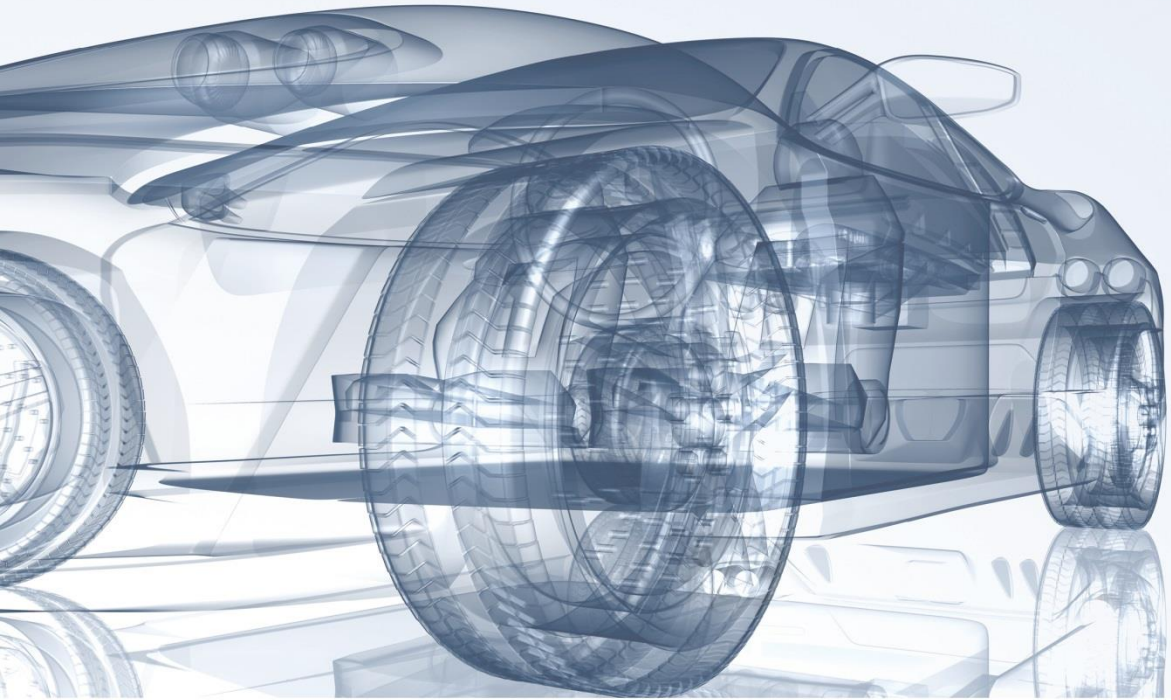
evs 30



The 30th International
Electric Vehicle
Symposium & Exhibition

October 9–11, 2017

Messe Stuttgart, Germany

www.evs30.org

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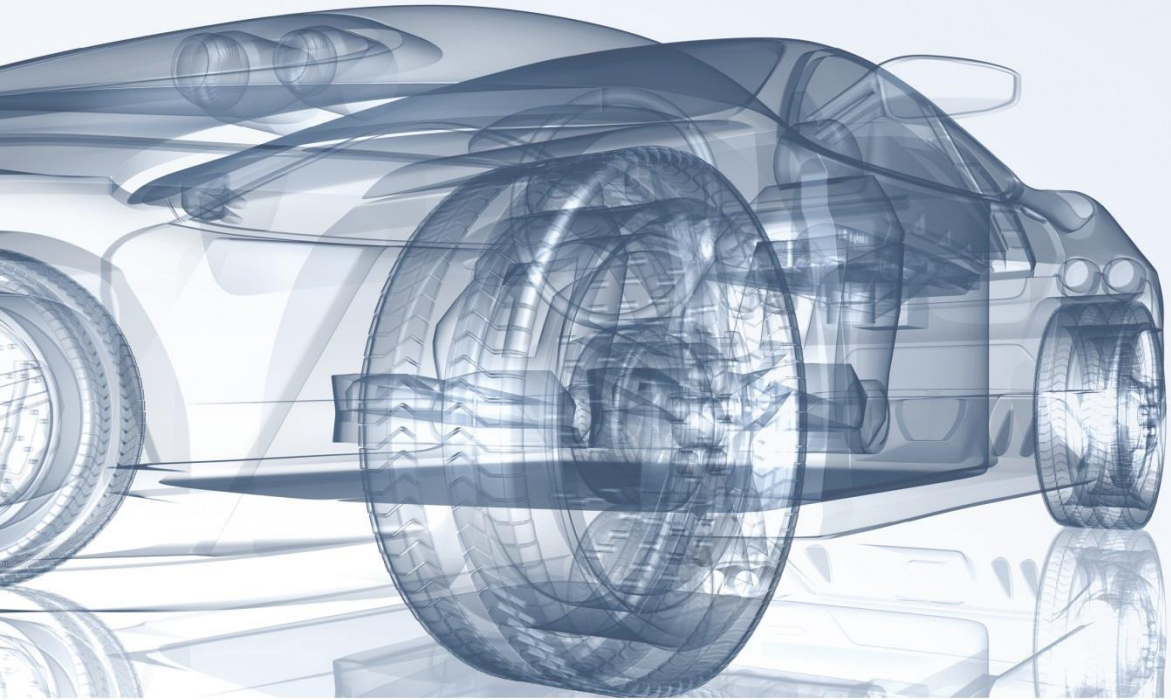
DAIMLER BOSCH Invented for life GROUPE RENAULT MAHLE EnBW PORSCHE swarco



