USING MULTIPHYSICS TO PREDICT AND PREVENT EV BATTERY FIRE

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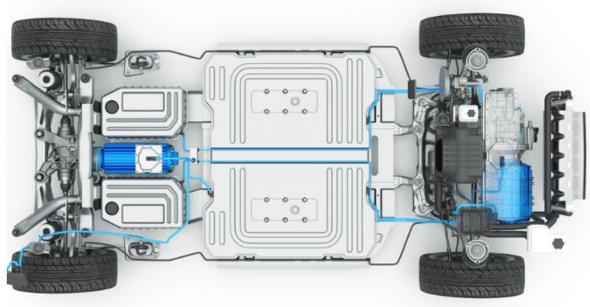


Introduction

Electric vehicles (EV) offer the exciting possibility to meet the world's transportation demands in an environmentally sustainable way. Mass adoption could help reduce our reliance on fossil fuels, but the lithium-ion (Li-on) batteries that power them still present unique challenges to designers and engineers, primary among them to ensuring safety against battery fire.

To achieve vehicle manufacturer's ambitious adoption goals, it is necessary to improve the safety of Li-on batteries by better understanding all of the complex, interconnected aspects of their behavior across both normal and extreme duty cycles.

Altair is focused on developing a comprehensive understanding of automotive battery safety issues which it has named the Altair Battery Designer project. It combines innovative design methods and tools to model and predict mechanical damage phenomena as well as thermal and electro-chemical runaway. Altair has developed an efficient way to calculate mechanical and short-term thermal response to mechanical abuses, providing accurate computational models and engineer-friendly methods to design a better battery.

This was made possible through the following collaborations:

- For the mechanical aspect, with the MIT Battery Modeling Consortium, which involves several automotive OEMs, battery manufacturers and US governmental research organizations.
- For the mechanical and thermal runaway coupling aspect, with the Vehicle Energy & Safety Laboratory (VESL) and North Carolina Motorsports and Automotive Research Center, out of the University of North Carolina, Charlotte (UNCC) under the leadership of Professor Jun Xu.

These collaborations provided both critical industry expertise as well as a wide range of reliable experimental data to validate Altair's methods.

Challenges

Given the complexity of an individual battery cell's structure, and moreover of a module or a full battery pack, homogenization techniques are required to keep the model size and CPU time compatible with the aggressive time schedules of industrial design cycles.

Based on the mechanical and electro-thermal experimental tests of battery cell components (anode, cathode, separator …), homogenized properties of the cell were identified using Altair Radioss^{TM} and Altair Flux^{TM} software.

The mechanical behavior of the homogenized element is modelled as an orthotropic elasto-plastic material. In addition, a failure model is used with orthotropy, strain rate, state of charge, and temperature effects. Post-rupture properties are also considered.

Thanks to the contribution of Dr Elham Sahraei from Temple University College of Engineering and co-director of the MIT Battery Modeling Consortium (2016-2019), an accurate method was established for identifying the mechanical properties of the battery cells, including its possible failure, using advanced numerical modeling techniques.

Figure 1 shows the correlation between the simulation's prediction and actual field data from a prismatic cell indentation test.

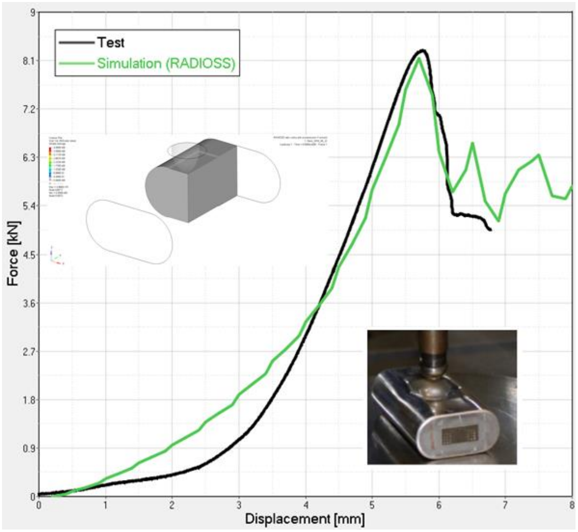


Figure 1 – Simulation vs test results of a battery cell hemispherical indentation

Problem Formulation

Used to predict whether the vehicle adheres to regulatory crash and impact regulations, Altair's homogenization method enables the accurate simulation of a full electric vehicle, including a realistic deformable battery pack, to be run in less than one night. Once implemented in an optimization process, the design of the entire vehicle can be optimized, leading to a high degree of safety at a production low cost.

