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Thermal Stress Analysis on the Solid Oxide Fuel Cell according to Operating Temperature

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Abstract : The fuel cell is one of the green energy receiving a lot of attention. Among the fuel cells, it is generally referred to SOFC(solid oxide fuel cell) which is made up composites of a solid. SOFC has excellent merits in the side of environment and energy. However because of the high operating temperature, it has economic loss by the using of expensive materials and problems of structural instability by thermal stresses. Therefore, this study aims to the effect of analysis by the FEMLAB. The results have deformations and the maximum stresses from the variation of the thickness of vulnerability spots. The deformation shows expansion as 0.82% and the stress σ_{xx} is 392MPa in electrolyte and -56.31MPa in anode. When increasing or decreasing the thickness to 50% of the reference thickness about the electrolyte which is vulnerable spots.

Key words : Solid oxide fuel cell, Operating temperature, Thermal stress, Maximum stress, Electrolyte, Vulnerable spot

1. Introduction

Although modern civilization has made unbelievable progresses depending on the fossil fuel, it occurs environmental problems because of the atmosphere pollution using a lot of the fossil fuel. Recently, many studies for developing of the green energy have been done to solve these environmental problems. Among the green energy, the fuel cell is a power generator using the chemical energy of the providing fuel. Unlike general cells, the fuel cell can produce electricity continuously by the fuel injection. The fuel cell is classified by a sort of electrolyte and it is called SOFC(solid oxide fuel cell) which is made up composites of the solid. On the energy efficiency side, SOFC is the most efficient among the fuel cells. If SOFC operate with cogeneration system, it has generating efficiency up to 80% [1]. We can confirm the superiority of the generating efficiency of SOFC. On the environmental pollution side, SOFC has a positive effect for reduced CO_2 and it does not almost produce SOx, NOx. However SOFC has some problems because the temperature rises up to 800~1000°C during the operation.

On the mechanical deformation side, SOFC has the problems of structural unsafe by thermal stresses due to the differences of thermal expansion among the layers of solid. Besides high temperature-resist materials should be used in SOFC. It causes cost problems. Lin [2] analyzed the thermal stress of a planar SOFC stack. However the study did not include the effect of thickness of composites. Ko [3] estimated the voltage according to the thickness of the electrolyte. However it has no consideration for a stress by analysis. Zhang [4] analyzed residual thermal stresses when SOFC cools with a several thickness. However the study did not consider the relationship of deformation and residual thermal stresses by the temperature. Thus, this study aims to investigate the effect of the thickness at the vulnerable spots when the operating temperature rises from room temperature to 800°C. The study shows the analysis for the thermal stress and deformation according to the change of the thickness at the vulnerable layer. It

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provides the basic data for determination of the proper thickness of vulnerability spots on the structural safety side of SOFC.

2. Numerical Analysis

Fig. 1 presents the geometrical configuration and dimension [5] of the analyzed model. It shows the electrolyte layer is very thin. The reason is because SOFC have a high voltage by reducing the electrical resistance. Table 1 shows the materials and physical properties of the analyzed model. The properties data come from the previous studies. 8YSZ (8 wt.% Y_2O_3 stabilized ZrO_2) is most widely studied and used as a thermal barrier coating (TBC) material because it provides the best performance in high-temperature applications [6]. LSM (Strontium-doped $LaMnO_3$ perovskites) have been mostly investigated and are considered as the most appropriate cathode material due to their good electrical properties, catalytic activity, physical and chemical stability [7]. The anodes have been composed of bulk Ni and YSZ (Ni-YSZ). The main reasons for using Ni-YSZ anodes are the reasonable cost of the materials, the stability and excellent catalytic activity of Ni fuel gas environments, and the fact that a high density of three-phase boundaries and formed in the cermet, increasing electrochemical reaction rates [8]. SOFC undergoes chemical reactions when it heats up beyond its ideal temperature. and because the operating temperature is generally known as 800ºC, the temperature of SOFC is considered as varying from room temperature to 800ºC. And also the thickness of vulnerability spots (electrolyte) changes between 0.01 mm and 0.03 mm by the 0.002 mm interval. The deformation and thermal stress caused by the difference of a thermal expansion coefficient of materials are estimated. And the alteration of the maximum stress is compared for the each thickness.

