

Mechanical Testing Solutions for Lithium-Ion batteries in Automotive applications

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Lithium-ion batteries in automotive applications

Tests on lithium-ion batteries

Mechanical tests on lithium-ion batteries

Zwick testing solutions

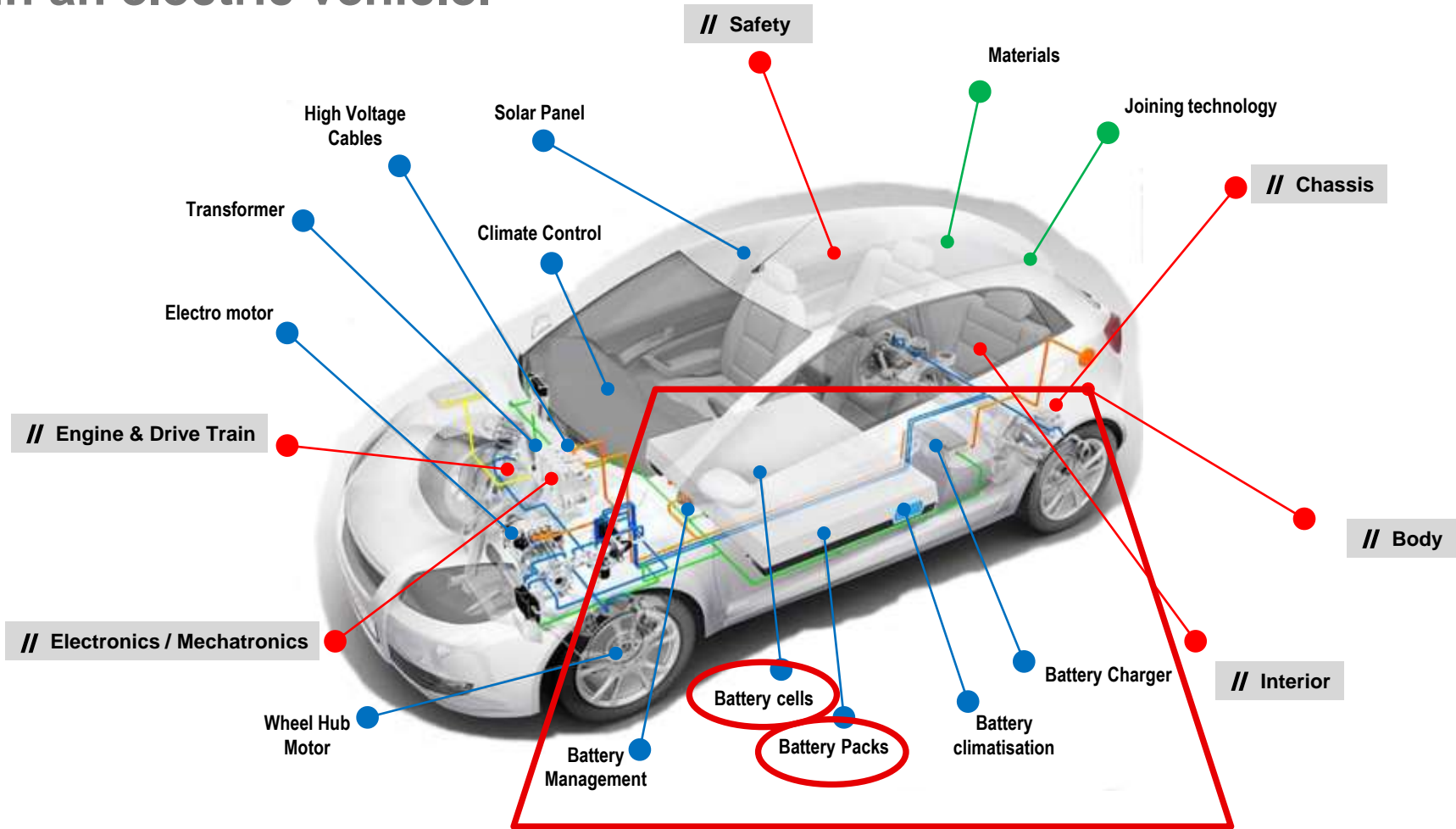
Battery usage in automotive applications

Lithium-ion batteries are used as the main rechargeable energy source in electrical vehicles.