Assessing battery safety using a combined simulation approach from cell to vehicle level

Dr. Bernhard Brunnsteiner
AVL List GmbH

www.evs30.org

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AVL COVERS ALL CUSTOMER SEGMENTS


Passenger Cars

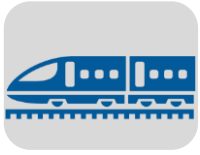

2-Wheelers


Racing

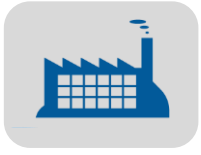

Construction


Agriculture

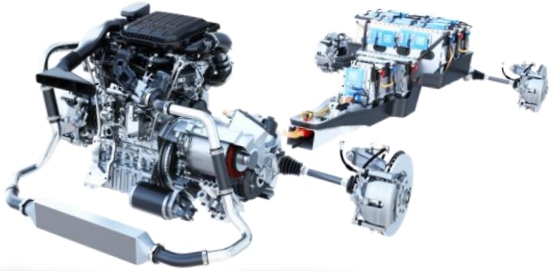

Commercial Vehicle


Locomotive


Marine


Power Plants

POWERTRAIN ENGINEERING



Development Platform

ADVANCED SIMULATION TECHNOLOGIES & **INSTRUMENTATION AND TEST SYSTEMS**

ELECTRIFICATION AT AVL

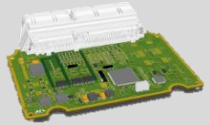
Energy Management

System Design

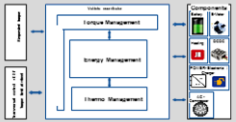
System Simulation

Battery Development

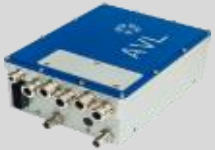
Battery Management System



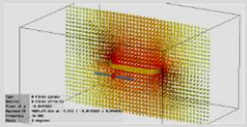
Vehicle Controls



Power Electronics



EMC Simulation

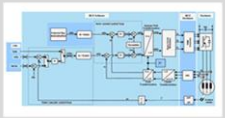


Range Extender Dev (ICE & FC)

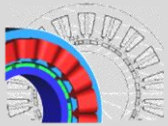
Transmission Control

Transmission Development

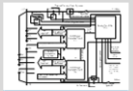
Emotor control



Emotor development



Range Extender Controls (ICE & FC)



ENTERPRISE DEVELOPMENT AUTOMOTIVE

RESEARCH 10% of turnover in-house R&D

INNOVATION 1500 granted patents

STAFF

8.600 employees

65% engineers and scientists

GLOBAL FOOTPRINT

30 engineering locations
- **>220** testbeds
- Global customer support network

GROWTH

SALES

1995:
0.15 billion €

2016:
1.40 billion €

Plan 2017:
1.52 billion €

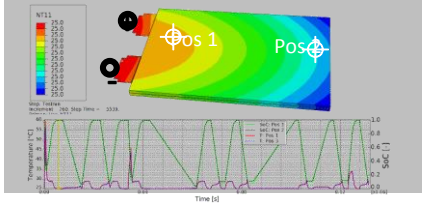
EXPERIENCE
65 years !

5 powertrain elements

ONE
PARTNER

R&D OVERVIEW IN ELECTRIFICATION
ANTICIPATION OF CUSTOMER NEEDS IN R&D

2007
1st electro-thermal battery model



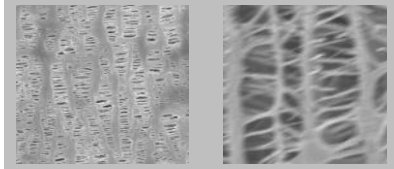
2013
Cell hazard test and simulation

2016
EV crash & NVH simulation incl. E/E

2009
EV development for 800V battery

2015
Thermal runaway test bed

2017
Damage modeling on cell inner components

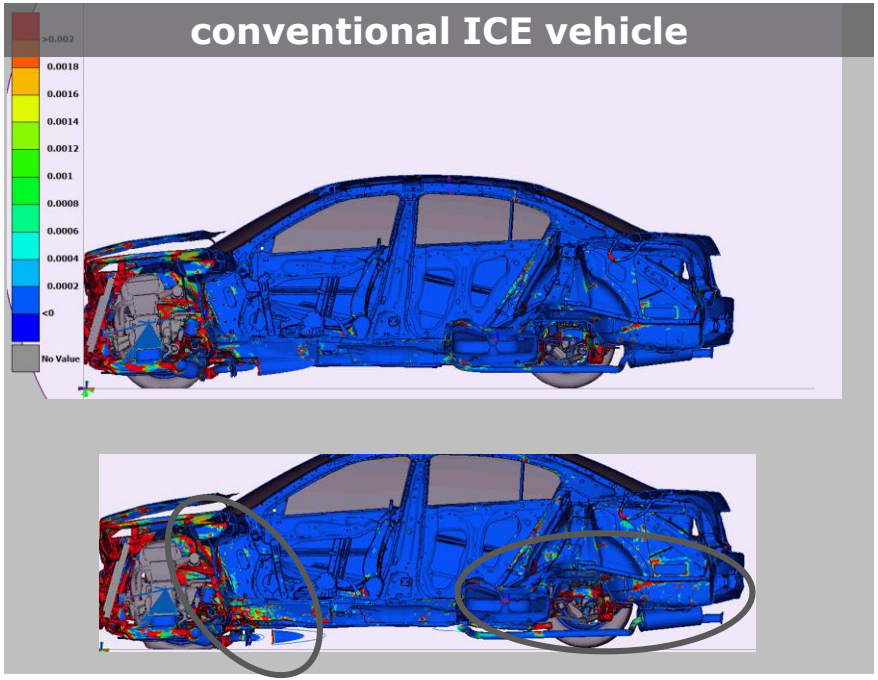


More than 80 R&D projects provided input into > 250 accumulated engineering projects in the last 10 years

