Zwick / Roell

Intelligent Testing

Mechanical Testing Solutions for Lithium-Ion batteries in Automotive applications

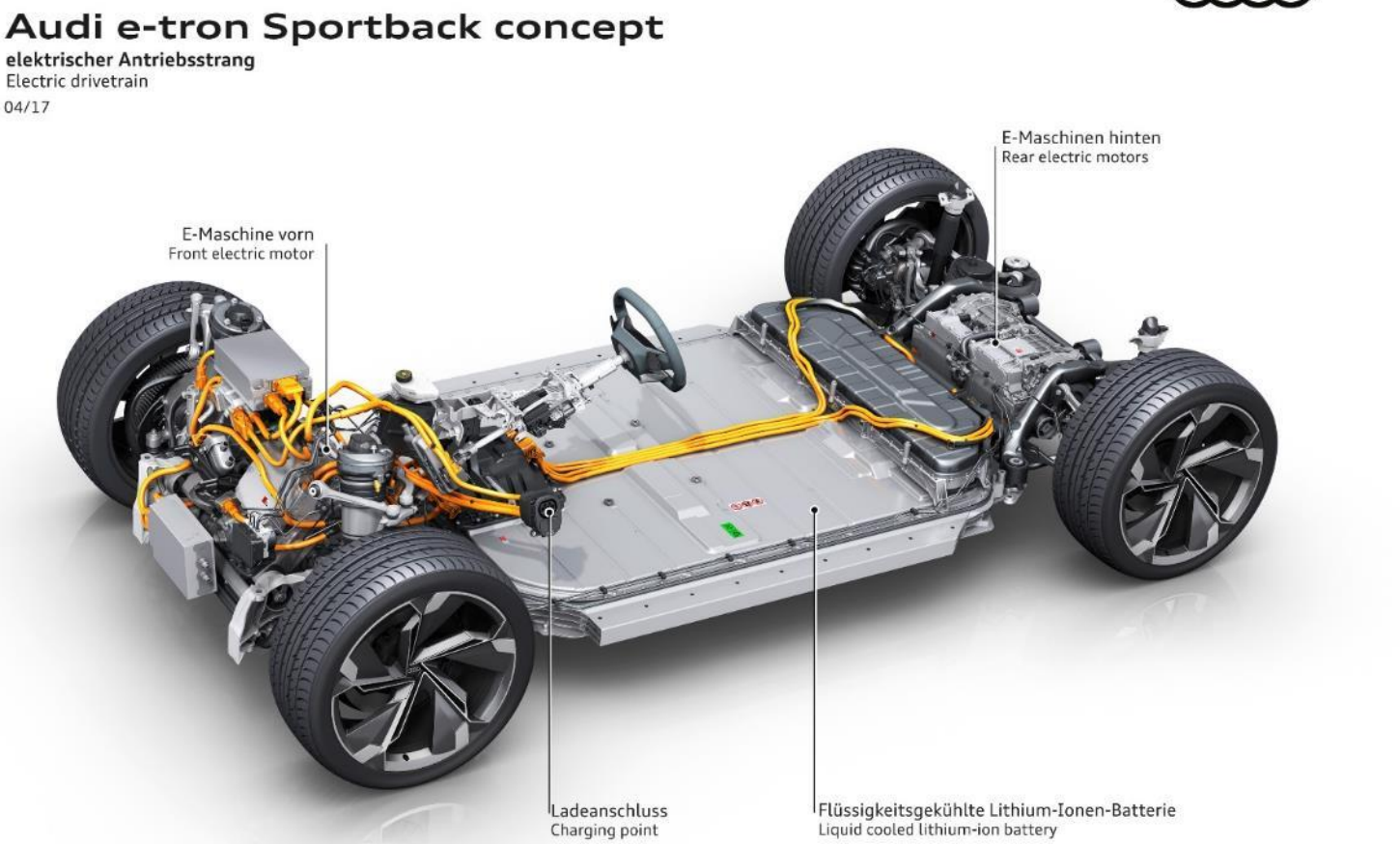
A. Koprivc

testXpo 2019

Contents

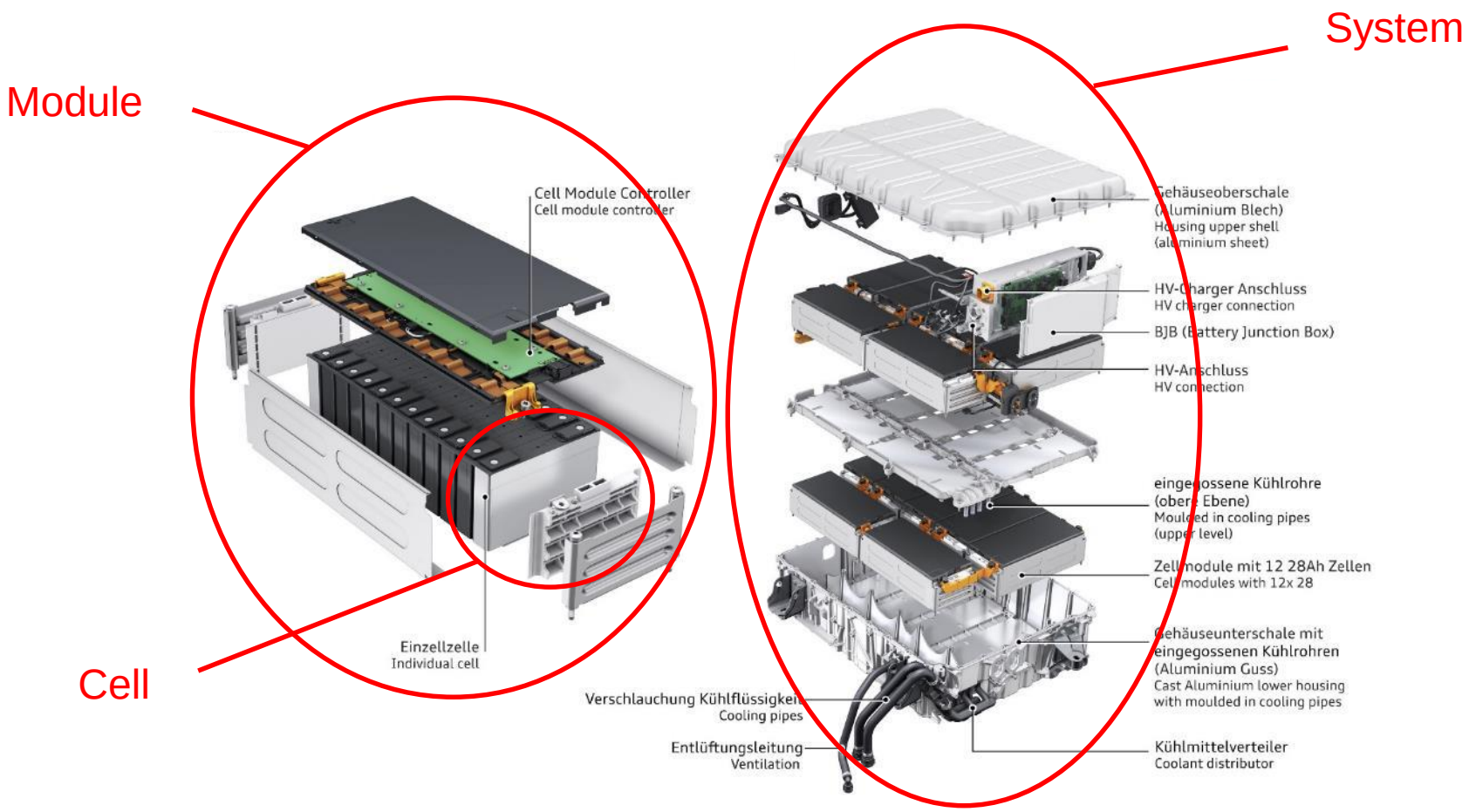
