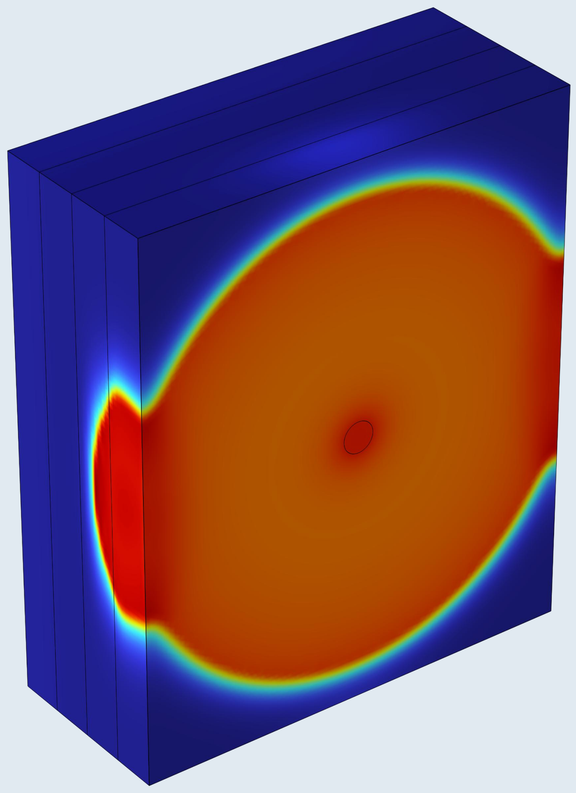


Reveal the Internal Heat Transfer of Sodium-ion Batteries under Nail Penetration Thermal Runaway

A novel three-region dynamic thermal model of internal short circuits (ISC) is developed, incorporating both pure Joule heating at 0% SOC and coupled Joule heating with side-reaction heat at 75% SOC.

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Abstract

Each of the four jellyrolls was divided into three regions: core layer, middle layer, and outer layer. Joule heating from an ISC was applied to the core layer as a time-varying heat source, and the concentration of side reactions was solved using domain-dependent ordinary differential equations, then converted into a heat source via the Arrhenius equation.

Simulations show that heat from ISC is concentrated in the first two jellyrolls, and the transition from net heat absorption to net heat dissipation occurs earlier—at 48 s at 75% SOC compared to 470 s at 0% SOC.

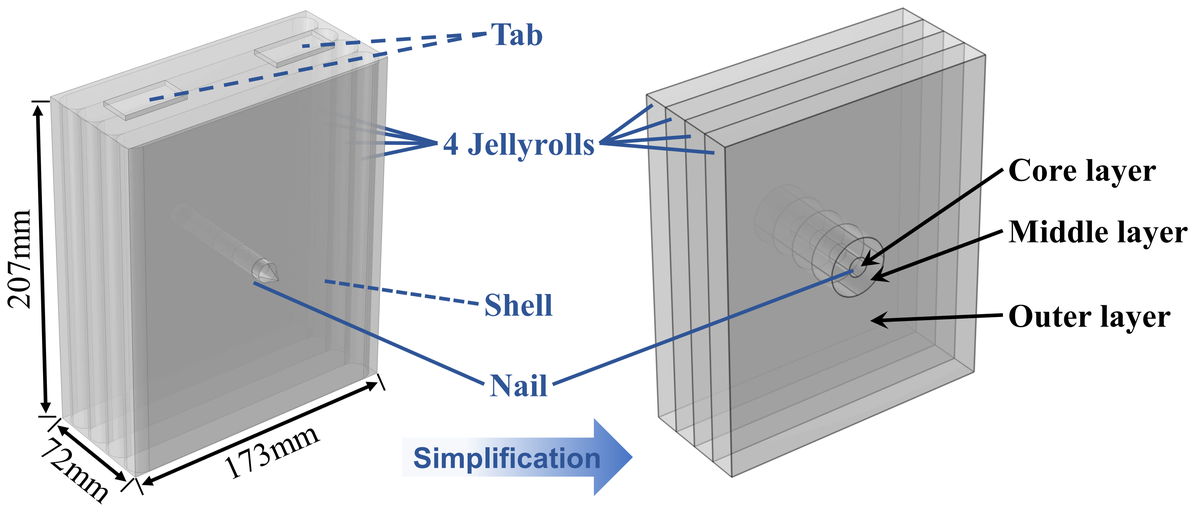


FIGURE 1. Three region model with battery divided into core layer, middle layer and outer layer.

Methodology

Governing equations:
$$C_p\rho_{core}\frac{\partial T}{\partial t}=q_{ohmic}+\lambda_x\frac{\partial^2 T}{\partial x^2}+\lambda_y\frac{\partial^2 T}{\partial y^2}+\lambda_z\frac{\partial^2 T}{\partial z^2}$$

Short circuit current:
$$I_{short}=\frac{U_{\exp}}{R_{short}}$$

Ohmic heat rate:
$$q_{ohmic,core}=\begin{cases}I_{short}^2R_{short}+\dfrac{V_{core}}{V_{cell}}I_{short}^2R_{cell} & r\le r_{nail}\\ \dfrac{V}{V_{cell}}I_{short}^2R_{cell} & r>r_{nail}\end{cases}$$

Side reaction rate:
$$R_{side,i}=-\frac{dc_i}{dt}=-A\cdot\exp\left(-\frac{E_a}{R\cdot T}\right)\cdot c_i$$

Results

The spatio-temporal evolution of the temperature distribution indicates that, at the moment the nail penetrates, Joule heat rapidly accumulates at the penetration point, forming a localized high-temperature core concentrated within the first two jellyrolls.