The deformations at the battery pack for a pole impact EuroNcap test are calculated in the EV model Figure 2.

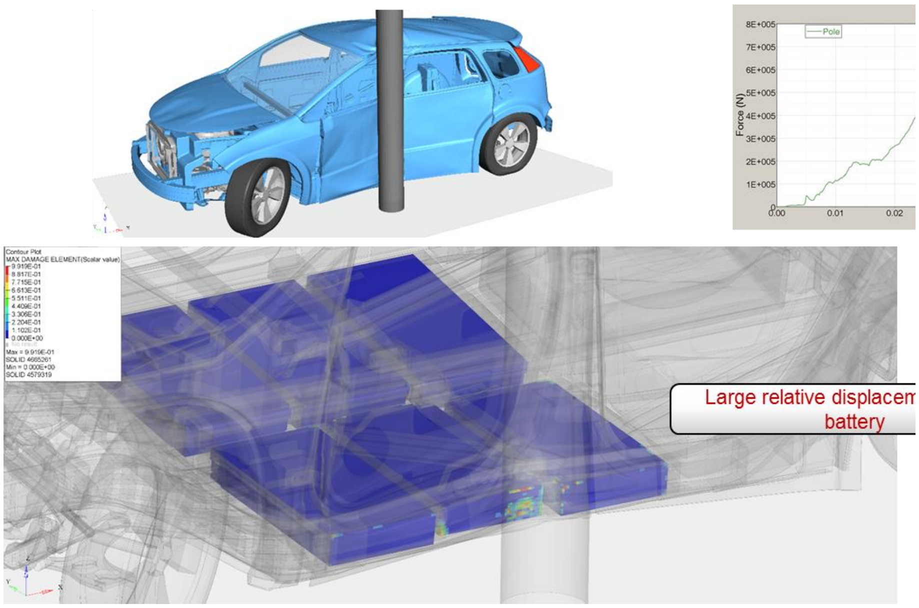


Figure 2 – Battery mechanical response to a vehicle pole impact

The next step consists of calculating the thermal effect caused by deformations of materials inside the battery components to determine the risk of thermal runaway.

A method has been designed and validated in collaboration with Professor Jun Xu's team at UNCC using a cylindrical cell.

Altair Flux is used to perform the electro-thermal characterization of the homogenized element. Internal short circuits are considered based on a compressive strain criterion and the power loss in the material is extracted from the tests.

Figure 3 shows the power loss variations as a function of the strain in the material. The ensuing change of resistivity is established based on experimental data as shown in Figure 4.