New components in E-Cars

The battery system and its components are the key elements in an electric vehicle.



Battery system components

Battery systems are playing an important role in the performance of electric vehicles.



Battery system components

Traction battery systems are typically made of cells which are combined in modules. Additionally the systems require structural enclosures, management electronics, cabling and cooling.



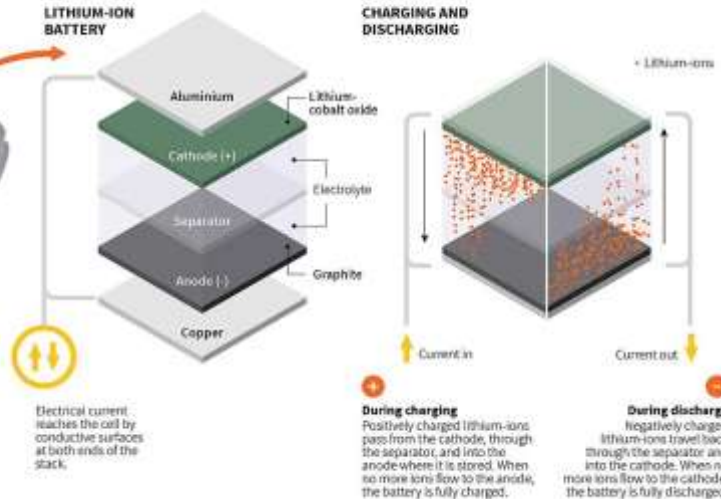
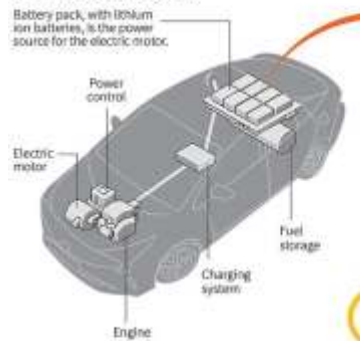
Lithium-ion batteries are highly efficient energy storage devices which allowed modern electric vehicles to become an alternative mobility solution.

- Cell components:
 - Positive electrode (cathode) typically LiCoO_2 or LiFePO_4 – coated aluminum
 - Separator (polymer-film)
 - Negative electrode (anode) typically graphite-coated copper
 - Electrolyte
- During charging lithium-ions move from the positive electrode to the negative electrode -> energy is stored
- During discharge lithium-ions move back from the negative electrode to the positive electrode -> energy is released

How Lithium-ion battery works

The growth of hybrid and electric vehicles over the next decade is likely to affect demand for certain raw materials – most notably, through increasing demand for lithium-ion batteries. Here's a look at how lithium-ion battery works.