Fig. 2 shows finite element mesh configuration. Mapped

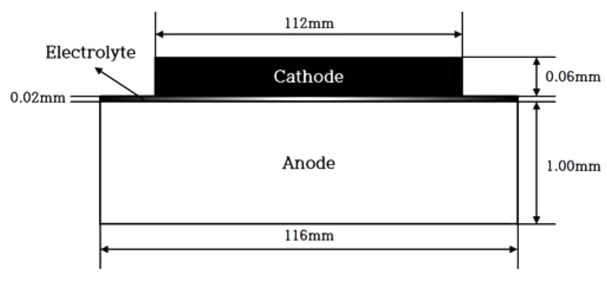

Fig. 1. A geometrical configuration of planar SOFC.

Table 1. Materials and physical properties of SOFC

	Material	Young Modulus (GPa)	Poisson's ratio	Tec α 10^{-6}(1/K)
Electrolyte	8YSZ	215 [9]	0.32 [9]	10 [9]
Cathode	LSM	35 [9]	0.25 [9]	11 [9]
Anode	Ni-YSZ	55 [9]	0.17 [9]	13 [9]

	Cathode	Electrolyte	Anode
Element Quality	0.198	0.0998	1

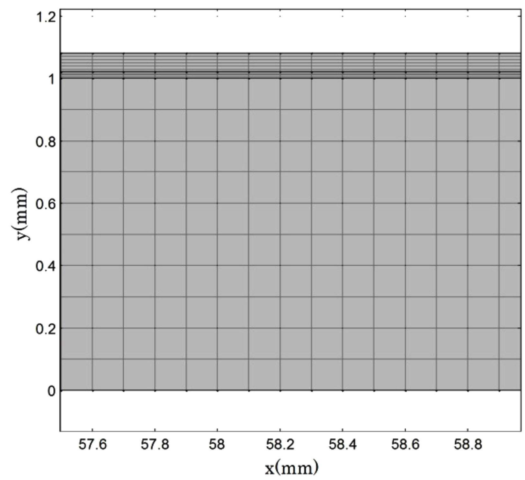

Fig. 2. An example of mesh configuration.

mesh was used for this study and the number of the elements are 22960. Mesh area of cathode, electrolyte and anode layer is 6.72 mm^2, 2.32 mm^2 and 116 mm^2, respectively.

In this analysis, the loading condition is just temperature variation. The constitutive equations for the thermal stress analysis are written as equation (1), (2), (3) and (4).

$$\sigma = D\varepsilon_{el} + \sigma_0 = D(\varepsilon - \varepsilon_{th} - \varepsilon_0) + \sigma_0 \tag{1}$$

$$\varepsilon_{th} = \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{xz} \end{bmatrix}_{th} = \alpha_{vec}(T - T_{ref}) \tag{2}$$

$$\sigma = \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{xz} \end{bmatrix} \qquad \varepsilon = \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{xz} \end{bmatrix} \tag{3}$$

$$\sigma_0 = \begin{bmatrix} \sigma_{x0} \\ \sigma_{y0} \\ \sigma_{z0} \\ \tau_{xy0} \\ \tau_{yz0} \\ \tau_{xz0} \end{bmatrix} \qquad \varepsilon_0 = \begin{bmatrix} \varepsilon_{x0} \\ \varepsilon_{y0} \\ \varepsilon_{z0} \\ \gamma_{xy0} \\ \gamma_{yz0} \\ \gamma_{xz0} \end{bmatrix} \tag{4}$$

Here D, σ, T, T_{ref}, ε_{el} and α_{vec} are elasticity matrix, stress vector, actual temperature, reference temperature, elastic strains and coefficient of thermal expansion respectively. Also ε_x, ε_y, ε_z, γ_{xy}, γ_{yxz}, γ_{xz} are strain components respectively.

3. Results and Discussion

Fig. 3 shows the general distribution area of the stress which is induced by rising temperature on operating SOFC. Tensile stresses happened generally in a cathode and on electrolyte but compressive stresses partially happened in the end of the corner of the cathode and electrolyte. And compress stresses happened generally in the anode

Fig. 4 shows the stress concentration at area A in Fig. 3. The strongest tensile stress occurred at area A (electrolyte), the value is 392 MPa. The electrolyte is consists of 8YSZ and its stress is higher than ultimate flexural stress, 279 MPa of 8YSZ [7]. This shows that SOFC may be damaged or/and the crack can be initiated from the contact corner of a cathode and electrolyte owing to the high temperature during the operating.

