Journal of Power Sources 243 (2013) 913–918

Contents lists available at SciVerse ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

Creep analysis of solid oxide fuel cell with bonded compliant seal design

Wenchun Jiang [a,*], Yucai Zhang [b], Yun Luo [a], J.M. Gong [c], S.T. Tu [b]

[a] State Key Laboratory of Heavy Oil Processing, College of Chemical Engineering, China University of Petroleum (East China), Qingdao 266555, PR China
[b] Key Laboratory of Pressure System and Safety (MOE), School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai 200237, PR China
[c] School of Mechanical and Power Engineering, Nanjing University of Technology, Nanjing 210009, PR China

HIGHLIGHTS

- Thermal stress induced creep in the SOFC with the BCS design is calculated.
- BCS design can decrease the thermal deformation by using creep effect.
- The failures would initiate at the middle of the cell edge and BNi-2.

ARTICLE INFO

Article history:
Received 31 January 2013
Received in revised form
13 June 2013
Accepted 13 June 2013
Available online 25 June 2013

Keywords:
Planar solid oxide fuel cell
Bonded compliant seal
Creep
Thermal stress

ABSTRACT

Solid oxide fuel cell (SOFC) requires good sealant because it works in harsh conditions (high temperature, thermal cycle, oxidative and reducing gas environments). Bonded compliant seal (BCS) is a new sealing method for planar SOFC. It uses a thin foil metal to bond the window frame and cell, achieving the seal between window frame and cell. At high temperature, a comprehensive evaluation of its creep strength is essential for the adoption of BCS design. In order to characterize the creep behavior, the creep induced by thermal stresses in SOFC with BCS design is simulated by finite element method. The results show that the foil is compressed and large thermal stresses are generated. The initial peak thermal stress is located in the thin foil because the foil acts as a spring stores the thermal stresses by elastic and plastic deformation in itself. Serving at high temperature, initial thermal displacement is partially recovered because of the creep relaxation, which becomes a new discovered advantage for BCS design. It predicts that the failures are likely to happen in the middle of the cell edge and BNi-2 filler metal, because the maximum residual displacement and creep strain are located.

1. Introduction

Planar solid oxide fuel cell (SOFC) is a clean energy conversion device which converts chemical energy into electrical energy directly by an electrochemical reaction [1]. But SOFC has not achieved large-scale commercialization because of its reliability and durability problems [2]. An important issue is the sealing technology due to operating at a harsh environment and high temperature [3]. It needs a good hermetic sealant to prevent the leakage of air and fuel, and effectively isolate the fuel from the oxidant.

There are two main types of seal: rigid seal and compressive seal [4]. For the rigid seal [5,6], metal, glass or glass–ceramic can be used to bond the components. But they are brittle and cracks will be generated after some thermal cycles. Silver or gold can be used for metal braze but they are too expensive. Now the researchers are trying to develop innovative self-healing glasses which can effectively heal the cracks during thermal cycling [1,7,8]. In recent years, F. Smeacetto et al. [9–14] have made great progress in life extension by designing several new composite sealants to produce a hermetic joint between the ceramic and metallic components. For the compressive seal [15–17], a compressive load is applied on SOFC stack to keep the tightness by using metals or mica-based composites as sealants. It doesn't bond the SOFC components rigidly together, but the applied load can be relaxed by creep, leading to the generation of leakage. In order to solve these problems, a third method named bonded compliant seal (BCS) has been developed

* Corresponding author. Tel./fax: +86 532 86983482.
E-mail addresses: jiangwenchun@upc.edu.cn, jiangwenchun@126.com (W. Jiang).

0378-7753/$ – see front matter Crown Copyright © 2013 Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jpowsour.2013.06.096

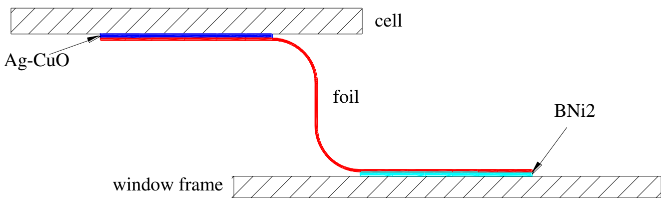

Fig. 1. The cross section of the BCS structure in planar SOFC.

by Weil et al. [18], which combines the advantages of both rigid and compressive seals. If the BCS method is proven to meet the stringent long-term operating requirements, it can be a good solution to the seal problem for SOFC applications.

