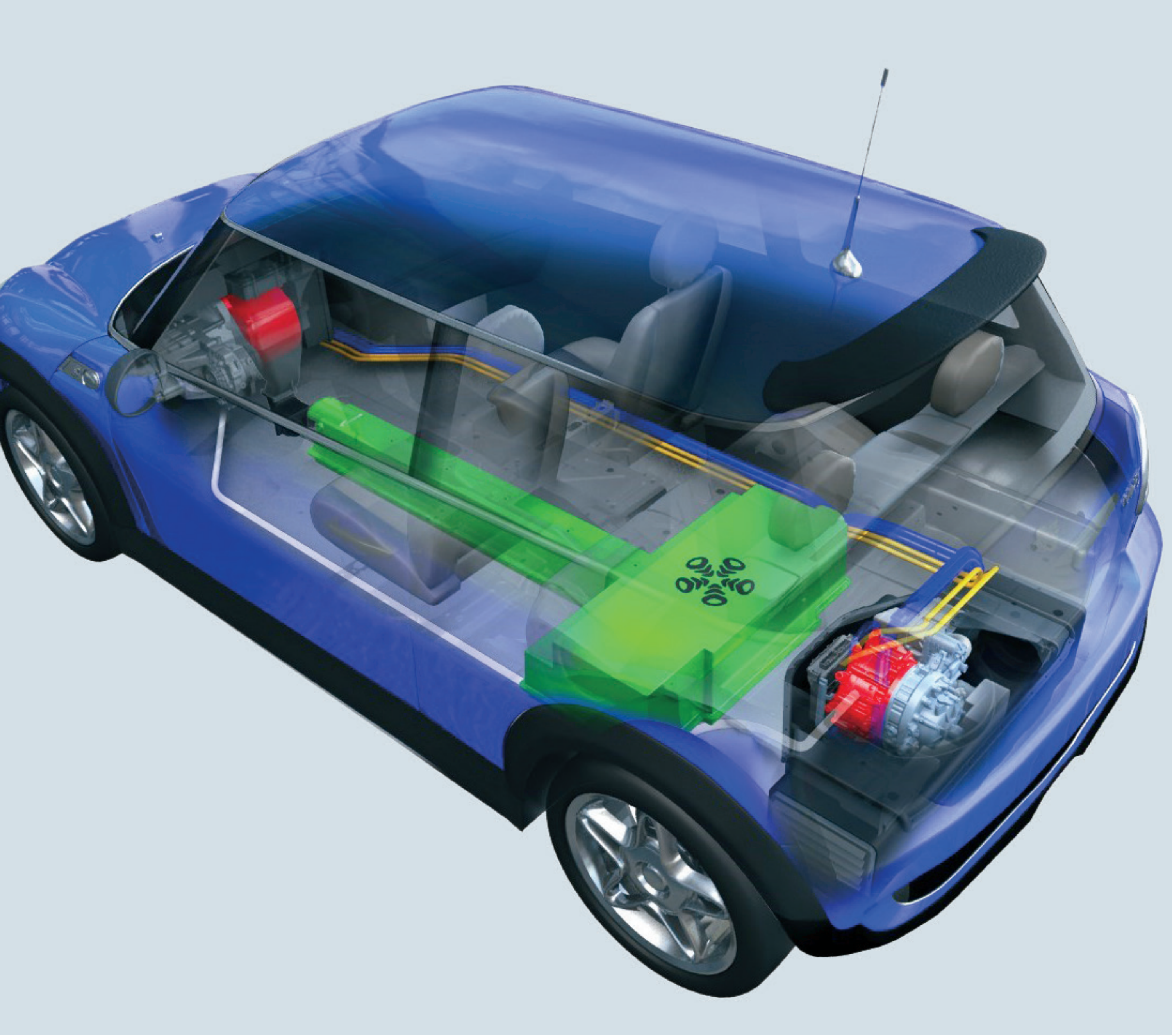
AVL

Transportation & Mobility Case Study



Challenge

With rising market demand for Lithium-ion (Li-ion) batteries to power electric vehicles, AVL needed to identify the best way to package its customers' battery cells for optimum thermal and electrical performance.

Solution

AVL employed the electro-thermal capabilities in Abaqus Unified FEA, coupled with their proprietary software, to capture the characteristics of Li-ion cells and analyze thermal behavior in different battery system configurations.

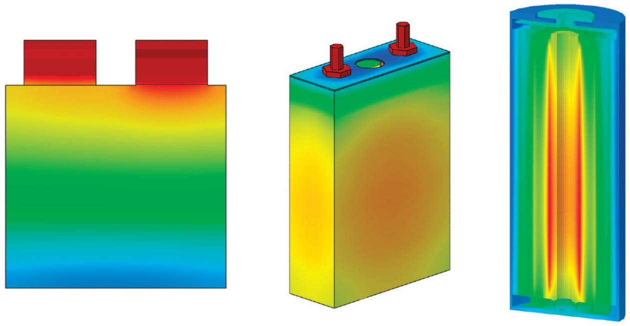
Benefits

Good correlation between FEA models and lab measurements gives AVL the confidence to develop increasingly complex battery models, enabling them to offer their clients more sophisticated performance evaluations and product design recommendations.

