A Study on Machine Learning -based Prediction of EV Thermal Runaway and Simulation of Thermal Runaway Prevention

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ABSTRACT

Lithium-ion batteries are widely used in electric vehicles due to their high energy density and long lifespan, offering superior performance compared to other battery types. However, the issue of thermal runaway propagation caused by internal short circuits remains serious safety problems. This study aims to mitigate thermal runaway by inserting thermal runaway prevention films between the cells of a 12-cell battery module and conducting simulations. The simulations were carried out to analyze the thermal runaway initiation time and temperature under different conditions, including film materials (mica, aerogel, polyurethane, carbon composite, glass fiber) and internal short circuit locations (front and side of the battery module). Additionally, machine learning models (Random Forest and LSTM) were developed to predict thermal runaway graphs based on the simulation data. The results indicate that when using carbon composite films, thermal runaway did not occur within 1,000 seconds when the short circuit was located at the side of the module, whereas it occurred at 950 seconds when the short circuit was at the front. The machine learning models demonstrated high accuracy, with the Random Forest model achieving a Mean Squared Error (MSE) of 0.0008. This study shows that simulation and AI-based approaches can effectively address complex challenges in battery safety and provide a reliable method for optimizing thermal management system designs in electric vehicle batteries.

KEY WORDS

Thermal Runaway propagation, Simulation, Prevention film, Machine learning

1. INTRODUCTION

With the strengthening of environmental regulations aimed at reducing carbon emissions, the adoption of electric vehicles (EVs) is increasing globally. Lithium-ion batteries, favored for their high energy density and long lifespan, are widely used in EVs but are prone to thermal runaway propagation caused by rapid temperature escalation due to external impacts or internal short circuits. To mitigate thermal runaway propagation, strategies such as air cooling, liquid cooling, phase change materials (PCMs), and thermal runaway prevention films have been explored. This study focuses on thermal runaway prevention films, which offer faster and more direct thermal control compared to other cooling systems. Simulations were conducted using five different film materials (mica, aerogel, polyurethane, carbon composite, glass fiber), modeling a battery module with prevention films inserted between lithium-ion cells. Internal short circuit scenarios were simulated using ANSYS Fluent, considering short circuits at both the front and side of the module. Thermal runaway initiation time, peak temperature, and propagation effects on 12 adjacent cells were analyzed to provide insights into the performance of different film materials and short circuit locations. Additionally, an AI-based prediction model was developed using the simulation data. Random Forest and Long Short-Term Memory (LSTM) were employed to predict thermal runaway graphs, with Mean Absolute Error (MAE) used to evaluate model performance. The proposed simulation and AI methods offer an efficient approach to addressing complex battery safety challenges and optimizing thermal management system designs.

2. METHOD AND SIMULATION

2.1 Battery modeling

In this study, the multi-scale multi-domain (MSMD) model provided by ANSYS Fluent is employed to simulate thermal runaway. The NTGK model is utilized as the electrochemical sub-model, and the thermal abuse model is applied. The battery cell is designed with a width of 145 mm, a height of 192 mm, and a thickness of 2 mm, while the thermal runaway prevention film is designed with a thickness of 2mm. [1]

2.2 Prevention film materials

The thermal runaway prevention film materials are set as polyurethane, carbon composite, aerogel, glass fiber, and mica. Simulations are conducted by changing the material to evaluate their effectiveness in preventing thermal runaway. [2]

Table 1 : Properties of prevention film materials

Material	Density [kg/m]	Cp [kg·K]	Thermal conductivity [W/m·K]	Electric conductivity [S/m]
Mica	2100	880	0.5	1E-15
Aerogel	180	502.3	0.018	1E-18
Polyurethane	1800	1800	0.02	1E-14
Carbon composite	180	1300	60	10
Glass fiber	1900	360.58 +1.49T	0.03	1E-11

2.3 Internal short circuit locations

To represent internal short circuits, which are the primary cause of thermal runaway, an external impact is assumed to create a spherical object with a radius of 0.01 m. The trigger cell is designated at both the front and side of the module, and simulations are conducted twice for each material.

