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# Analysis of micro-tubular SOFC stability under ambient and operating temperatures

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ABSTRACT

The stability of micro-tubular solid oxide fuel cell (MT-SOFC) is predicted at ambient and operating temperatures via simulation method. The results reveal that as long as the anode failure probability satisfies the failure criterion of 1E-6 at ambient temperature, the anode will retain its structural integrity at operating temperature. For the electrolyte or cathode, the stress strength ratio at operating temperature is significantly higher than that at ambient temperature. For an inappropriate component thickness, the cathode maybe fractures at operating temperature. In order to ensure the stability of MT-SOFC, the cathode thickness must be smaller than the maximum cathode thickness ($t_{\max-cathode}$), which is derived from: $t_{\max-cathode} = 5.49 + 5.54\, t_e$



## 1. Introduction

In recent years, micro-tubular solid oxide fuel cell (MT-SOFC) has gained increasing attention due to its distinctive superiorities, such as thermal stability, high volume power density, and rapid start-up capability [1–6]. However, high cost and short life span are the major obstacles for MT-SOFC commercialization. During fabrication and operation, MT-SOFC is subjected to residual stress due to the mismatch in the thermal expansion coefficients (TEC) of the different cell components, which significantly affects the yield and life time of the cells [7]. Therefore, there is an urgent need to minimize the residual stress in order to reduce the cost and improve the stability of MT-SOFC.

The residual stress exerts several negative effects on the integrity of MT-SOFC. For instance, it may influence the straightness and roundness of the tubes, which will cause mounting and sealing problems in a stack. In worst cases, fracture and delamination occur, which is unacceptable for gas-tightness and cell performance. In view of this, many efforts have been dedicated to investigating the residual stress in MT-SOFC as well as its negative effects and the counter measures. From the experimental aspect, Sammes et al. [8] and Sinet al. [9] measured the mechanical properties of a MT-SOFC via burst test. Griesser et al. [10] characterized the faults and geometries in the formation of SOFC tubes with X-ray tomography. Meng et al. [11] studied the influence of sintering temperature on the mechanical strength of hollow fibers and the compactness of the electrolyte layer. Mani et al. [12] compared the mechanical behavior of multi-layer half-cells fabricated by co-extrusion with that of the conventionally extruded single layer samples. Further, Paciejewska et al. [13] observed the cracks in gadolinium doped ceria (GDC) buffering layers under various fabrication conditions. On the other hand, some numerical models provided more visible details about the MT-SOFC residual stress. Cui et al. [14,15] presented the stress field of MT-SOFC under working condition through a coupled thermo-electrochemical model. Serincan et al. [16] performed a more comprehensive MT-SOFC stress analysis including the stress from TEC mismatch during fabrication and operation and the stress induced by exterior fixture. Li et al. [17] considered the effect of electrode composition on the MT-SOFC stress under room and working temperatures. Our previous work [18] further investigated the MT-SOFC residual stress at room temperature under different component thicknesses. In that study, the minimum safety standards were recommended, which has provided great convenience for MT-SOFC design. However, the stress state at room temperature is quite different from that at working temperature, the former one being larger because of the greater temperature drop from stress-free temperature. However, this does not imply that a MT-SOFC is safer at working conditions, because its mechanical strength also reduces at high temperatures. Therefore, the conclusions of our previous work [18] cannot be applied to

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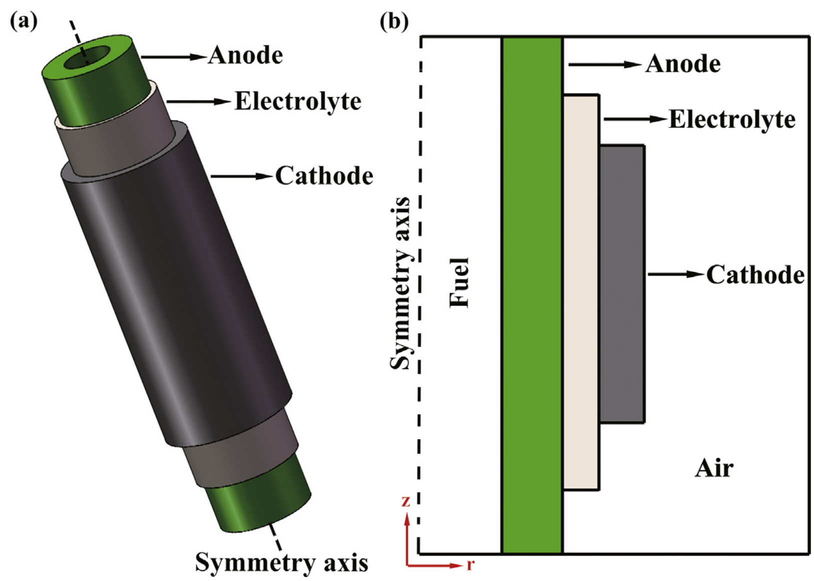