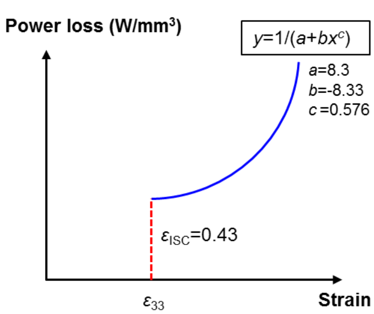


Figure 3 – Power loss vs strain curve

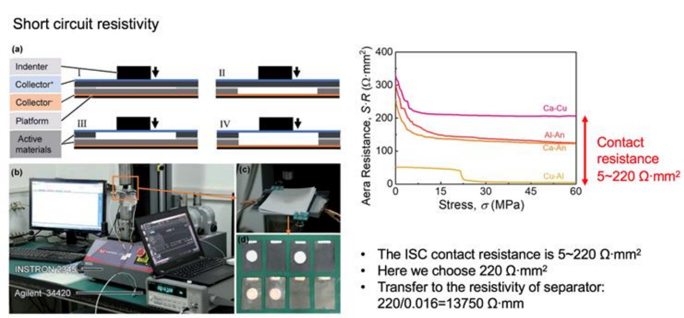
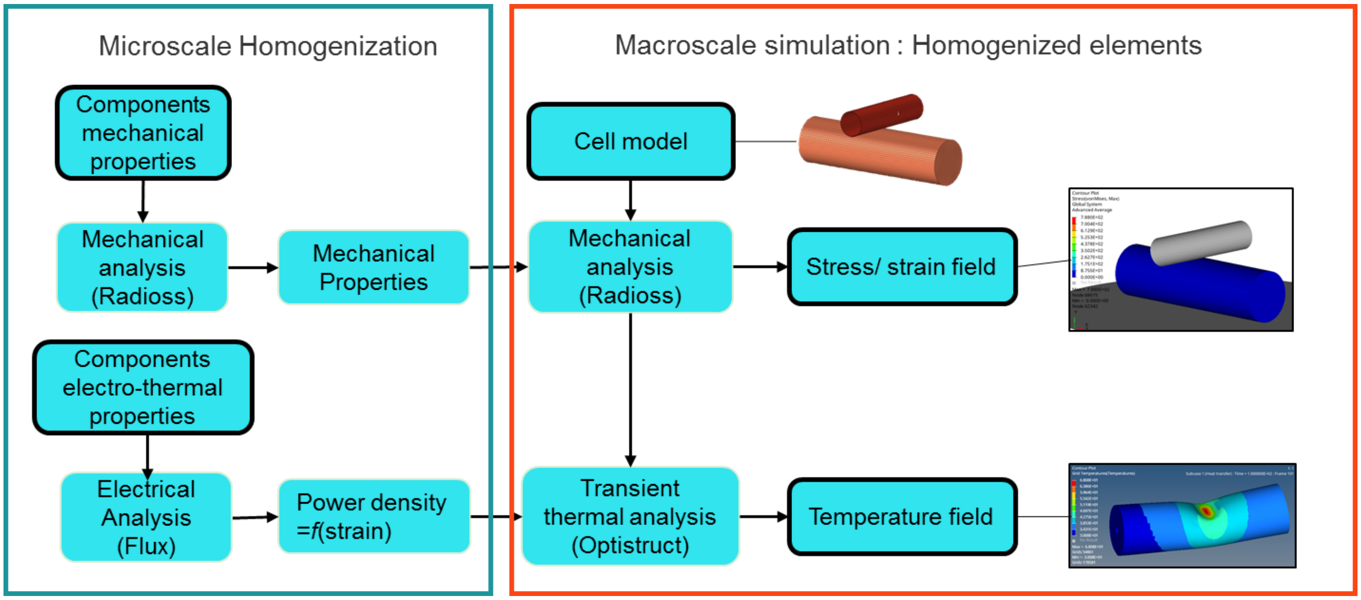


Figure 4 – Experimental ISC measurement

Once the homogenized element is fully characterized, an explicit transient nonlinear dynamic calculation is performed using Radioss to obtain the mechanical response of the cell. A transient heat transfer analysis is accomplished using Altair Optistruct™, exploiting the deformed shape of the battery calculated by Radioss and the power losses calculated from the homogenized element strain values.



Altair Battery Designer process description

Experiments and Results

The process involves several complex operations - numerical Multiphysics simulations including highly nonlinear structural dynamic analysis, transient thermal analysis, and electro-thermal interactions. It is therefore fundamental to validate the accuracy of the results and the predictivity of the process on simplistic applications before conducting it on a full-scale battery or electric vehicle design.

The validation was performed on an NCR 18650B battery cell, 30% SOC. Two tests were performed: compression and indentation (Figure 5). Both Voltage/force and temperatures/impactor displacements variables were measured.

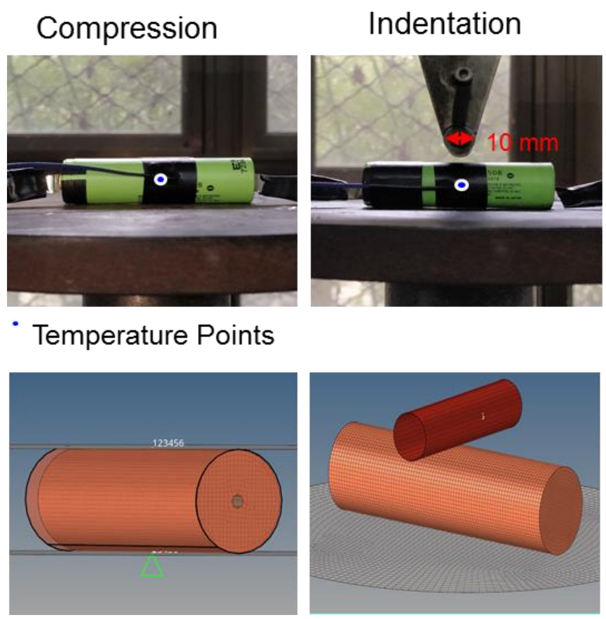


Figure 5 – Test setup & structural simulation models

The calculation times were completed in just a few minutes on a laptop for the mechanical analysis and few seconds for the thermal analysis.