TYPICAL CONFIGURATION OF PLUG-IN HYBRID VEHICLES

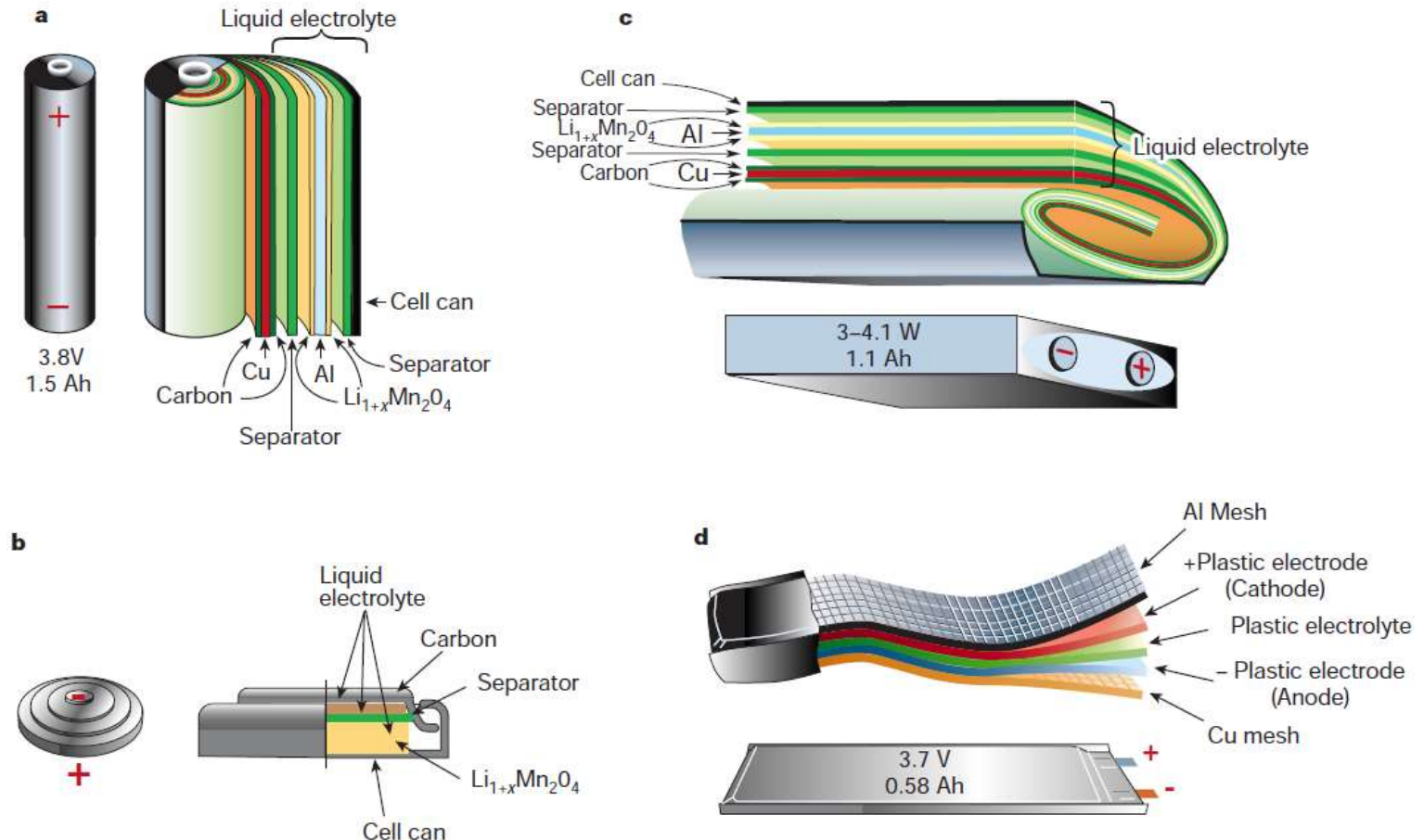


Sources: Toyota, BASF
C. Inon, J. Wu, 26/12/2018

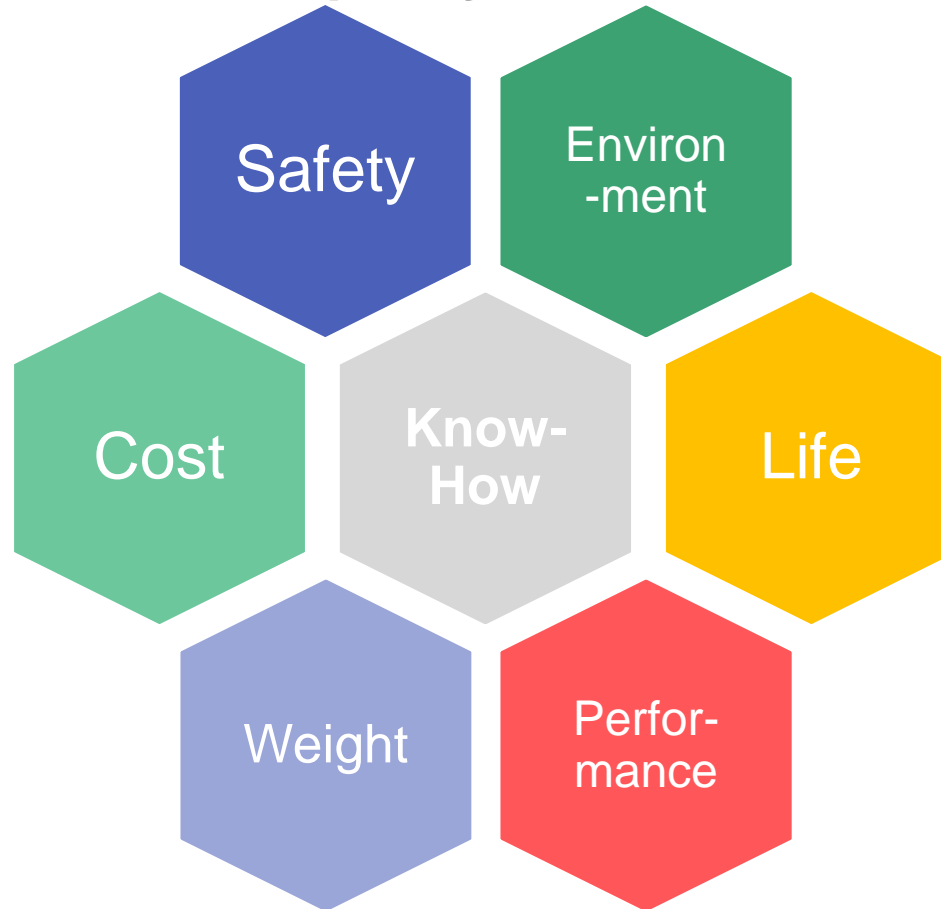
REUTERS

Types of lithium-ion battery cells

Lithium-ion battery cells come in different sizes and shapes. Batteries for electrical vehicles are bigger and store much more energy.



There is a lot of effort going into the improvement of the batteries and the search for the best compromise. Testing is crucial for R&D as well as quality control.



Lithium-ion batteries in automotive applications

Tests on lithium-ion batteries

Mechanical tests on lithium-ion batteries

Zwick testing solutions

A wide range of tests is performed on high power lithium-ion batteries for electrical vehicles.

- Types of tests:
 - Incoming material inspection
 - Electrical characterization *
 - Ageing tests *
 - Safety tests (*)
 - Environmental tests
 - Abuse tests (*)
- Typical standards:
 - UN ECE 100 – R2
 - ISO 12405 - 1, 2, 3
 - SAND2005 – 3123
 - VW PV 8450
 - ...

Overview of typical abuse tests:

Nr.	Test	Result
1	Controlled Crush	✓
2	Penetration	✓
3	Drop	✓
4	Immersion	✓
5	Roll-over Simulation	✓
6	Mechanical Shock	✓
7	Thermal Stability	✓
8	Simulated Fuel Fire	✓
9	Elevated Temperature Storage	✓
10	Rapid Charge / Discharge	✓
11	Thermal Shock Cycling	✓
12	Overcharge / Overvoltage	✓
13	Short Circuit	✓
14	Overdischarge / Voltage	✓
15	Partial Short Circuit	✓

* not or partially in Zwick Roell portfolio

An electric-vehicle battery (EVB) is a high energy device that requires considerable precaution for testing to prevent an uncontrolled fire (thermal runaway).