Battery system components

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



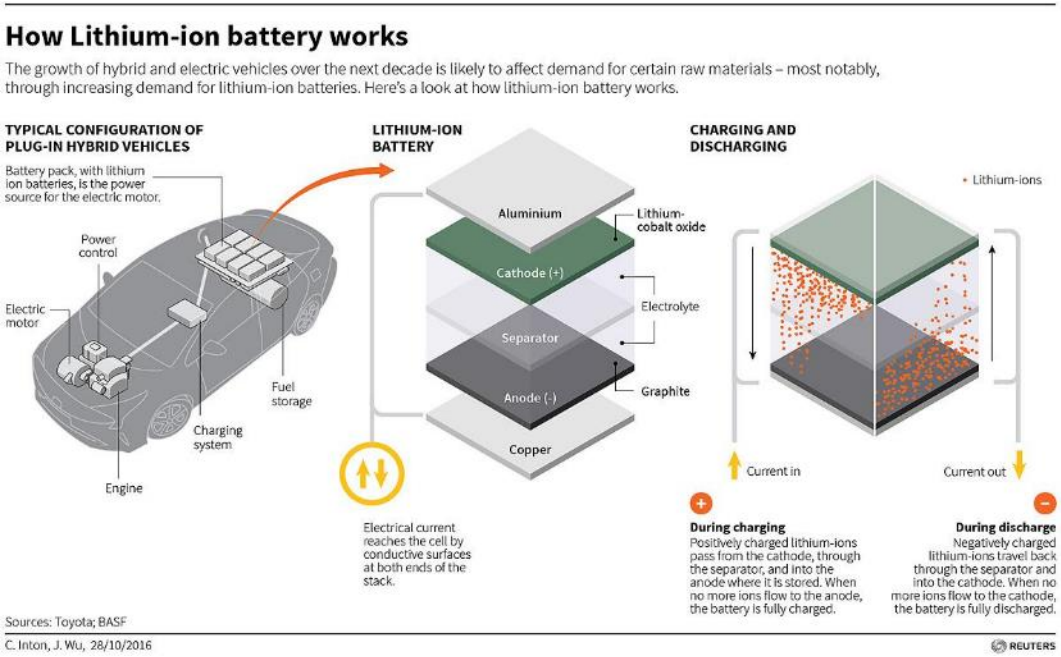
Battery system components

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