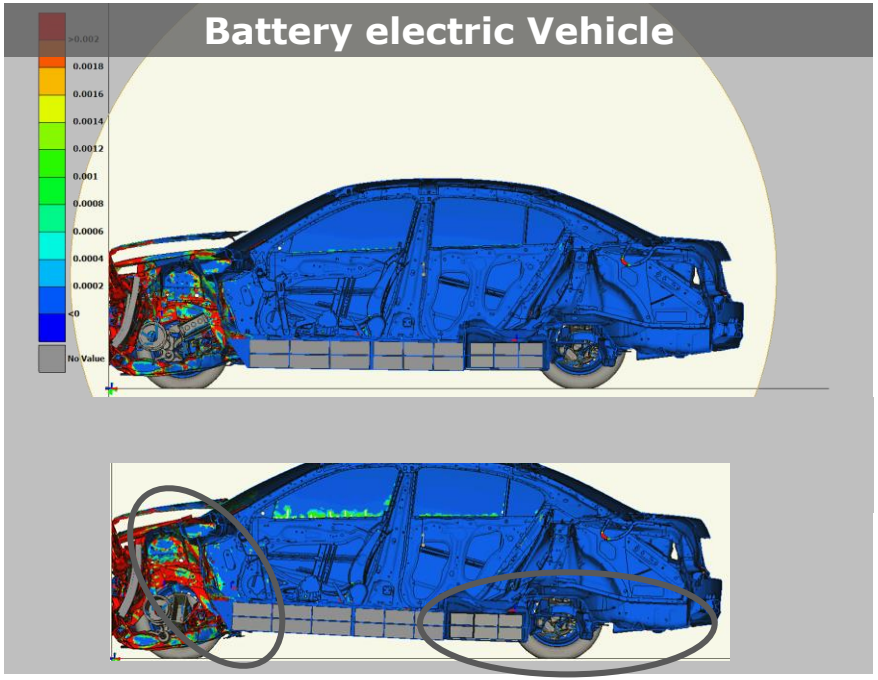
IMPACT OF ELECTRIFIED POWERTRAIN ON VEHICLE CRASH BEHAVIOR

Huge Impact of battery mass & battery requirements to overall vehicle development

conventional ICE vehicle



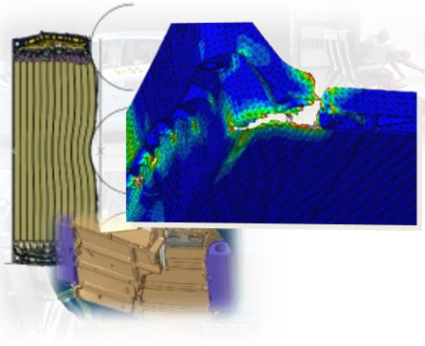
Battery electric Vehicle

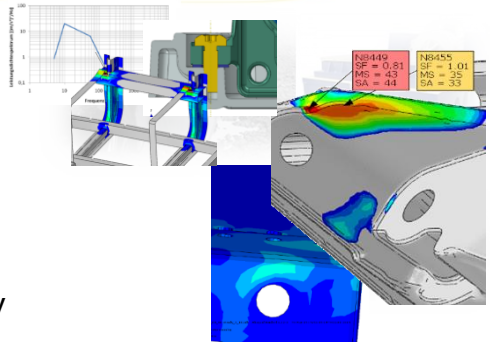


USE CASES

- **Short introduction of AVL List GmbH**
  - Anticipation of customer needs in R&D
- **Motivation**
  - Impact of Electrified Powertrain on vehicle crash behavior
- **Use cases**
  - Battery Crash: safety assessment from vehicle to cell
  - Thermal system: cooling from vehicle circuit to cell connection
  - Robustness: rough road impact on cell electrical connection
- **Methodology & workflow overview**
  - Simulating mechanical behavior of single cells
  - Simulating thermal runaway in cell, module and pack level
- **Summary & take away message**

CELL /MODULE / PACK SIMULATION
FULL VIRTUAL VALIDATION PROGRAM AVAILABLE





Sled test

Crush

intrusion

Crash

Worst case events

pothole

Durability

Strength

High Cycle Fatigue (HCF)

Isolation failure &
Short circuit

venting

Tightness & leakage

Hazard

Thermal

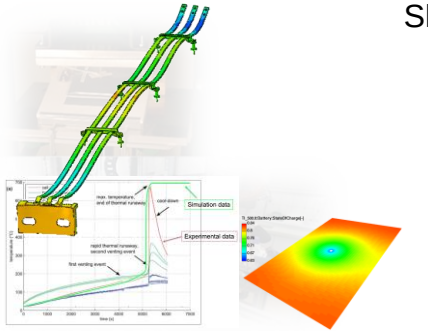
Battery Lifetime
(cells & components)

