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Selection of container materials for modern planar sodium sulfur (NaS) energy storage cells towards higher thermo-mechanical stability

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ABSTRACT

Sodium sulfur (NaS) cell is recognized as a promising candidate for advanced grid-scale large energy storage systems (ESS). In this work, we study the impacts of planar NaS cell container materials on the accumulation of residual stresses in the cell joints and solid electrolyte during the cell assembly and operation processes. Concentration of such thermo-mechanical stress in these vulnerable areas in the modern NaS cells can lead to catastrophic cell failures, which can present a huge challenge for developing large planar NaS cells towards commercial deployment. Here, we employ the finite-element analysis (FEA) computational technique to quantitatively assess the thermo-mechanical stress accumulation using prototype planar NaS cells. Relevant experimental procedures with corresponding thermal cycling conditions for the cell assembly, operation, and maintenance processes are incorporated into the FEA model. The influences of Al alloy (Al3003), stainless steels (STS304 and STS340), and iron-nickel-cobalt superalloy (KOVAR) on the residual stress accumulation are tested and thoroughly discussed. The computation results show that high stress concentration can be developed in the cell joint area. Through the comprehensive computational analysis, it is suggested that applying smaller CTE (less than $\sim 12 \times 10^{-6}\,K^{-1}$) alloys is necessary to secure the thermo-mechanical stability of NaS cells that can be implemented in a large scale ESS.

1. Introduction

Sodium (Na) β/β”-alumina batteries (NBB) have become increasingly recognized as one of the most promising contenders for large-scale energy storage systems (ESS) due to their high theoretical specific energy, high energy efficiency, low cost of raw materials, and long lifespan [1–11]. The NBB system generally consists of a molten sodium anode, a β/β”-alumina solid electrolyte (BASE), and a cathode compartments. Depending on the cathode chemistries, NBB is typically classified into two types, i.e., NaS and Na metal-halide ($Na/NiCl_2$ or $Na/FeCl_2$) cells. Because the active anode Na materials must be maintained in their molten states, the cell operation temperatures of these NBB are relatively high (e.g., 300–350 °C for NaS and 270–300 °C for Na metal-halide chemistries, respectively). Out of these two types of NBB, the NaS cell utilizes molten sulfur (S) as its cathode materials that can endow high theoretical specific energy ($760\,Wh\,kg^{-1}$), high theoretical energy density ($2584\,Wh\,l^{-1}$), and very high theoretical specific capacity ($1675\,Ah\,kg^{-1}$) [5]. The cell reaction occurs in an NaS system is described by [12],

$$\underset{\text{(charged state)}}{xS + 2Na} \rightleftharpoons \underset{\text{(discharged state)}}{Na_2S_x(x = 5-3)}, E = 2.08 \sim 1.78\text{ V at }350^{\circ}C \quad (1)$$

Contemporarily, this NaS cell technology is broadly available for grid-scale applications. NGK (NGK Insulators, Ltd.) has delivered NaS battery systems at approximately 200 sites worldwide, accounting for a total output of 530 MW and a storage capacity of 3700 MWh since its commercialization in 2002 [13]. In addition to the successful product-realization of NGK, other efforts to develop advanced NaS cell systems have been continuously exerted in recent years [14–21]. For commercial deployment of practical NBB systems, two cell shapes (i.e., tubular and planar cells) have been commonly suggested. Representative NaS cell geometries of these two shapes are provided in Fig. 1 (fabricated at RIST, South Korea). The distinct advantages of the planar design over the tubular design may include the easiness for stacking, direct inter-cell connection without any external connectors, lower manufacturing cost, elimination of the orientation and gravity effects, larger active area of BASE per unit weight of the cell, high

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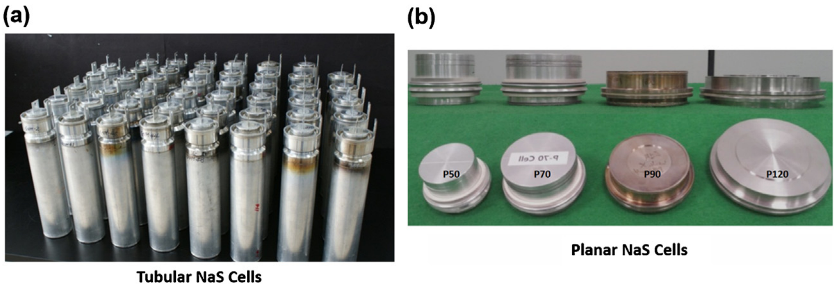

Fig. 1. Representative NaS cell shapes of (a) tubular and (b) planar designs.