Working principle of a Lithium-ion battery

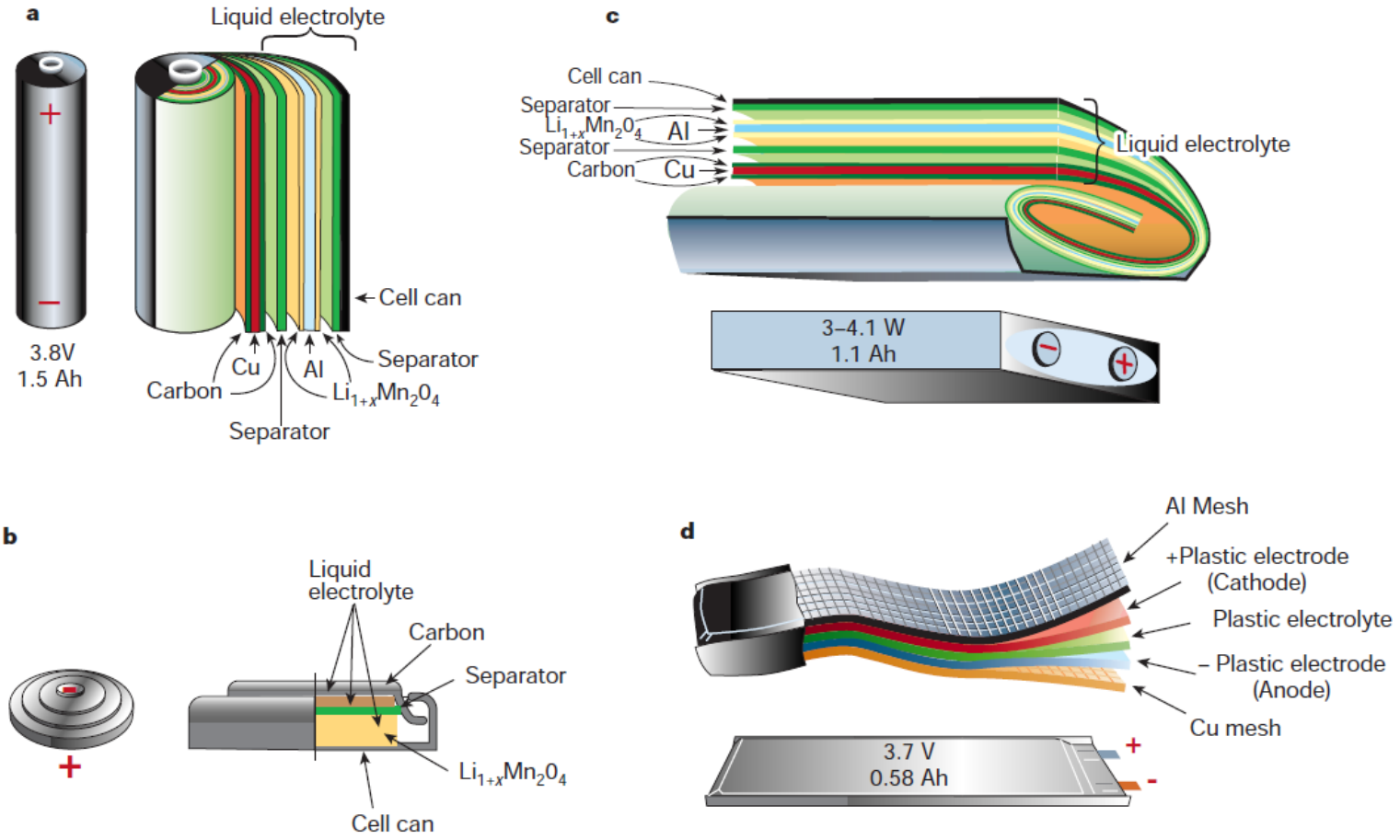
Lithium-ion batteries are highly efficient energy storage devices which allowed modern electric vehicles to become an alternative mobility solution.