**Fig. 1.** Schematic of the (a) MT-SOFC; (b) 2D axisymmetric MT-SOFC model.

the working conditions of MT-SOFC. Therefore, the main purpose of this work is to investigate the stress state and the mechanical stability of a MT-SOFC at the working temperature. The influence of component thicknesses on the MT-SOFC stress will be systematically discussed in order to extract useful principles for MT-SOFC design.

## 2. Model development

### 2.1. Mechanical model

In this study, the MT-SOFC is simplified into a 2D axisymmetric model, as can be seen in Fig. 1(a) and (b). The geometric parameters of this model are the same as in our previous study [18], which has not been discussed here for brevity.

The MT-SOFC components in this study include a porous composite Ni-YSZ anode, a dense YSZ electrolyte, and a porous composite LSM-YSZ cathode. The effective mechanical properties of the porous composite electrodes, such as the TEC, Young's modulus and Poisson's ratio are derived using the same formulas adopted in our previous work [18].

### 2.2. Morphology and structure

Fig. 2 shows a flowchart of the simulation procedures. In traditional fabrication processes, the stress-free temperature is universally regarded as the sintering temperature. In the present study, 1473 K, 1473 K and 1373 K were set as the stress-free temperatures for anode, electrolyte and cathode, respectively. After the completion of high-temperature co-sintering, the MT-SOFC was cooled down to room temperature (298 K). The residual stress was derived at this stage. The obtained residual stress was then used as the initial condition and the temperature was increased to 1073 K to study the stress state under working temperature.

### 2.3. Stress calculation

By assuming that all the materials undergo elastic deformation, the overall strain can be written as the summation of the elastic strain ($\varepsilon_{el}$), thermal strain ($\varepsilon_{th}$) and initial strain ($\varepsilon_0$):

$$\varepsilon = \varepsilon_{el} + \varepsilon_{th} + \varepsilon_0 \tag{1}$$

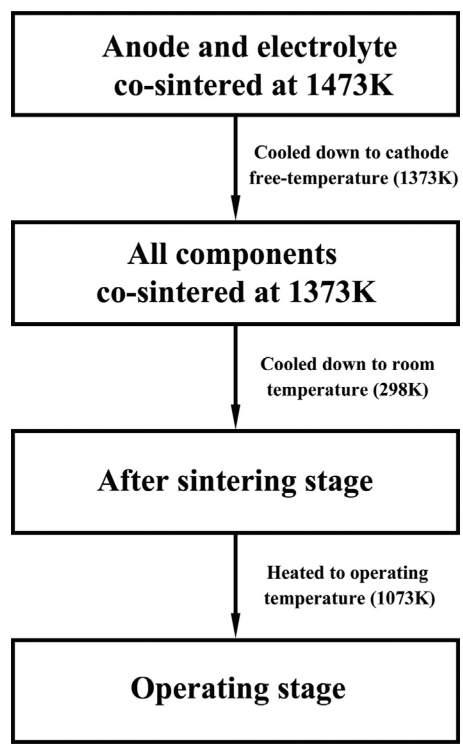


**Fig. 2.** Flowchart depicting the simulation procedures.

The form of elastic strain is:

$$\varepsilon_{el} = (\varepsilon_{xx}, \varepsilon_{yy}, \varepsilon_{zz}, \gamma_{yz}, \gamma_{xz}, \gamma_{xy}) \tag{2}$$

in which the subscripts *xx*, *yy* and *zz* denote the normal strain, *yz*, *xz* and *xy* denote the shear strain.

The thermal strain is calculated by:

$$\varepsilon_{th} = \alpha(T - T_f) \tag{3}$$

where α is the TEC of the material, $T$ is the temperature at which the thermal stress is derived, and $T_f$ denotes the stress-free temperature.