Doctoral Dissertation
Doctoral Program in Materials Science and Technology (37th Cycle)

Joining and Integration Solutions for High-Temperature Sodium-Zinc Batteries:

Design, Optimization, and Performance Analysis

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Abstract

The development of efficient, reliable, and durable sealing materials for sodium-zinc (Na||Zn) batteries is crucial for advancing energy storage technologies. This thesis investigates and optimizes sealing solutions to address the challenges associated with high-temperature battery operation, focusing on active brazing and glass-based sealants. The study investigates the thermochemical interactions, mechanical stability, and corrosion resistance of components joined using different joining techniques, aiming to improve battery performance and durability.

This work was carried out within the framework of the SOLSTICE project, which aimed to develop two different Na||Zn battery technologies: the Solid Electrolyte Cell (SEC) and the All-Liquid Cell (ALC). These technologies were designed to offer cost-effective and sustainable alternatives for large-scale stationary energy storage.

Active brazing alloys, particularly TiZrCuNi systems, were evaluated for their suitability in high-temperature environments. While these materials exhibited good wettability and mechanical adhesion, they demonstrated limitations in long-term oxidation resistance. This prompted a shift towards glass-based sealing solutions, which offer enhanced chemical stability and compatibility with ceramic and metallic substrates.

A major achievement of this research was the formulation and optimization of glass-alumina composite sealants. These materials were specifically designed to minimize thermal expansion mismatches, thereby reducing mechanical stresses at the interfaces. Additionally, surface treatment techniques, including controlled oxidation of metallic substrates, were employed to enhance the adhesion and durability of the seals. Experimental validation included thermal cycling tests, mechanical stress evaluations, and corrosion assessments, all of which confirmed the superior performance of the developed sealing materials.

Industrial scalability was a key consideration in this study. The adoption of advanced deposition techniques, such as robocasting, ensured precise and repeatable application of sealant materials. This approach not only improved manufacturing

efficiency but also enhanced the overall reliability of the battery sealing process. Prototype Solid Electrolyte Cells incorporating the optimized sealants were subjected to extensive electrochemical testing, demonstrating stable performance across multiple charge/discharge cycles at elevated temperatures. Post-mortem analyses confirmed the integrity of the sealed joints, highlighting their potential for large-scale application.

The findings of this thesis make a significant contribution to the fields of materials science and battery technology by establishing a comprehensive methodology for de-signing and implementing high-performance sealing solutions. The research highlights the benefits of glass-based sealants over traditional brazing techniques, offering insights into their practical integration into commercial battery manufacturing processes.

Future work should focus on further enhancing the long-term durability of the developed materials under real-world conditions, as well as investigating alternative glass compositions with superior chemical resistance. Ultimately, the advancements achieved in this study pave the way for more economically viable sodium-zinc battery systems, supporting the transition towards sustainable energy solutions.