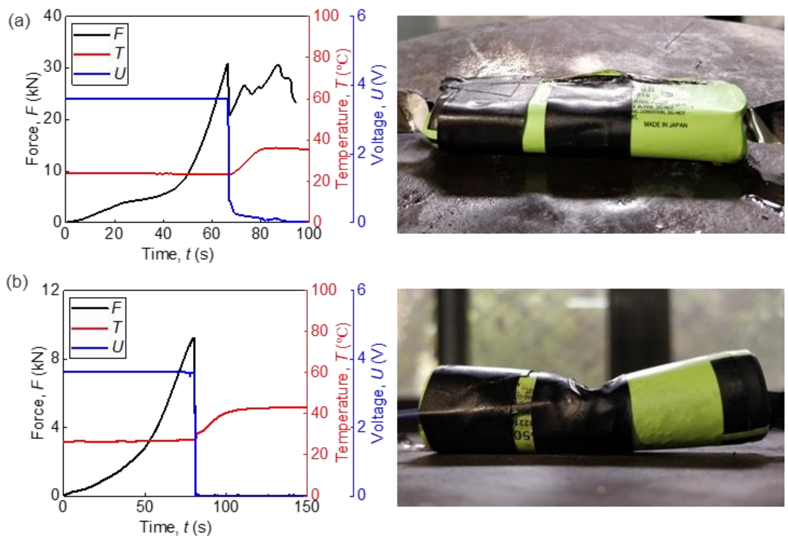


Figure 6 – Experimental results

The different force, voltage, and temperature curves histories from the tests are plotted on Figure 6. The mechanical rupture of the cell corresponds to the short circuit event with the voltage drop and the beginning of the temperature increase.

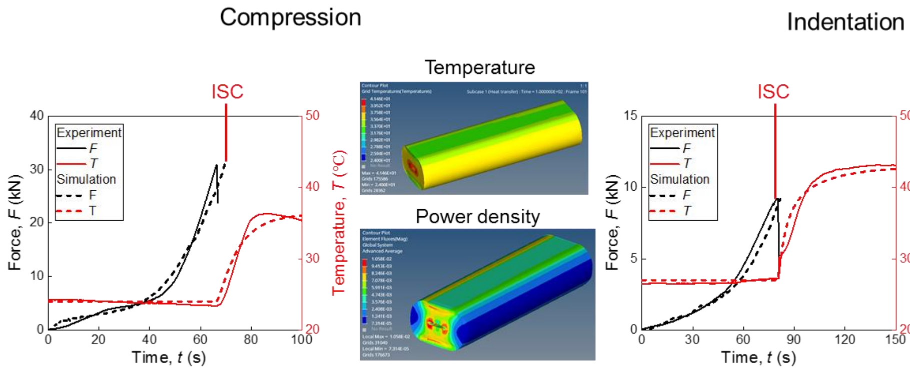


Figure 7 – Numerical results vs experimental curve

The mechanical and the thermal simulation results (Figure 7) all correlate well with the physical tests, which demonstrates that the process properly accounts for the Multiphysics behavior.

Temperature increases within the battery pack can also be calculated at the moment of a vehicle crash. Using Altair's multiphysics methodology, the electric vehicle model was submitted to a lateral pole impact test. The instantaneous temperature changes due to the mechanical deformations of the cells inside the battery pack were considered.

