected when the amount of electrochemical active sites of the SOFC cathode had graded designs [15,16]. Greene et al. [17]found that the cell had an ascendant performance with a higher ratio near the electrolyte interface with a graded porosity-tortuosity ratio of the electrodes. Ni et al. [18]discovered that a decreased particle size at the electrode-electrolyte interface would help to gain a pronounced performance with a much higher power density. However, they had overlooked the effects of microstructure on the electrodes when the thermal stress was studied. The relationship between the thermal stress and microstructure of electrodes was found significant since they both were related to the temperature distribution [14]. The influence of mass and heat transfer took the porosity and tortuosity into account [19,20]. The correlation of porosity and gas permeability as well as an effective charge-transfer resistance were also reported [21]. Furthermore, the material's mechanical properties were confirmed as functions of porosity which directly determined the thermal stress distribution [22–24]. Selcuk and Atkinson[25] presented measured results of the effective Young's modulus and shear modulus for SOFCs, meanwhile the relationship between these parameters and porosity was discussed.

In the current investigation, a three dimensional comprehensive model was built to investigate the distribution of thermal stresses in an anode supported single cell. Variation of mechanical properties as a function of anode porosity was studied, based on the finite element method with COMSOL Multiphysics (version 5.2). The governing equations of five different groups: ion and electron transport, momentum, mass and heat transport and thermal mechanics are solved.

Mathematical model

To analyze the thermal stress of an SOFC, a half-cell model with bipolar channels operating with dry hydrogen was built as shown in Fig. 1. The gas fed was defined as counter-flow and the fuel and air fed direction was also marked. The geometry parameters of the cell were listed in Table 1. Note that the outermost boundaries of the two interconnects were set in fixed constraint conditions to simulate the in-between unit cell's condition in a SOFC stack, and the initial displacements were set to zero in all directions. In this model, free of thermal expansion meant no prescribed displacement constraint asset on the boundary or domain. During operation, the thermal stress was raised to keep the interfaces' size and continuation, which were subjected to many different constraints [8].

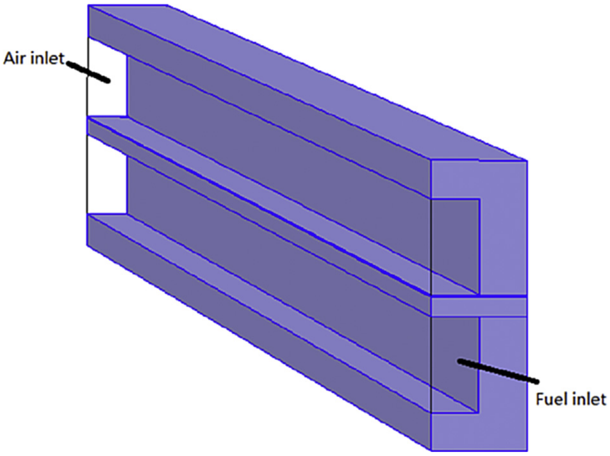

Fig. 1 – The shape of a single cell in this work.

Table 1 – The main parameters for the modeling SOFC.

Geometry parameter	Value	Unit
Cell length	100	mm
Gas channel height	0.5	mm
Gas channel width	0.25	mm
Interconnect rib thickness	125	μm
Interconnect thickness	125	μm
Anode thickness	0.1	mm
Cathode thickness	5	μm
Electrolyte thickness	5	μm

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