- Various factors can influence the risk of a short circuit and a „thermal runaway“:
 - State of charge (SOC)
 - Chemical composition
 - Mechanical damage
 - Material quality
 - Manufacturing quality
 - Temperature
 - Vibration
 - Design
 - ...
- **Risk for operators and/or equipment has to be limited by:**
 - **Isolating these critical tests in especially explosion protected rooms**
 - **Using special temperature chambers which add an additional protection**
 - **Ideally a combination of both**

Lithium-ion batteries in automotive applications

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Design goal for **no-fire** should be minimizing risk of short circuit while tolerating certain level of deformation

Impact deformation

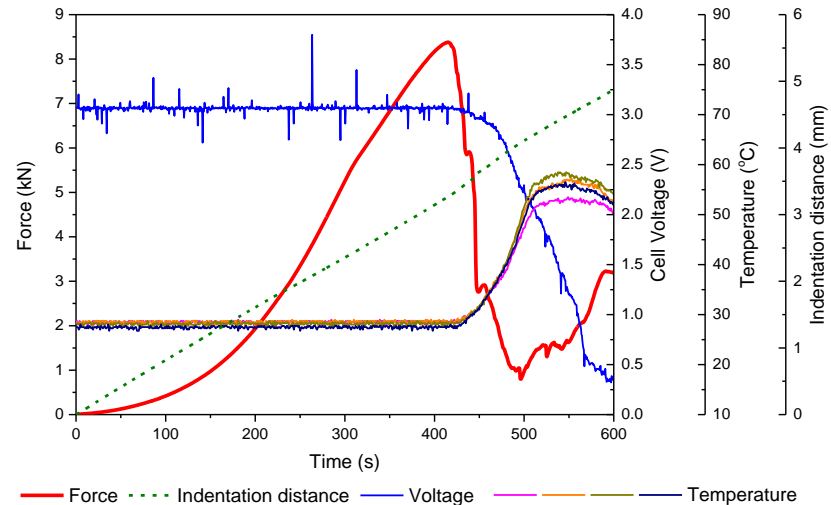
- Damage
- Short circuit
 - Heat accumulation
 - Thermal runaway (fire)



Characterizing and modeling failures of battery materials and short circuit of battery cells



- ✓ indentation increase
- ✓ force peak
- ✓ voltage drop
- ✓ temperature rise



Luo, Jiang, Xia, Zhou. Fracture mode analysis of lithium-ion battery under mechanical loading. 2015 ASME Congress. IMECE2015-52595.

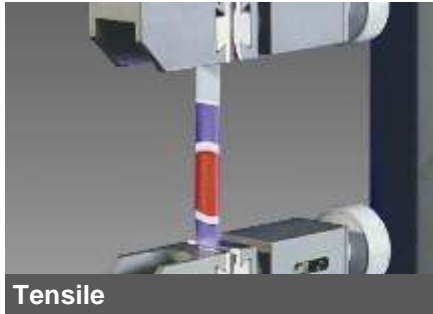
Li-ion battery – Cell materials

Highly automated production processes require a good understanding of material characteristics

- Components/layers of battery cells:
 - Coated and uncoated plastic films (anode, cathode, separators, enclosure)
 - Coating quality (Graphite, Lithium Cobalt Oxide)
 - Aluminum, Copper foil
 - Electrolyte (liquid/solid)
 - Connectors, weld tabs,...
- Tests are performed under various environmental conditions, i.e.
 - Temperature (e.g. $-40^{\circ}/+100^{\circ}\text{C}$)
 - Humidity
 - Chemical influence
 - Mechanical damage
 - Etc...



Various standard testing solutions fulfill the requirements for better characterization of battery cell components