The Lithium-ion (Li-ion) batteries that power today's electric vehicles require sophisticated electronics and a high degree of control. "In a very broad sense, the function of a Battery Management System is to constantly monitor and protect every single cell in the battery pack," says AVL technical specialist Kim Yeow. "It also constantly communicates with engine and other vehicle control systems to ensure the safe and efficient operation of the battery pack. The battery system has to endure and work well in extreme environments and respond rapidly to changes in vehicle driving conditions, all in real time. It's quite complex."

Yeow is part of the advanced simulation technology team that has been researching and evaluating Li-ion battery systems for various customers at AVL's technical center in Plymouth, Michigan, for several years now. Working on an internal R&D project to adapt a gasoline powered car to an Electric Vehicle and Range Extender (EVARE) demonstration platform, the team at Plymouth was challenged to come up with an efficient cooling system for the battery pack. This pack was assembled with 14 battery modules that were bought off the shelf and packaged within a constrained space for optimum thermal and electrical performance. "That's when it became clear we needed to apply realistic simulation with finite element analysis (FEA) to predict battery working temperatures," says Yeow.

Li-ion batteries have been around for decades. What secrets could FEA uncover now? "There's still a lot to learn," says Yeow. "Due to a large market shift, there's been heavy research on vehicle electrification for the past few years within AVL." Much of the research that Yeow was involved in centers on the thermal management of the battery pack.



Electro-thermal model of cells of different geometries.

There are many things that must be considered in the design of a battery system for use in vehicle electrification (EV, PHEV or HEV), such as the power capacity of the battery system, cell selection, cell and module packaging constraints, pack architecture, volumetric and gravimetric energy densities of the pack, cost, structural durability of the battery system under various loadings, limiting ambient temperatures, etc.

"Thermal management of the battery packs is just one of many important considerations," says Yeow. "From the battery performance and safety standpoint, we would like to maintain an optimal operating temperature range for the battery pack regardless of the ambient temperatures and operating conditions. We need to cool the batteries when they become too hot and to warm them up when their temperatures are too low."

With 3D FEA modeling, individual cell temperature patterns throughout the battery pack can be evaluated. The FEA model can identify the cell temperature distributions within the pack, which provides guidance in placement of temperature sensors in monitoring the operating temperatures of the battery pack. "The pack power capability is affected significantly by temperatures of the cells in the pack," says Yeow. "If the temperature of a cell is too high, the power draw from the total pack must be reduced to prevent that cell from overheating. On the other hand, if the temperature is too low, it

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> **Kim Yeow, technical specialist, AVL**

needs to be warmed up because low cell temperatures limit the power draw." The maximum cell temperature and the maximum differential cell temperature are crucial factors to cell safety and durability.

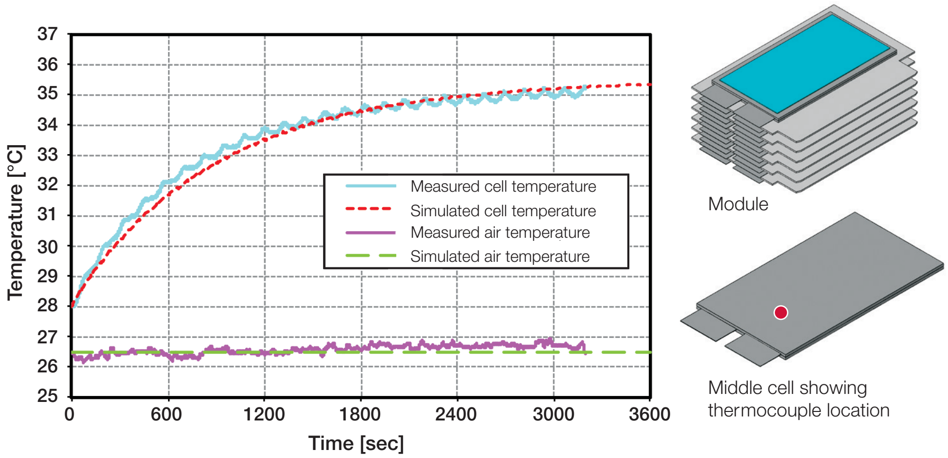

Figure 1. Good correlation of an indirect air-cool module under continuous discharge-charge condition.

For the EVARE project, the team at AVL was challenged to develop the battery pack configuration that would provide the most efficient battery cooling at the lowest possible cost. Key to this was a good understanding of what was happening inside the pack. "We needed a tool for analyzing the thermal behavior in a battery system, and the electro-thermal capabilities in Abaqus FEA were a good fit to our need," says Yeow. The software was already employed widely throughout AVL for conducting thermal-mechanical analyses on the engine component as well as non-engine work.