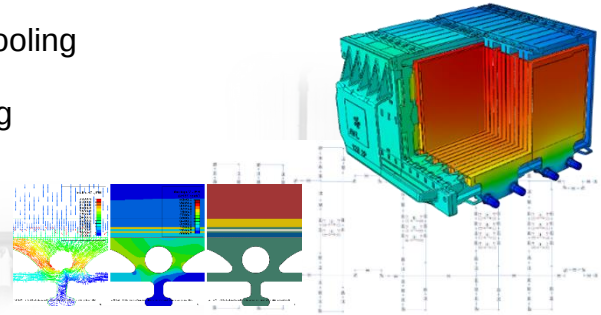
Cooling

Heating

Fast charging

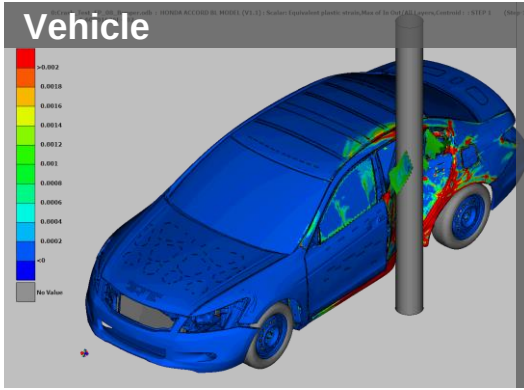
Thermal runaway





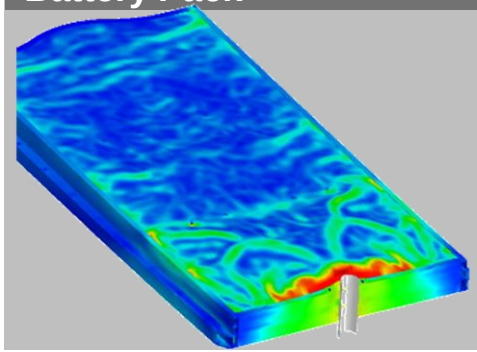
CRASH & SAFETY EVALUATION FROM VEHICLE TO CELL LEVEL

Vehicle



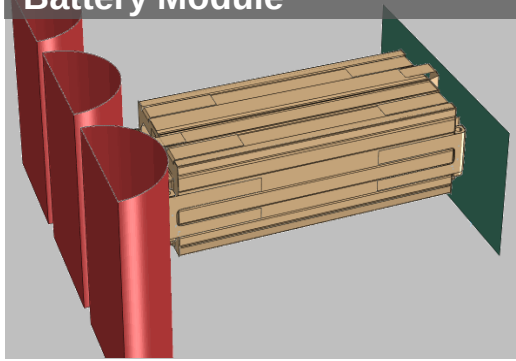
Side pole crash on vehicle level indicates the crush load on battery

Battery Pack



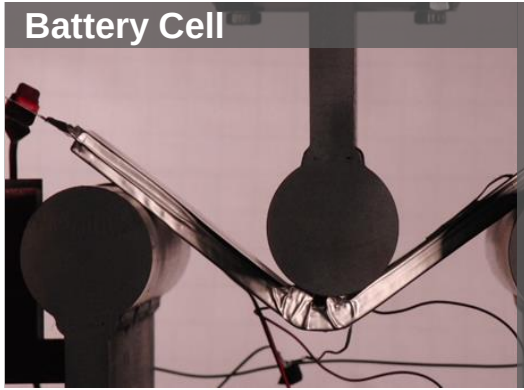
Crush simulation on pack level for assessing housing integrity

Battery Module



Module crush with assessment of cell stiffness & deformation

Battery Cell



Abuse cell tests for predicting hazard events in crash cases

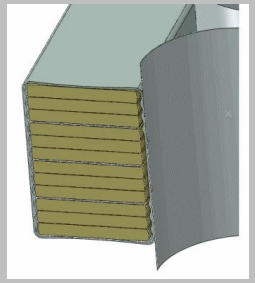
MAJOR CONTRIBUTION OF SINGLE CELLS TO OVERALL STIFFNESS

Module crush test

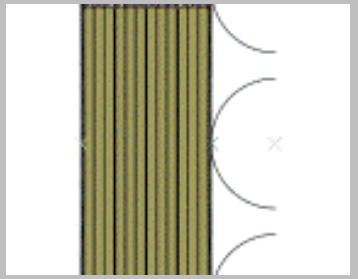
GB/T 31485-2015: crush test definition

The **crush tests** purpose is to **verify the safety performance** of the Device Under Testing (DUT) **under contact loads** by simulating force applied relatively slow in the orientation reasonable for the vehicles normal use. The DUT is crushed between a fixed surface and a crush fixture **that results in sufficient localized deformation to cause shorting.** The crush fixture varies dependent on type of DUT and in most cases must exceed the dimension of the DUT.

