行政院原子能委員會
委託研究計畫研究報告

研究 SOFC 電池堆熱應力分析
及實驗量測

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受委託機關（構）：國立中央大學
計畫主持人：林志光 教授
核研所參與人員：江烈光、邱耀平
聯絡電話：03-4267340
E-mail address：t330014@cc.ncu.edu.tw
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摘要

固態氧化物燃料電池（SOFC）由陶瓷材料的陽極、電解質、陰極所組成（通常稱為 PEN），因為在高溫下運作，使得 SOFC 相較於其它燃料電池擁有最高的效率。然而，SOFC 在高溫下運作會因為熱膨脹係數不匹配以及溫度梯度而產生明顯的熱應力，因此，對於一個可靠的 SOFC 設計及運作而言，完整的 SOFC 熱應力分析是必要的，而本研究的目的就是利用有限元素模擬軟體來分析平板式SOFC在暫態及穩態運作時的熱應力分佈。

首先，利用電化學及熱傳分析產生含三層單元電池之 SOFC 電池堆在各個啟動及穩態階段的溫度分佈圖，然後將這些獲得的溫度場輸入此 3-D 三層電池堆的有限元素模型中，每個單元電池基本上都包含了 PEN、金屬連接板、鎳網以及封裝玻璃陶瓷。在以往的研究中，封裝玻璃陶瓷的結構功能並未被考慮，因此，為了提供更接近實際情況的熱應力分析結果，本研究所建立之三層電池堆有限元素分析模型將包含玻璃陶瓷，特別是將探討玻璃陶瓷黏滯行為對電池堆熱應力分佈的影響。除此之外，亦將探討電池堆支撐條件、溫度梯度、週期運作以及組件間熱膨脹係數差異的影響。模擬結果顯示，在給定的三種不同電池堆支撐條件下，熱應力分佈的差異並不大。在三層電池堆中，各個單元電池的熱應力分佈並沒有明顯的差異，這可以歸因於垂直於面板方向的溫度梯度並不明顯。藉由考慮玻璃陶瓷在高溫時的黏滯特性，模擬結果顯示 PEN 及玻璃陶瓷在工作環境溫度下皆有應力鬆弛的現象。模擬週期運轉對熱應力影響的運算結果顯示，PEN 及封裝玻璃陶瓷的熱應力將隨著運轉週期數的增加而有明顯的增加。在熱膨脹係數影響方面，由於金屬連接板與框架占了 SOFC 電池堆大部分的體積，其熱膨脹行為對於 PEN 板所產生之熱應力的影響較封裝玻璃陶瓷來得大。

Abstract

Solid oxide fuel cells (SOFCs) utilize ceramics as the anode, electrolyte, and cathode (often called a positive electrode-electrolyte-negative electrode, PEN) and operate at high temperatures such that they have the highest efficiencies of all fuel cells. The high-temperature operation, however, gives rise to significant thermal stresses caused from the mismatch of coefficient of thermal expansion (CTE) and temperature gradients in the SOFC system. Therefore, a comprehensive thermal stress analysis of SOFC stack is necessary for the success in design and operation of a SOFC system. The aim of this study is, by using finite element simulation, to characterize the thermal stress distribution in a planar SOFC stack during transients and steady operation.

An integrated electrochemical and thermal analysis was first conducted to generate the temperature profiles in a 3-cell SOFC stack during various start-up and steady stages. The obtained temperature fields within the cell stack were subsequently applied to a thermal stress analysis using a 3-D finite element model of a 3-cell stack. Each unit cell consists basically of a PEN assembly, interconnect, nickel mesh, and gas-tight glass-ceramic seals. Incorporation of the glass-ceramic sealant, which was never considered in other previous studies, into the 3-cell FEA model would produce more realistic results in thermal stress analysis. In particular, the effect of viscous behavior of glass-ceramic sealant on thermal stress distribution within the cell stack was investigated. In addition, the effects of stack support condition, temperature gradient, cyclic operation, and CTE mismatch between components were also characterized. Modeling results indicated that a change in the support condition at the bottom frame of the 3-cell stack would not cause significant changes in the thermal stress distribution. Thermal stress distribution did not differ significantly in each unit cell within the 3-cell stack due to a negligible out-of-plane thermal stress gradient. By considering the viscous characteristics of glass-ceramic sealant at temperatures above the

glass-transition temperature (T_g), relaxation of thermal stresses in PEN and glass-ceramic sealant was predicted. Effect of operating cycles on the variation of thermal stress was also simulated and the results indicated that a significant increase in thermal stress in PEN and glass-ceramic sealant would be expected with increasing cycle number. The thermal expansion behavior of metallic interconnect and frame had a greater influence on the thermal stress distribution in PEN than did that of glass-ceramic sealant due to the domination of interconnect/frame in the volume of a planar SOFC assembly.