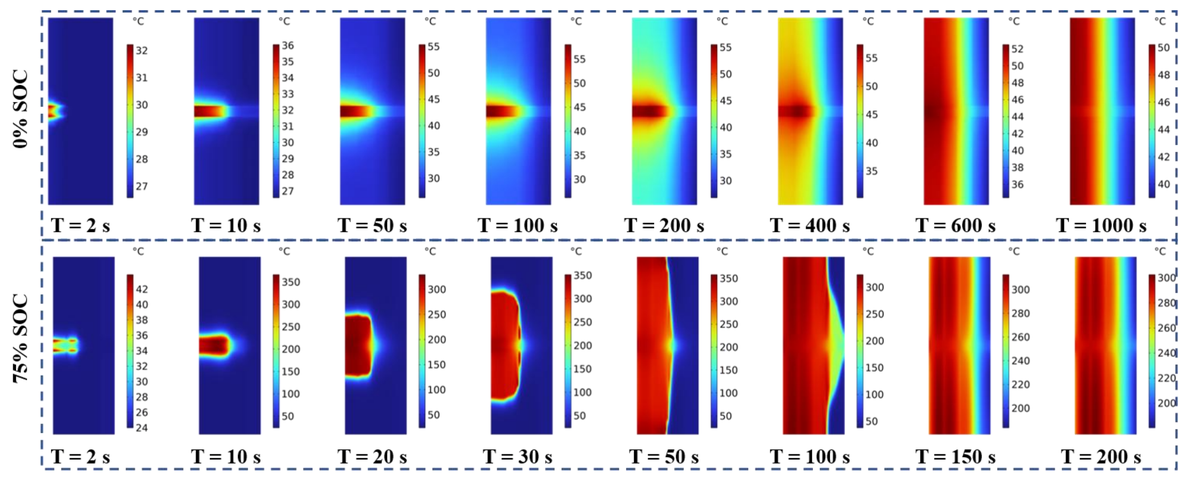


FIGURE 2. Internal temperature distribution in SIB under nail penetration.

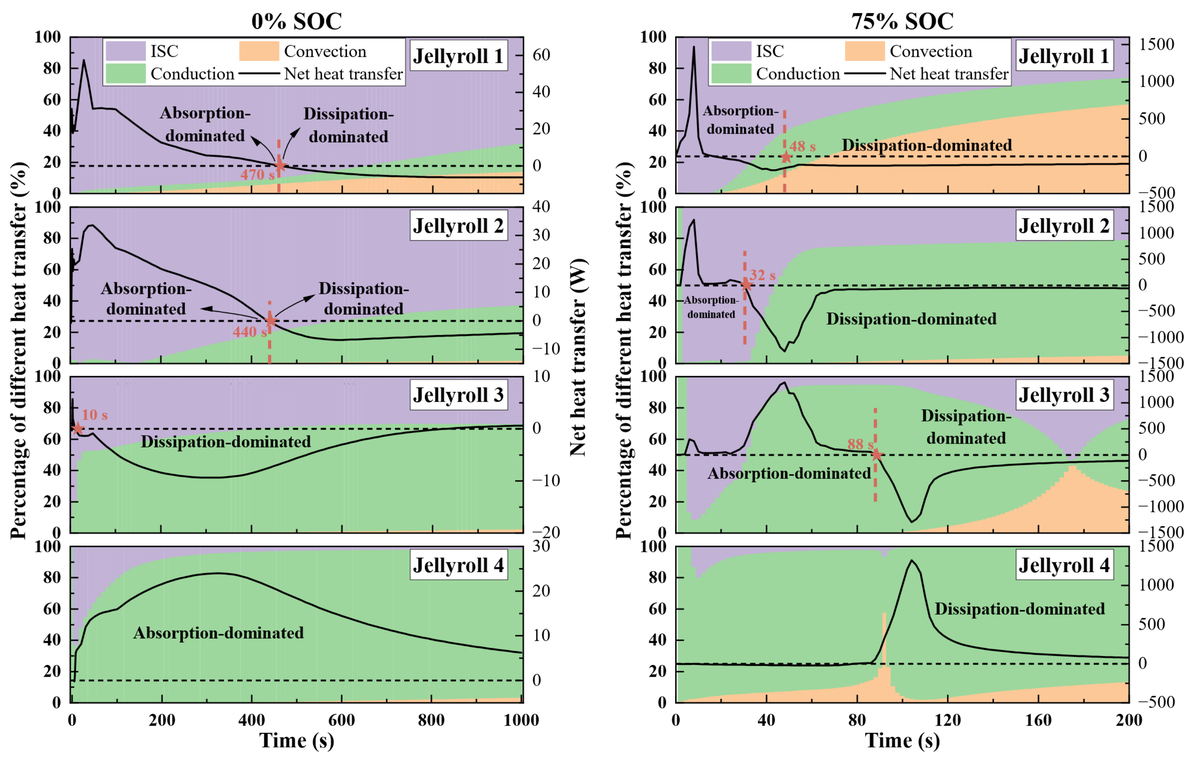


FIGURE 3. Heat transfer power and contribution of different heat transfer mechanisms among four jellyrolls during nail penetration.

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