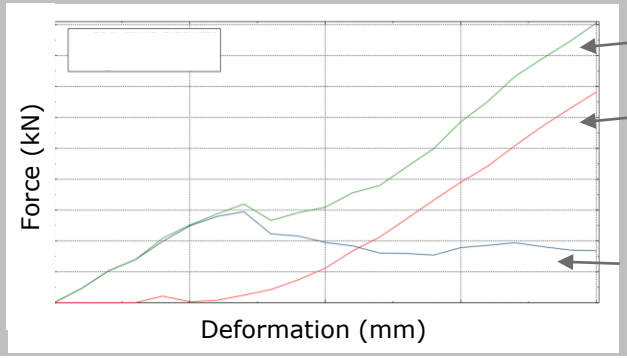
FE material modeling of Li-Ion cells



FreedomCAR crush in longitudinal (left) and thickness direction (right).

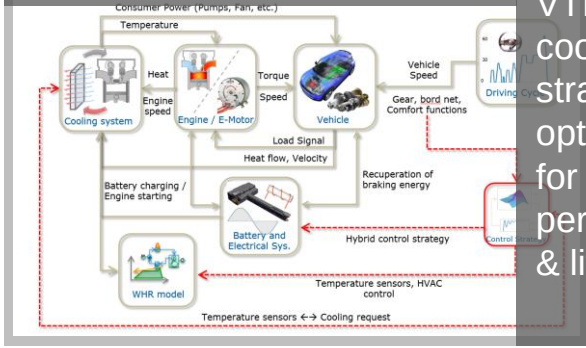


FE material modeling of Li-Ion cells



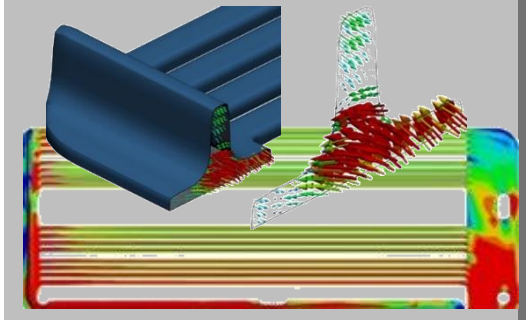
THERMAL SYSTEM
FROM VEHICLE TO CELL LEVEL

Vehicle



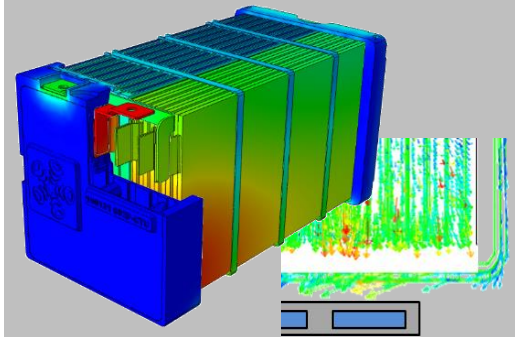
VTMS allows cooling strategy optimization for max. performance & lifetime

Battery Pack



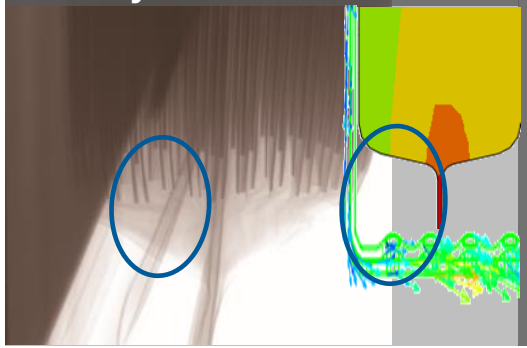
3D CFD simulation of coolant flow in pack for homogenous cooling conditions

Battery Module



Temperature hot spot prediction & heat path analysis from module to cooling plate

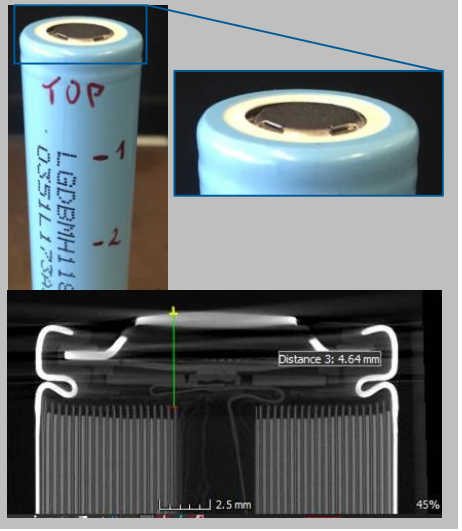
Battery Cell



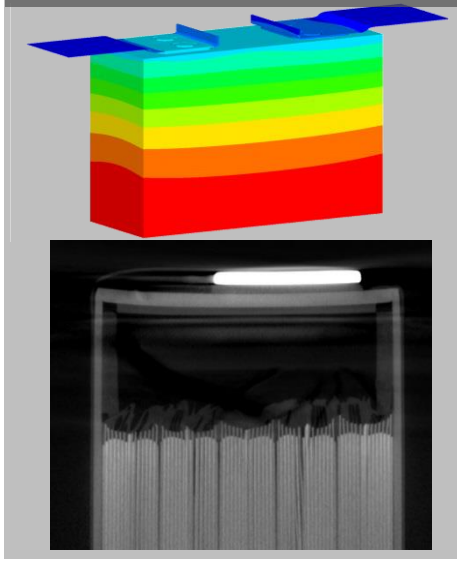
Cell inner design & cell to cooling plate connection limits cooling possibilities

UNDERSTANDING INNER CELL CONNECTION OF ACTIVE PARTS TO OUTER SURFACE

Cylindrical cells



Prismatic cells



Pouch cells

Internal isolation areas separate the cell housing from the chemistry.
Inner Cell design limits the cooling and heating capability.