Because the tool was not specifically designed for battery simulation, the team at AVL wrote special subroutines and coupled them to Abaqus. "A good feature of the software is its ability to interface with user written subroutines," he says. "So we were able to capture the characteristics of the Lithium-ion cells using our own software and link them to the FEA model within Abaqus."

The special subroutines developed for the EVARE project now enable AVL to evaluate the thermal behavior of assorted cell geometries and configurations, as well as the efficiency of various cooling methods.

"One Lithium-ion battery is not like another, so for different cell types—whatever the geometry or chemistry—the cell geometric information and performance are inputs to our subroutines. This allows us to characterize the different cells," says Yeow.
The team's battery modeling typically starts with a quick 1D simulation. "This gives us a sense on how the pack will work, on the basis of which we can dial in the cell selection and the cooling system requirement," says Yeow. Once the full information on the pack's cooling system is available, AVL performs a detailed 3D assessment, beginning with electro-thermal analysis of the modules.

"Initially we assume good contact and hence good heat transfer paths between, say, the cooling plate and the cells," says Yeow.

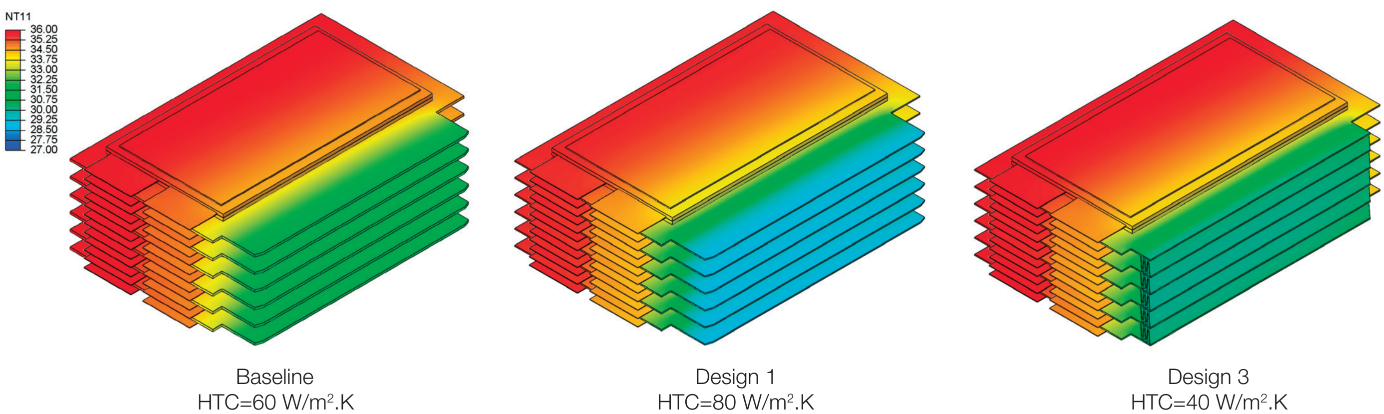

Figure 2. Abaqus FEA models of stabilized cell temperatures for three module designs with similar steady state temperatures. Compared with the baseline, Designs 1 and 3 are smaller. However Design 1 requires higher air flow.

"Abaqus is very good with contact, and all these components are touching each other. As the design matures we'll simulate the assembly condition to find out where there might be gaps and find ways to minimize those gaps, and re-evaluate how gaps in certain areas would impact the cooling of the battery cells."

The complexity of the cell structures themselves adds more challenges to the task. Based on the cell capacity, a cell might have up to 50 pairs of thin anode-cathode layers, with the thickness of each layer on the order of 200 microns. "With 96 cells or more in a battery pack, it's not practical to model the cell in such detail from engineering and production standpoint," says Yeow. "So we approximate with one to three equivalent cell layers per cell, and use the equivalent composite properties to characterize the behavior of the batteries at a macro level.

"Complicating things is the search for accurate material data," he adds. "It's always about solving the mystery. The cell manufacturers supply us with some ballpark numbers, but we often end up doing literature searches, or turning to other researchers, to get more accurate figures. Oftentimes we end up with a range of material values.

"It all trickles down to the model results," he notes. "The validity of that assumption will be measured against tests."

Despite the many challenges, Yeow notes that they are seeing good correlation of their models to actual lab measurements; under either continuous discharge condition or continuous discharge-charge condition; with liquid cooling or with air cooling; with direct or indirect cooling systems. The correlated model was used to further improve and optimize the battery system design (as shown in Figures 1–2).

Yeow notes that, as with any emerging technology, theirs is a work in progress. "We know it's not possible to have uniform cooling, even though that's our goal. We'll continue to improve the veracity of our models, refining our assumptions and incorporating additional parameters. Abaqus is our analysis tool of choice for structural evaluation of the electrical and thermal behavior of Lithium-ion batteries. We're already using it for the required structural integrity assessments. Going forward, we want to more closely link the electro-thermal model of the battery system with the corresponding structural and CFD models."

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