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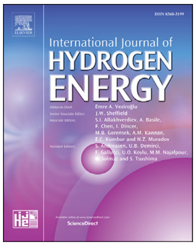

Effect of operating temperature on creep and damage in the bonded compliant seal of planar solid oxide fuel cell

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ABSTRACT

This paper studies the effect of operating temperature on creep and damage in bonded compliant seal of solid oxide fuel cell by finite element method. A strain based creep damage model is used, and its feasibility to predict the creep damage behavior of the materials is verified firstly by the experimental data. The results show that the failure locates at the foil and the location varies with the temperature increasing. When the temperature is lower than 600 °C, there is nearly no crack occurs. When the temperature is 600 °C, the creep crack belongs to internal crack and the length is about 2.5 mm. While the temperature is 650 °C or higher, the crack locates at the foil surface and the length is larger than 25 mm at an operation time of 50,000 h. Compared to the size of the whole structure, an internal crack of 2.5 mm is small and the gas leakage will not happen. Therefore, it can satisfy the requirement of safe operation for more than 40,000 h. Thus, it recommends that the operating temperature should not be higher than 600 °C on the condition of insuring the power performance and operation cost of the SOFC.

Introduction

Fuel cell, which can covert the chemical energy between the hydrogen and oxygen directly into electricity with fuel flexibility and high efficiency, is considered as one of the important renewable energy sources in future. Compared with the others high-temperature fuel cells such as molten carbonate fuel cell and Phosphoric acid fuel cell, solid oxide fuel cell (SOFC) is the most widely developed power generation device due to its higher energy conversion efficiency, more flexibility of the fuel as well as the more versatility of electrolyte [1,2]. Therefore, the utmost research interest of the fuel cell throughout the word has mainly focused on the solid oxide fuel cell. For the solid oxide fuel cell, two types of the planar SOFC and tubular SOFC are categorized according to its geometrical shape [3]. The seal performance of the tubular SOFC is superior to that of the planar SOFC, so the tubular SOFC is assessed to be more safety than planar SOFC. However, the output power density of the planar SOFC is much higher than that of tubular SOFC. Besides, the planar SOFC is

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easier to fabricate than the tubular SOFC [4]. Therefore, the planar SOFC has received much attention in recent years. The power of the single planar SOFC is limited, in order to meet the industrial power requirements, a SOFC stack which piled up in series by many single SOFC is needed to provide a higher working power [5,6].

Long-term reliability is a key prerequisite for the commercialization of the SOFC. The least required life time of the SOFC stack should be longer than 40,000 h with power loss of less than 10% [7–9]. For the long term operation of the SOFC, keeping the chemical performance stability of the cell materials is one of significant influencing factors, and the cathode poisoning caused by the chromium or silica [10] is seen as the dominant factor of the SOFC performances degradation. For the cathode poisoning, Blum et al. [11] used a two-layer short solid oxide fuel cell stack to evaluate its life time and long term stability at 700 °C. The results show that the continuous operation time can reach to 70,000 h, but the average voltage degradation is 0.6% per 1000 h, which exceeds the requirement of the minimum power loss. Based on the experience with other stack and cell tests, they concluded that cathode poisoning caused by the chromium diffusion from the interconnection material to cathode is the main reason for the power degradation. When the atmospheric plasma-sprayed protective layer has been introduced to the air side of the interconnector plate, which can reduce chromium evaporation to almost zero, the average voltage degradation of the SOFC has been reduced greatly. This demonstrates that the introduced atmospheric plasma-sprayed protective layer technology has the potential to solve cathode poisoning problem.

The other important factor that affecting the long term operation stability is the seal between the cell and interconnect. For the planar SOFC stack, the interconnect which located between the two single SOFC, is an important component that act as a bipolar gas separator contacting the anode and the cathode of the two adjoining cells. And it also provides the mechanical support and electrical connections between the two adjacent single SOFC [12]. The robust joining and sealing are demanded between the SOFC and interconnect to bond the stack and avoid the mixing or leakage of gases between the cathode and anode compartments. Usually, the operating temperature of the SOFC is about 600–1000 °C [1,4], Therefore, it places high mechanical performances stability demands on the interconnect and sealing materials. Once the mechanical properties of the component material declined, the gas leakage between the cells and interconnects will occur, and thus the power output of the SOFC will be seriously affected. The interface of the cells and interconnects can easily be detached by the subjected stress and the creep deformation of the materials [13,14], the detachment of the cells and the interconnects would cause the gas leakage of the SOFC, so the power degradation of the SOFC would be severely impacted. On about the seal of the planar SOFC, rigid seal and the compressive seal are the main two sealing methods. For the rigid seal, it is used the glass or glass-ceramic to join the cells and interconnects by the sintering technology. Although the sealing performance of rigid seal is well, large thermal stress has been generated due to the mismatch properties of the sealant and the other components [15]. So the failure of the rigid can be easily found. The compressive seal is a method that the sealant is compressed by the external force. The compressive seal allows the contacted surface to slide with each other while maintaining a good gas seal [15]. The materials choose of this sealing method is wider than that of the rigid seal, but the gas leakage also easily occurs since the creep deformation can cause the abnormal concentration of stresses in the seal materials or the SOFC components. In recently years, a sealing method name bonded compliant seal (BCS) is proposed [16], which incorporated the advantages of both rigid and compressive methods [17–19] by using a thin foil metal to bond the interconnect and cell through brazing technology. It has been proved that this method can decrease the thermal stress and deformation in the cell by ‘trapping’ much of stress as elastic or plastic strains within the sealing foil and thus increase the life of SOFC stack [20].

However, the BCS structure of the planar SOFC is composed by the multi-layer materials, the thermal stresses caused at the operating process combined with the as-brazed residual stress can greatly affect the life of the planar SOFC stack due to the formation of cracks [21]. Meanwhile, in the long term operation process, creep and damage also can cause the cracks. For the operation of the SOFC, there exist a competition between the stress and creep deformation. With the temperature rising, the thermal stress decreases due to the yielding phenomenon of the materials. However, the creep and damage behaviors of the materials become more and more dominant, and thus requires the higher strength materials. Therefore, the choice of sealing material is strictly restricted. Lower the operating temperature of planar SOFC is possible by decreasing its electrolyte thickness [22], but the expensive catalyst is needed in order to insure the normal operation of the SOFC. Thus, the operation cost of the SOFC will be increased. In the current study on about the high temperature structural integrity of SOFC, only the thermal stress [21], creep deformation [23] and damage [24] at a certain operating temperature are concentrated. In our previous study [24], we discussed the effect of the brazing filler metal thickness on the creep and damage of the SOFC with bonded compliant seal. The results show that reducing the brazing filler metal thickness can decrease the damage of the whole structure. However, how the different operating temperatures can affect the creep damage evolution of the planar SOFC is still unclear, and an optimal operation temperature of the SOFC stack from the viewpoint of the high temperature integrity is needed to determine.

Since the SOFC operate at high temperatures and its scale is tiny, experimental study on stress and creep damage in the planar SOFC is difficult. To develop such a performance analysis, a finite element program was carried out by ABAQUS to evaluate the creep and damage behaviors of the BCS structure. The temperature of 600, 650, 750, and 800 °C were adopted in present paper to discuss the effect of operating temperature on creep and damage of the planar SOFC, and then to suggest an optimal operating temperature from the view of creep and damage evolution.