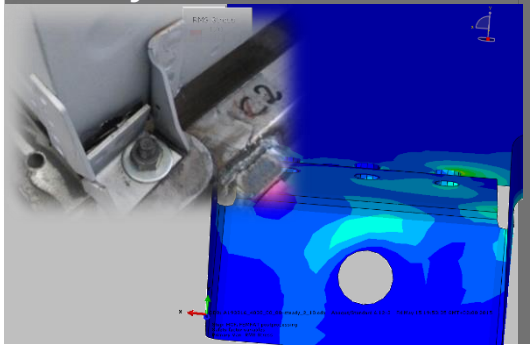
→ A proper connection of the cell to the coolant is crucial

DURABILITY & ROBUSTNESS ANALYSIS VEHICLE AND CELL LOADS

Vehicle

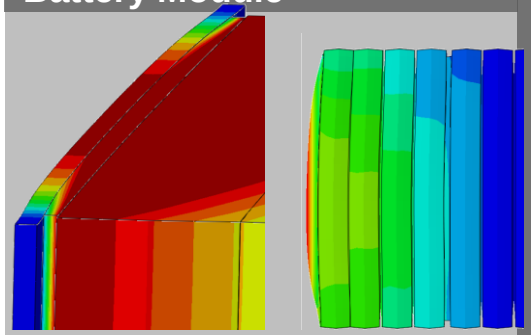
Vehicle rough road simulation defines realistic vibrational loads on battery

Battery Pack



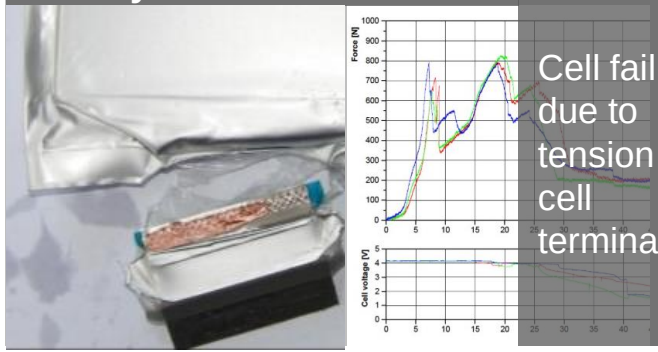
Bracket and pack housing assessment under vibration load

Battery Module



Module strength analysis under **cell swelling** load driven by lifetime and SOC

Battery Cell



Cell failure due to tension on cell terminals

METHODOLOGY & WORKFLOW

- **Short introduction of AVL List GmbH**
  - Anticipation of customer needs in R&D
- **Motivation**
  - Impact of Electrified Powertrain on vehicle crash behavior
- **Use cases**
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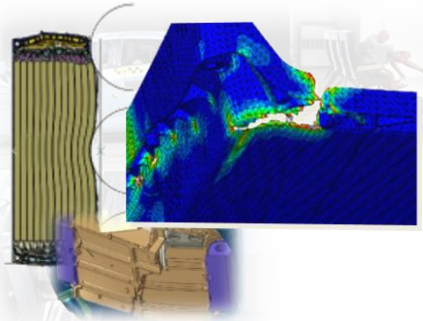
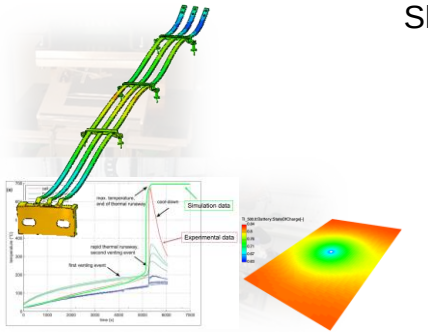
  - Simulating thermal runaway in cell, module and pack level
- **Summary & take away message**

CRASH & SAFETY ANALYSIS
CELL HAZARD EVALUATION





Sled test

Crush

intrusion

Isolation failure &
Short circuit

venting

Tightness & leakage

Thermal runaway

Crash

Strength

Hazard

Thermal

Worst case events

pothole

Durability

High Cycle Fatigue (HCF)

Battery Lifetime
(cells & components)

Cooling

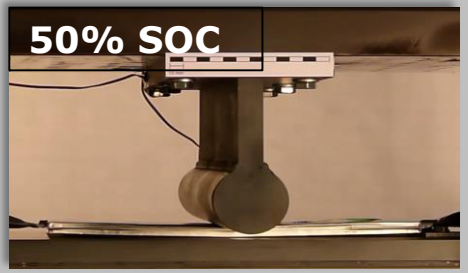
Heating

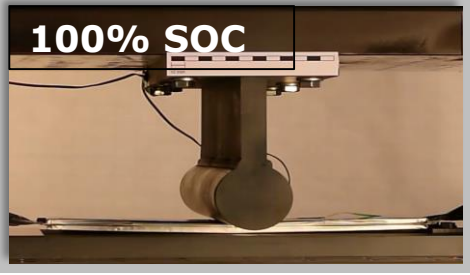
Fast charging

STANDARDIZED CELL TEST PROCEDURE FOR DERIVING MECHANICAL CELL PROPERTIES

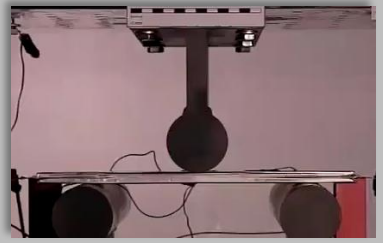
Standardized cell test procedure

Mechanical tests on cell level
- Active cells
- With voltage measurement
- SOC dependent