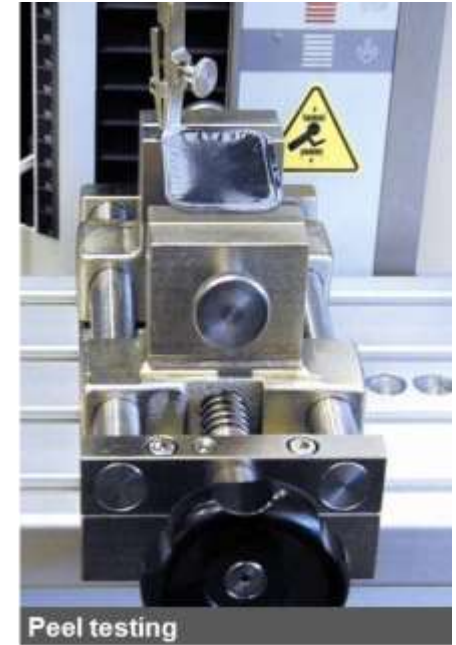
Tensile



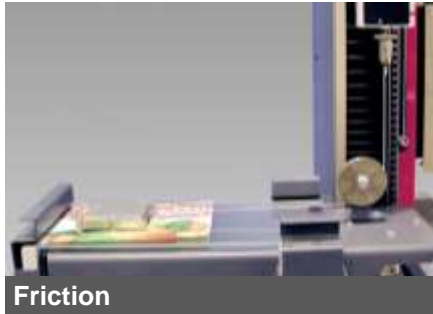
Puncture



2-point flexure



Peel testing



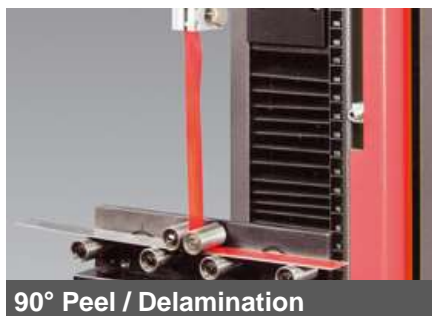
Friction



Horizontal tensile



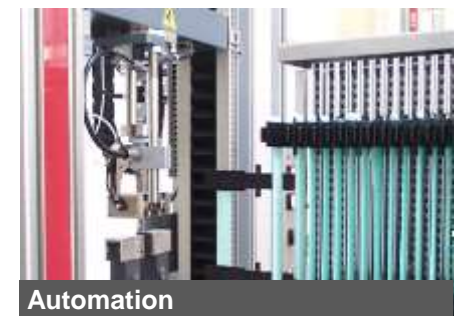
Tensile creep in bath



90° Peel / Delamination



Bi-axial test in bath

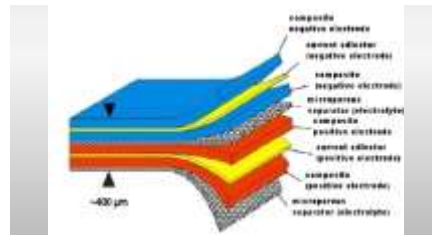


Automation

Testing surface coating adhesion (Graphite and lithium cobalt oxide) on anodes and cathodes of lithium-ion cells



Z-direction tensile test on cathode coating



Li-ion battery cell layers

Description:

determine the surface adhesion forces of electrode coating

Zwick solution:

- Machine: Z010 Allround-Line with testControl II electronics
- Fast (2000 Hz) synchronous measured-value acquisition
- Special Z-direction tensile fixture to measure adhesion forces
- High repeatability and throughput due to up to 5 tests in one setup

Li-ion battery – Cell integrity

Battery cells as smallest energy source entity need to satisfy a number safety critical tests, especially under abuse conditions

- Mechanical tests at different states of charge and environmental conditions:
 - Tensile, Torsion, (Static and Fatigue)
 - 3-/4-point bending (Static and Fatigue)
 - SOC Inflation/Deformation
 - Forced short-circuit (Nail penetration test)
 - Crush
 - Drop *
 - Impact
 - ...

* not in Zwick Roell portfolio

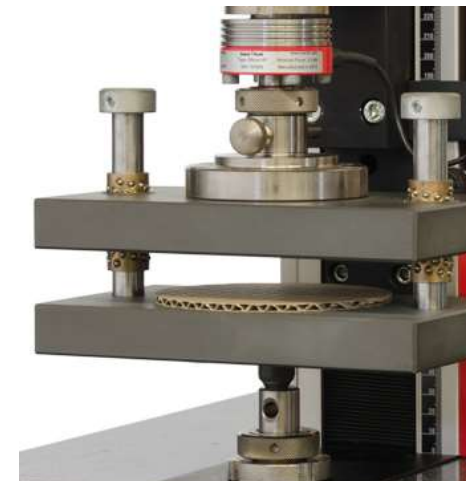
Examples of mechanical tests on lithium-ion pouch cells