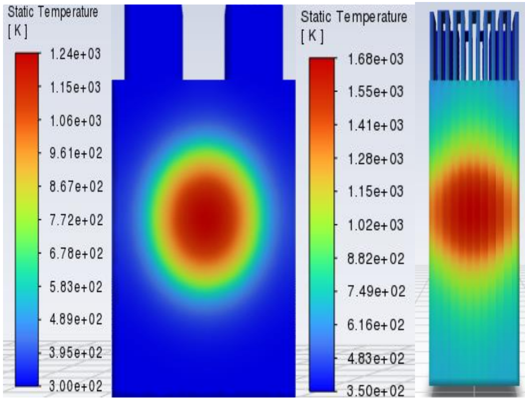

Fig.1 Internal short circuit locations: front and side

2.4 Machine learning model

In this study, thermal runaway data were collected based on different thermal runaway prevention film materials and internal short circuit locations. Using these data, machine learning models—Random Forest and Long Short-Term Memory (LSTM)—were developed to predict temperature variations in the battery module and each of the 12 cells, as well as the propagation reactions in neighboring cells. Random Forest is employed as an ensemble learning method, where multiple decision trees are constructed by randomly sampling the training data. The final outcome is determined through majority voting among the results of these decision trees. Random Forest offers high predictive accuracy for nonlinear data patterns such as those observed in thermal runaway, while effectively preventing overfitting. LSTM, a neural network model based on Recurrent Neural Networks (RNN), is applied to analyze time-series data. LSTM units are composed of three key components: the forget gate, input gate, and output gate. These gates allow relevant information from the input sequence to be selectively retained and remembered. Designed to prevent the loss of critical prior information, LSTM is particularly effective for handling large datasets and is well-suited for analyzing thermal runaway propagation, which requires capturing temporal changes.

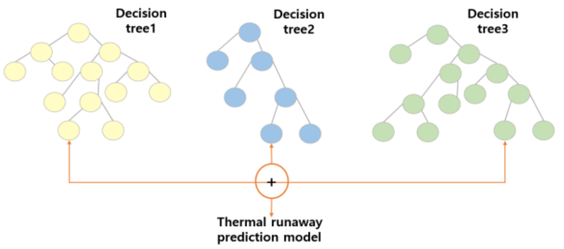

Fig.2 Diagram of random forest

The collected data were divided into 80% for training and 20% for testing to facilitate model training and validation. The performance of the two machine learning models was evaluated by comparing the simulation-based thermal runaway graphs with the predicted graphs using the Mean Absolute Error (MAE) as the evaluation metric. This approach enables a comparison of the models to determine which is more suitable for thermal runaway prediction.

CONCLUSIONS

The thermal runaway prevention simulation was conducted using a polyurethane thermal runaway prevention film, with the internal short circuit location set at the side of the module, and a Random Forest model was developed based on the results. As shown in Fig. 3, thermal runaway in the battery module begins at 537 seconds and 676 K. It was observed that the farther a cell is from Cell 6, where the internal short circuit occurs, the more delayed or even absent the onset of thermal runaway becomes. Notably, when using a carbon composite film, no thermal runaway occurred within 1,000 seconds when the internal short circuit was located on the side of the module, whereas thermal runaway was initiated at approximately 950 seconds when the short circuit was located at the front. The machine learning model demonstrated high accuracy, with the Random Forest model achieving a Mean Squared Error (MSE) of 0.0007, indicating a very low error rate.

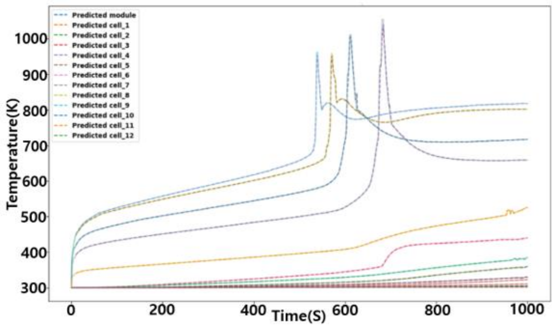

Fig.3 Predicted thermal runaway curves

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