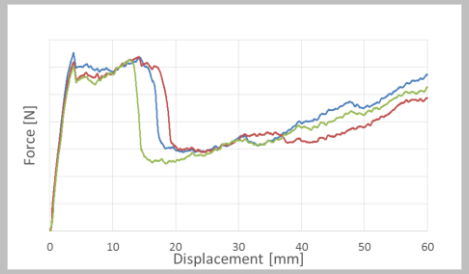




FE material modeling of Li-Ion cells



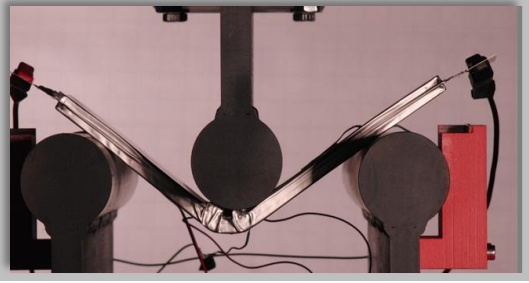
3 Point bending test (1mm/s)

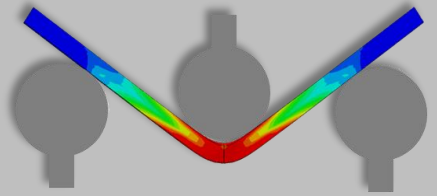


Measured Force – displacement curves for material modeling for FE solver

Calibrated & validated material model for usage in FEM analysis

Very accurate correlation

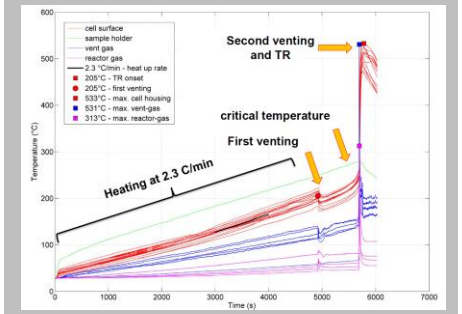




THERMAL PROPAGATION FROM 1 CELL TO THE NEXT: HOW LONG DOES IT TAKE?

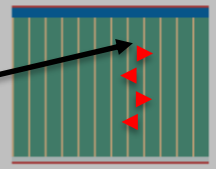
Cell abuse test

Measurement data

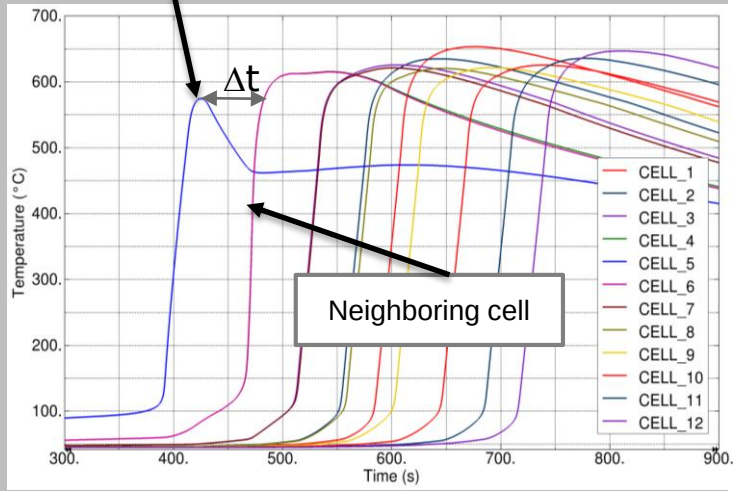


AVL thermal propagation model

model of a battery module



Cell is triggered to thermal runaway

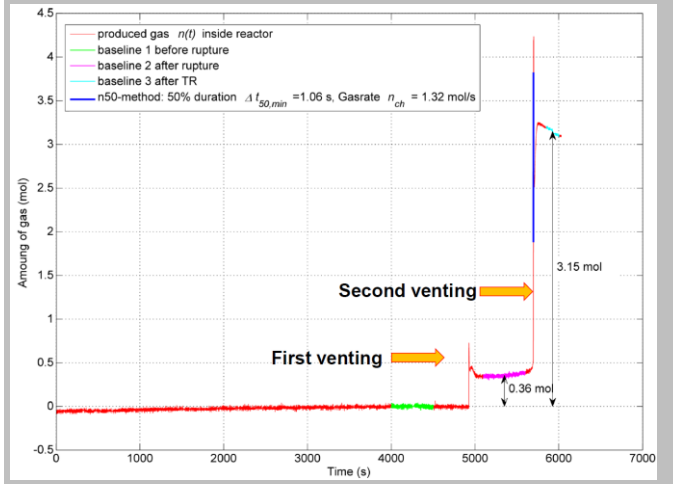


Prediction of time delay between 1st cell in thermal runaway and neighboring cells

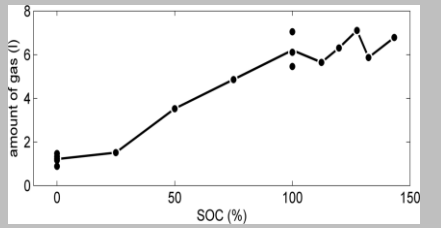
Tests on single cell level allow simulation on module level.
→ assessing counter measures and design strategies for increased safety