Nail penetration / Impact



Puncture



Flat crush

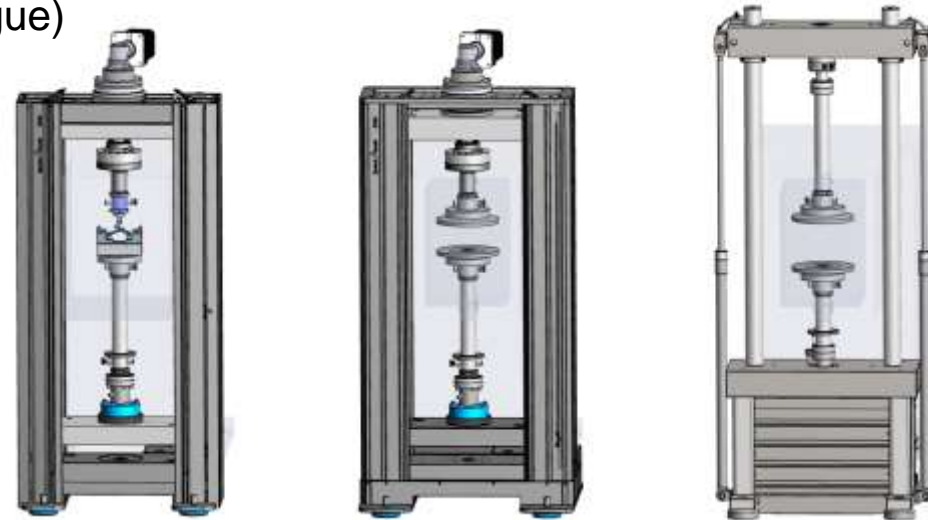


Edge crush

*Cardboard sample in place of pouch cell

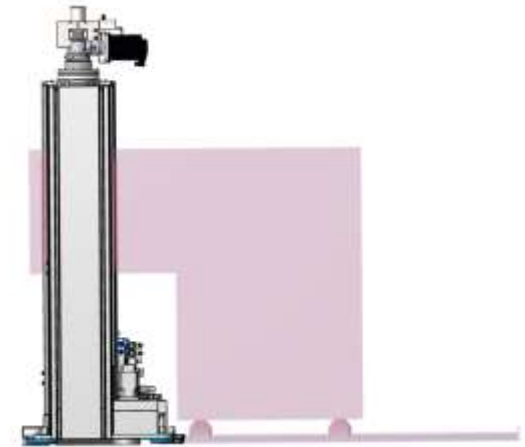
Example of a test configuration for advanced material research on lithium-ion and future technology battery cells

- Research objective:
 - R&D on new materials for high energy battery cells
- Types of test:
 - Tension, Flexure, Torsion (static and fatigue)
 - Temperature
- Equipment:
 - 2x Tension-Torsion (100 + 250 kN)
 - 1x Fatigue loadframe (100 kN)
 - 3x Temperature chamber (EUCAR 6)
 - Special tooling for future cell design
 - Integrated with room safety equipment



Mechanical tests on battery cells

Special temperature chambers (EUCAR 6) protect operators and testing equipment.



Universal Testing Machine
equipped with safety temperature
chamber

Li-ion battery – Modules

Battery modules are comprised of several battery cells. The integrity of the module is of high importance.

- Battery modules/packs:
 - Mechanical enclosure (Aluminum, Sheet metal, Plastics)
 - Cabling
 - Cooling
 - Connectors
- Tests:
 - Shock / Impact
 - Crush
 - Environmental
 - Structural
 - Abuse (*)
 - Vibration *
 - Electrical performance *

* not in Zwick Roell portfolio

Entire battery systems are typically tested for their performance in a vehicle in various conditions

- Entire battery systems:
 - Mechanical enclosure (Aluminum, Sheet metal, Plastics)
 - Cabling
 - Cooling
 - Connectors
- Tests:
 - Shock tests
 - Vibration tests
 - Environmental tests
 - Structural tests