In order to realize the use of BCS method, it is necessary to evaluate its mechanical performance and structure integrity [19–22], such as thermal stresses, residual stresses, creep and fatigue, etc. Weil et al. [23,24] performed a comparative finite element analysis of the stress–strain states in three different seal designs for SOFC, and found that the BCS design can accommodate a significant degree of thermal mismatch strain between the metallic support structure and the ceramic cell, and the thermal stresses in BCS design are much lower than those in glass–ceramic and brazed designs. Jiang and Chen [25] performed thermal stress analysis for an operating planar SOFC with BCS design by a thermo-electrochemical-structure model, and found that the thermal stress in the cell is relatively lower with a lower voltage, while the contribution of the temperature gradient to the thermal stress is higher. Jiang et al. [26] found that the Al_2O_3 protective film can generate a compressive stress on the surface of the foil. Jiang et al. [27,28] also investigated the as-bonded residual stress in planar SOFC with BCS design, and the effects of window frame material type, sealing foil thickness, filler metal thickness and window frame thickness on residual stresses have been discussed. The components of BCS design have different coefficients of thermal expansion (CTE), resulting in thermal stresses. The generated thermal stresses will induce creep deformation at high temperature [29]. Chiu and Lin [30] studied the thermo-mechanical fatigue properties of a ferritic stainless steel interconnect, and found that creep and creep–fatigue interaction are the two primary contributors to the fatigue damage. Therefore, a comprehensive analysis of creep behavior is necessary for evaluating the structural integrity of a planar SOFC with BCS design. In recent years, the creep study on SOFC are mainly focused on the interconnect [31], electrolyte [32], glass–ceramic seal materials [33], but little attention has been paid on BCS design. In this paper, creep analysis has been carried out to a planar SOFC with BCS design, which can provide a reference for the creep design.

2. Finite element creep analysis

2.1. Finite element model

Fig. 1 shows a cross section of the BCS structure in a planar SOFC. An S-shaped sealing foil is bonded to the cell and window frame by silver-based filler metal (Ag–4%CuO) and BNi-2 filler metal, respectively, which achieves the seal between cell and window frame. The materials of the foil and window frame are FeCrAlY and Haynes214, respectively. Their chemical compositions are listed in Tables 1–3, and mechanical strength is listed in Table 4.

At high temperature, thermal stresses will be generated because of the mismatching of CTE and subsequently induce creep

Table 1
Chemical composition of FeCrAlY (in wt%).

Fe	Cr	Al	Y	Mn	C	Si
≥69.62%	22%	4.8%	0.3%	≤0.04%	≤0.08%	≤0.70%

Table 2
Chemical composition of Haynes214 (in wt%).

Fe	Ni	Cr	Mo	Si	Mn	C	Co	B	P	Y	Zr
3	75	16	0.5	≤0.2	≤0.5	0.05	2	≤0.001	0.01	0.01	≤0.1

Table 3
Chemical composition of BNi-2 (in wt%).

C	Si	Mn	S	P	Cr	B	Ni	Fe	Mo
0.06	4.50	–	–	–	7.00	3.10	82.34	3.00	–

Table 4
Yield strength (20 °C) [23].

Material	FeCrAlY	Ag–4%CuO	BNi-2	Haynes214
Yield strength (MPa)	300	340	300	600

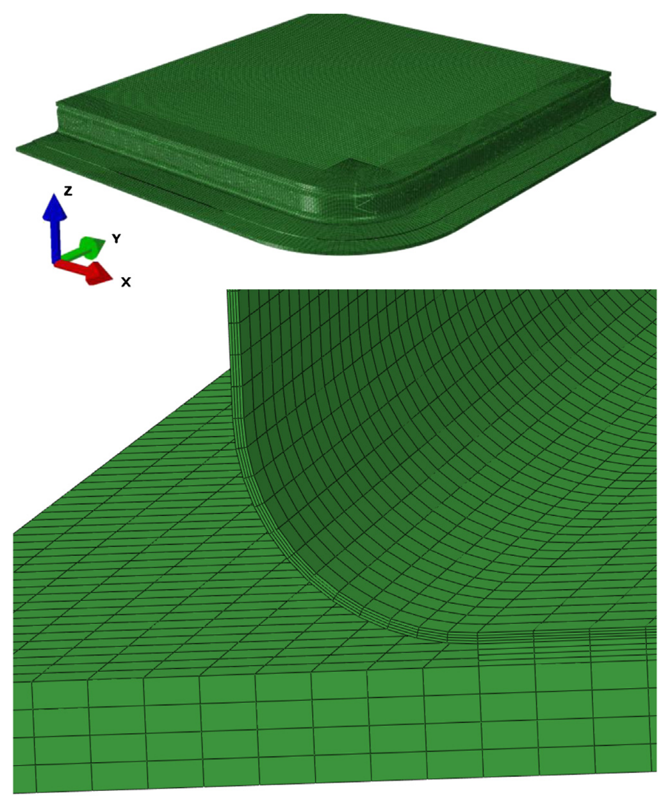

Fig. 2. Finite element meshing.

Table 5
Creep parameters (600 °C) [31,35–38].

Material	B (MPa^{-n} s^{-1})	n
FeCrAlY	2.251×10^{-29}	5.5
Haynes214	7.948×10^{-26}	6.896
BNi-2	2.431×10^{-43}	14.75
Ag–4%CuO	1.955×10^{-11}	1.867
Cell	2.64×10^{-11}	1.7