CELL VENTING
GAS FLOW AND BURST DISC ASSESSMENT

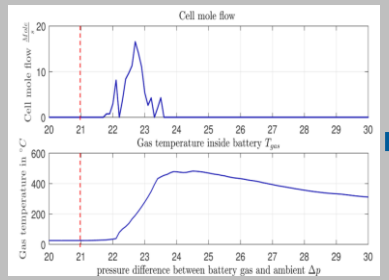
Cell venting test

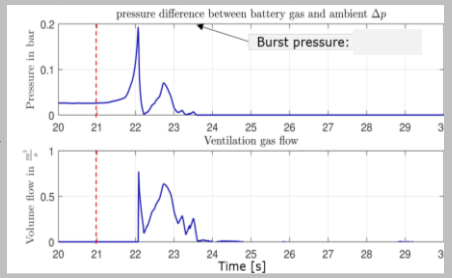


Cell abuse tests for measuring venting gas flow rate, composition & temperature



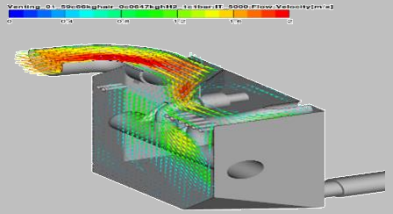
Venting burst disc evaluation





Simulation of pressure level in pack at cell venting case to evaluate burst disc

CFD simulation of venting gas flow

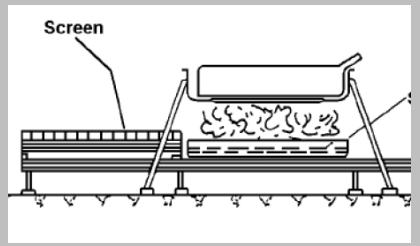


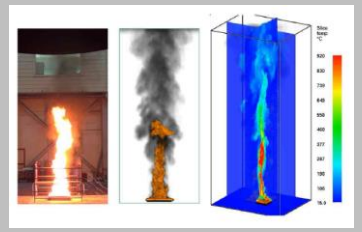
- Gasket and sealing evaluation
- Tightness
- Opening due to internal pressure
- CFD simulation of mass flow distribution through venting system

VIRTUAL FIRE RESISTANCE TEST
DOES CELL TEMP. REACH CRITICAL VALE?

Fire resistance test

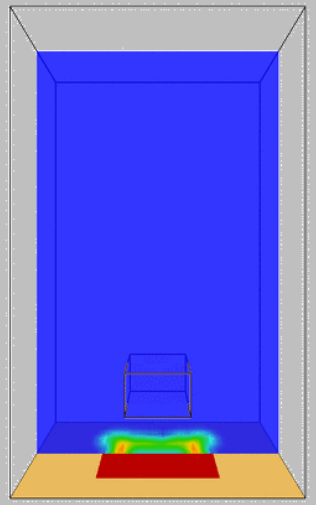
Accord. E/ECE/324/Rev.2/Add.99/Rev.2





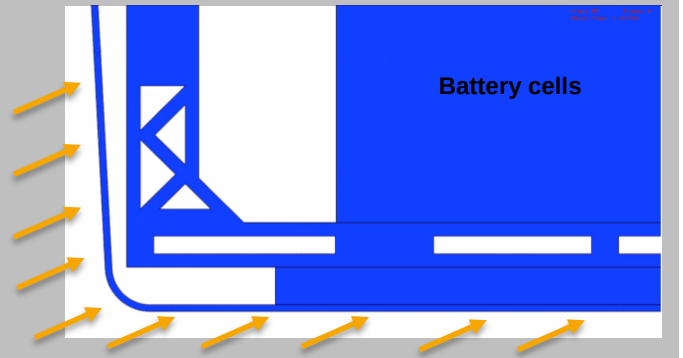
Simulating fuel fire

Fire simulation for deriving accurate boundary conditions on battery housing



Heat source from fire simulation

Simulating battery temperature in the case of external fire source



Boundary conditions from fuel fire simulation applied on housing

Temperature distribution within the battery while fire resistance test → Check if battery temperatures reaches critical cell temperatures

SUMMARY & TAKE AWAY MESSAGE

- **Short introduction of AVL List GmbH**
  - Anticipation of customer needs in R&D
- **Motivation**
  - Impact of Electrified Powertrain on vehicle crash behavior
- **Use cases**
  - Battery Crash: safety assessment from vehicle to cell
  - Thermal system: cooling from vehicle circuit to cell connection
  - Robustness: rough road impact on cell electrical connection
- **Methodology & workflow overview**
  - Simulating mechanical behavior of single cells
  - Simulating thermal runaway in cell, module and pack level
- **Summary & take away message**

SUMMARY

- A short introduction in AVLs current developments in safety and hazard assessment of Li-Ion cells in crash and abuse cases was given.

- Since batteries are essential part of an EV, this requires a comprehensive approach in development: in particular the following points have to be considered:
  - Vehicle related loads and requirements to the battery
  - Battery pack contribution to vehicle structure
  - Module design to support pack requirements
  - Mechanical stiffness of the cells
  - Inner cell design and its intrinsic limitations to the battery design in terms of cooling & robustness

- Various use cases were presented in which the need of a closed and interactive development of cells, modules, packs and vehicle is highlighted.

THANK YOU