

PROCEEDINGS

Study on Micro-Macro Multi-Scale Numerical Simulation of Electrode Drying in Lithium-Ion Batteries

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ABSTRACT

Drying represents a critical manufacturing process for lithium-ion battery electrodes. Fundamentally, this process involves strong multi-scale coupling between macroscopic heat and mass transfer and the dynamic evolution of microscopic pore structures. Nevertheless, most existing investigations remain confined to a single spatial scale, hindering the establishment of direct quantitative relationships among the drying process and microstructure evolution. This work develops a micro-macro multi-scale numerical model for electrode drying, with the objective of uncovering the cross-scale transport mechanisms underlying solvent migration during drying. At the microscopic scale, a coupled particle adsorption-pore topology model is established based on the pore network method, allowing for the realistic reconstruction of the complex pore structure and pore-throat network within the porous electrode. At the macroscopic scale, a multiphysics transport model is formulated by coupling the porous medium domain and the free air-flow domain within the framework of porous media theory. A suitable Arrhenius-type formulation is adopted to determine the effective moisture transport coefficient, with reference to the dry-basis moisture content reduction curve simulated using the pore network model. The response surface methodology is subsequently applied to quantify the effects of key pore structural parameters on the effective moisture diffusion coefficient, and a highly generalized predictive correlation is derived. Through a lumped parameter homogenization strategy, the effective moisture transport coefficient obtained from microscopic pore-scale simulations is upscaled and equivalent to the effective moisture diffusion coefficient in the macroscopic governing equations, thereby realizing cross-scale bridging and two-way coupling between microscopic and macroscopic models. The multi-scale model is employed to systematically investigate the influences of process parameters on macroscopic drying kinetics and internal transport characteristics. Results demonstrate that microscopic pore structure uniformity directly governs the effective moisture diffusion coefficient: a smaller pore-size variance corresponds to enhanced moisture transport efficiency. With increasing drying temperature, the migration time of conductive additive particles is shortened while the fraction of immobilized particles rises, leading to deteriorated microstructural homogeneity. From a macroscopic viewpoint, the evolved microstructural features in turn feedback to affect the overall drying behavior. A uniform pore structure facilitates a stable constant drying-rate period and alleviates the occurrence of localized over-drying. The falling-rate period is identified as a critical stage governing the adsorption and distribution of conductive particles. Properly prolonging this period or moderately lowering the drying temperature can promote sufficient adsorption of conductive additives and improve the uniformity of the electrode microstructure.

KEYWORDS

Lithium-ion battery electrode; drying process; numerical simulation; heat and mass transfer

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