possibility of applying a thinner solid electrolyte with higher ionic conductivity, easiness for post-analysis for cell components, and so forth [5,22]. Moreover, it was reported that the electrochemical performance from a planar NaS cell is much more stable than that from a tubular cell because of the cathode geometry [23]. As such, relatively small planar NBB with a typical BASE disk diameter in the range of 10–50 mm have been widely studied for various research purposes, from developing electrode materials/structures to testing new cell chemistries [6–11]. However, to provide a competitive specific energy, it was suggested that the diameter

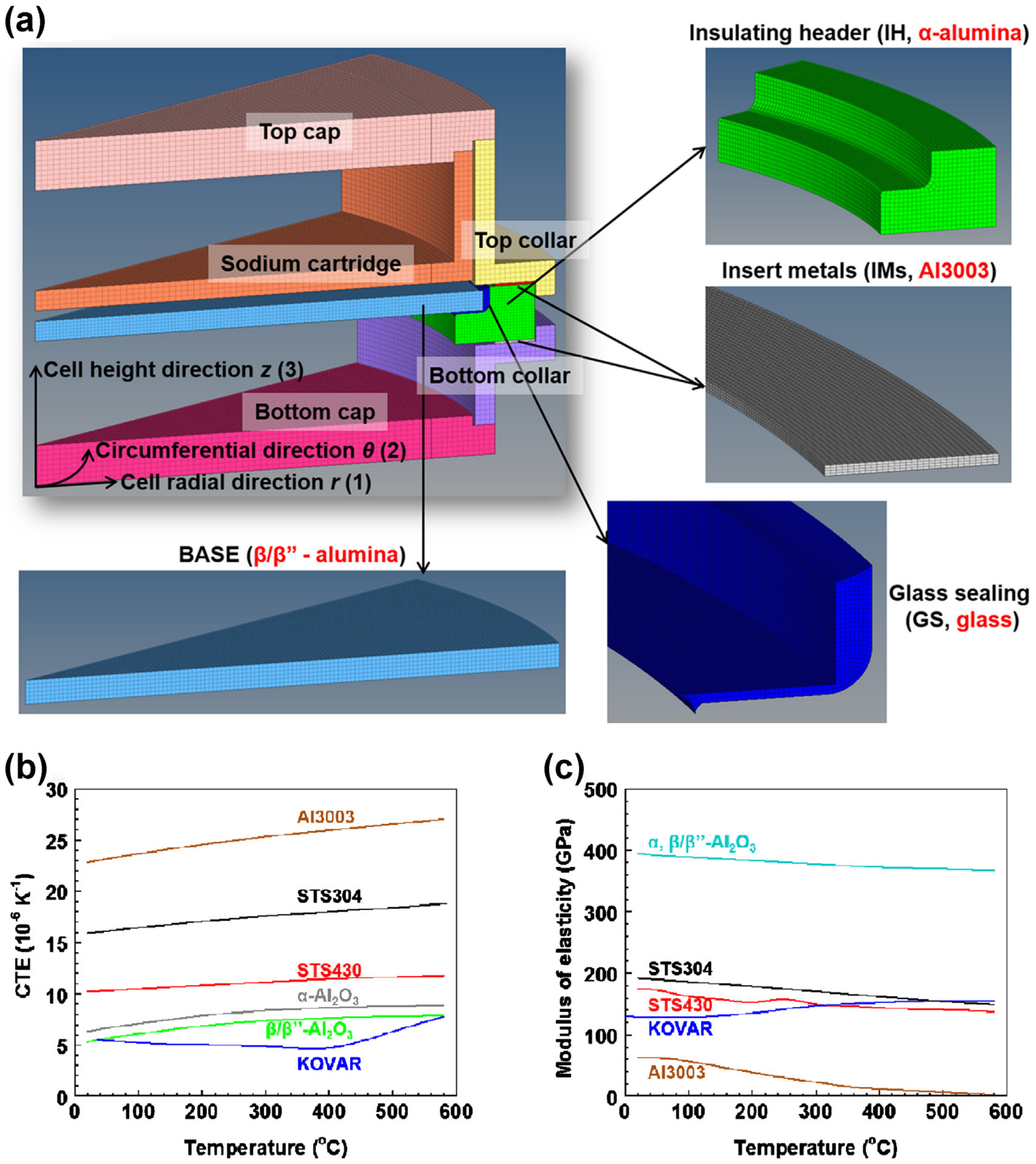

Fig. 2. (a) Cross-sectional structure of a planar prototype NaS cell, and (b) CTE and (c) elastic modulus variations with temperatures for cell container and α-, β/β"-alumina materials.