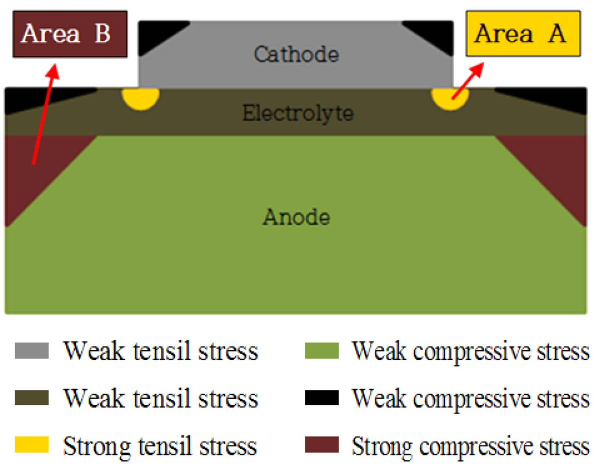

Fig. 3. Areas of the stress distribution at 800°C.

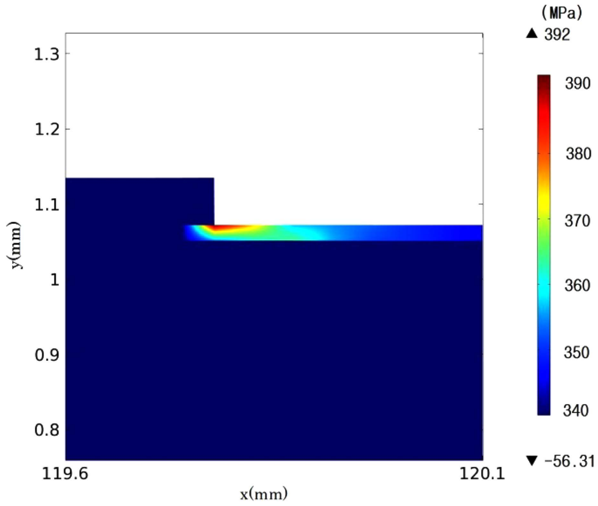

Fig. 4. Tensile stress concentration of SOFC due to rising temperature.

Fig. 5 shows the behavior of a maximum σ_{xx} stress by varying the thickness of the electrolyte which is vulnerable spots when the operating temperature rises from room temperature to 800°C. The maximum σ_{xx} stress decreases according to the increase of thickness of electrolyte and vice versa. Although the changing rate of thickness varies from -50% to 50% for the electrolyte thickness 0.02 mm (Fig. 1) the maximum stresses vary just in $0.95 < \frac{\sigma_{xx}^{max}}{\sigma_{0.0(2)}} < 1.06$. Therefore, to change the thickness of vulnerable electrolyte has little effect on stresses

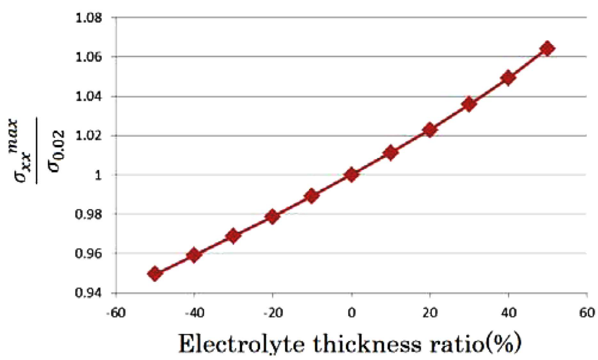

Fig. 5. The percentage stress variance ratio for the thickness change (0% : t=0.02 mm).

variation. Thus, determining the strength performance of SOFC, it is inadequate process to change the thickness for the electrolyte considering structural damage. Therefore, when choosing the fabrication condition of SOFC, considering structural damage, it can be determined just considering the electronic and chemical effects because the stresses by changing thickness can be ignored. The thickness of a electrolyte is suggested to be reduced because it can have better characteristics of electric power if reducing the thickness. When the thickness of electrolyte is thinner passing tracks of O^{-2} ion is shorter and it reduces ohmic resistance and polarization resistance. However, because maximum stresses is higher than maximum flexural bending strength. It's necessary to give supplementary solutions.

4. Conclusions

In this work, thermal stresses of planar anode supported SOFC by rising temperature are investigated. The stress is concentrated at the corner of an electrolyte and it is higher than flexural bending stress. Therefore, the damage on the vulnerable electrolyte may be considered for a structural stability. And to change the thickness of vulnerability spot have little effect on the stress. It has an advantage of increasing characteristics of electric power by reducing the thickness of vulnerability spot. However, it seems difficult that getting the stability with thinner thickness of an electrolyte. The obtained results follow as

(1) The maximum thermal tension stress occurs in an electrolyte(8YSZ) with 392 MPa. It is higher than flexural bending strength of 279 MPa

(2) Varying the thickness of vulnerable spot, electrolyte, the maximum stress increased, as 4.59% or decreased as –5.71%.

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