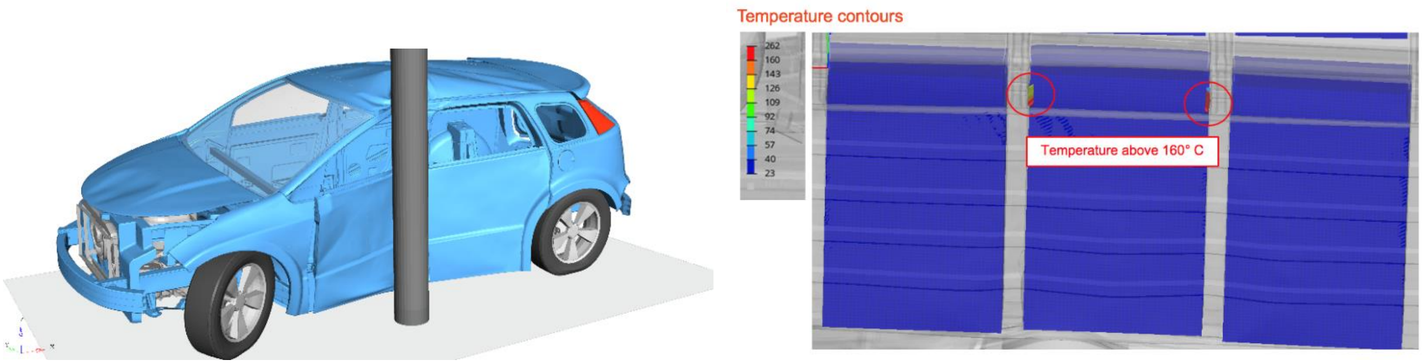


Figure 8 – Temperature increases at the end of the pole impact test

The melting temperature of the separator in the cells is 260 degrees Celsius. Any areas showing dramatic temperature increases at the point of impact tell analysts where design modifications may be needed. Figure 8 highlights two locations into the battery reaching 160°C when the state of charge is at 30 percent. Increasing the state of charge could increase the risk of thermal runaway in these two zones, so it would be recommended to perform further structural optimization studies to avoid compression of cells in these areas.

This method allows designers to quickly identify potential safety issues early in the battery design process, shortening development time and ultimately leading to the design of safer, more cost-effective, and better-performing electric vehicles.

Conclusion

With the increased use of Li-on batteries in the transportation world, verifying battery safety, even in abuse cases such as impact and shock, has become an important issue in our day to day life.

Using Altair Battery Designer's tools and simulation methods, it is now possible to accurately predict the short-term mechanical and thermal behaviors of a battery under abusive loading in a short period of time. This unique process can be applied to multiple load cases such as crash, crush, deceleration, and impacts with and without penetrations.

About the Authors

Jean-Baptiste Mouillet - Multiphysics Solutions Director, Altair

Mouillet has been working for 20 years on Radioss for multiphysics, defense applications, fluid-structure interactions, and composites. He is an expert in collaboration with customers from defense, aeronautic and automotive industries. Mouillet is very familiar with projects involving the coupling of multiple physical solutions and developing methods to properly and efficiently account several physical phenomena simultaneously.

Since 2017, he has overseen multiphysics solver solutions at Altair. He has been working on electric motor multiphysics optimization involving thermal, NVH, structural and electromagnetic phenomenon, fluid structure interactions and high frequency.

Marian Bulla - Program Manager, Material Data, Altair

Bulla is a civil engineer in mechanics with a degree of Dipl.-Ing. (FH) from the university of applied science in Iserlohn. He has been working for 20 years on material testing and simulations. Since 2003 he has worked as a lecturer at the University of Applied Sciences in Aachen (Germany) on the topics of Design of Experiments (DoE) and Finite-Element-Method (FEM) and Material Science. For 11 years, Marian worked at Altair in the Radioss support and trainings team and in the Radioss development and validation group for the last 5 years. He is a member of several public founded research projects. He also contributed to the MIT battery fracture consortium. He has experience in automotive industry as well as with composites, metallic and polymer materials and failure criteria.

Jean Michel Terrier - VP, Radioss Worldwide Business Development, Altair

For more than 30 years, Terrier has worked in the hydrodynamic field, including crash, impact, and explosions, covering automotive, aeronautics, defense industries. He has been involved in many R&D projects covering multiphysics and managed several companies in consulting and FEA software distribution.

Terrier has a civil engineering degree with a master's degree in soil mechanics from the French Engineering School "Ecole Centrale de Paris" (Paris). He received his Executive MBA from the European Business School HEC (Paris). At Altair, Jean Michel Terrier is VP, Worldwide Business Development, Radioss.

Patrick Lombard - Lead Application Specialist Manager, Altair

Lombard runs the Flux and FluxMotor Specialist team for Altair. He started his work in 1989 for CEDRAT as a developer of Flux 2D for introducing the circuit coupling to magnetic equation, the subject of his PhD in 1992 from Institut National Polytechnic of Grenoble, France. He has worked on many functionalities to ease the modeling of electrotechnical devices. His field of work includes modeling motors, transformers, actuators, and induction heating. In 2000, he took the lead for the support and valorization team to help users get the most of Cedrat's tools, which was acquired by Altair in 2016. His current applications of interest include hysteresis, multi-physics and optimization especially for electrical motors.