- Cell components:
  - Positive electrode (cathode) typically LiCoO2 or LiFePO4 – 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

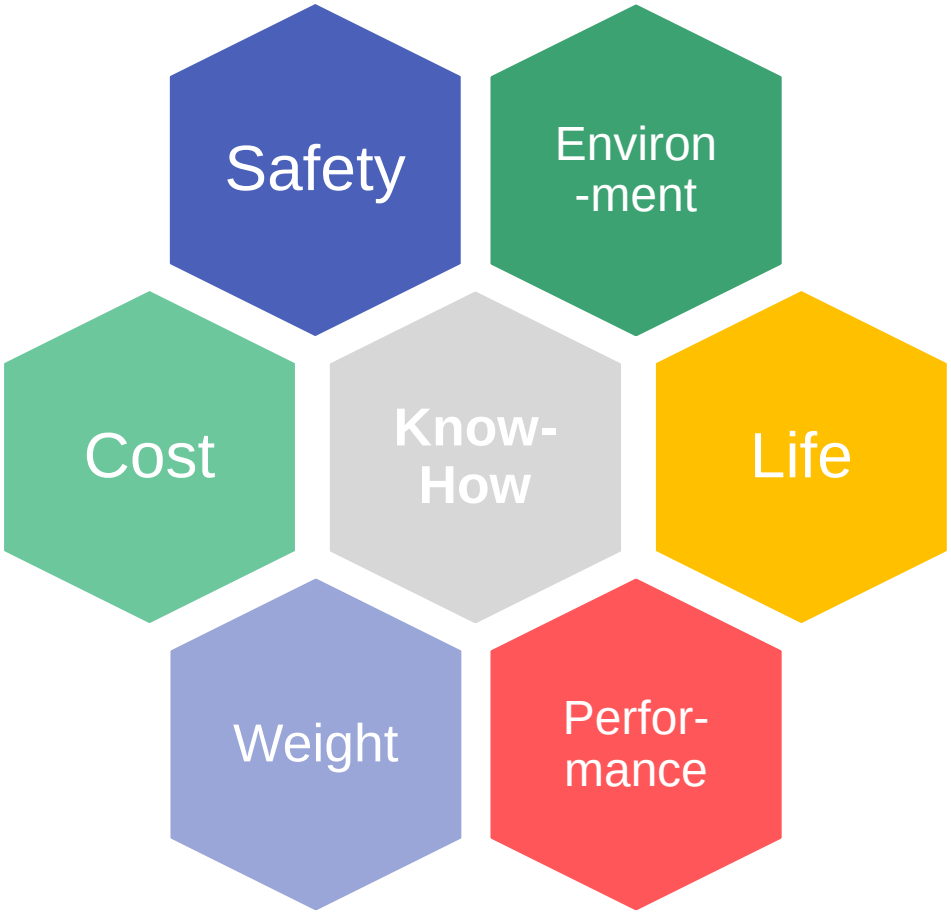
Types of lithium-ion battery cells

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



Design objectives for lithium-ion batteries

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.



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Testing of lithium-ion batteries

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	✓

Mechanical tests on battery cells

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**

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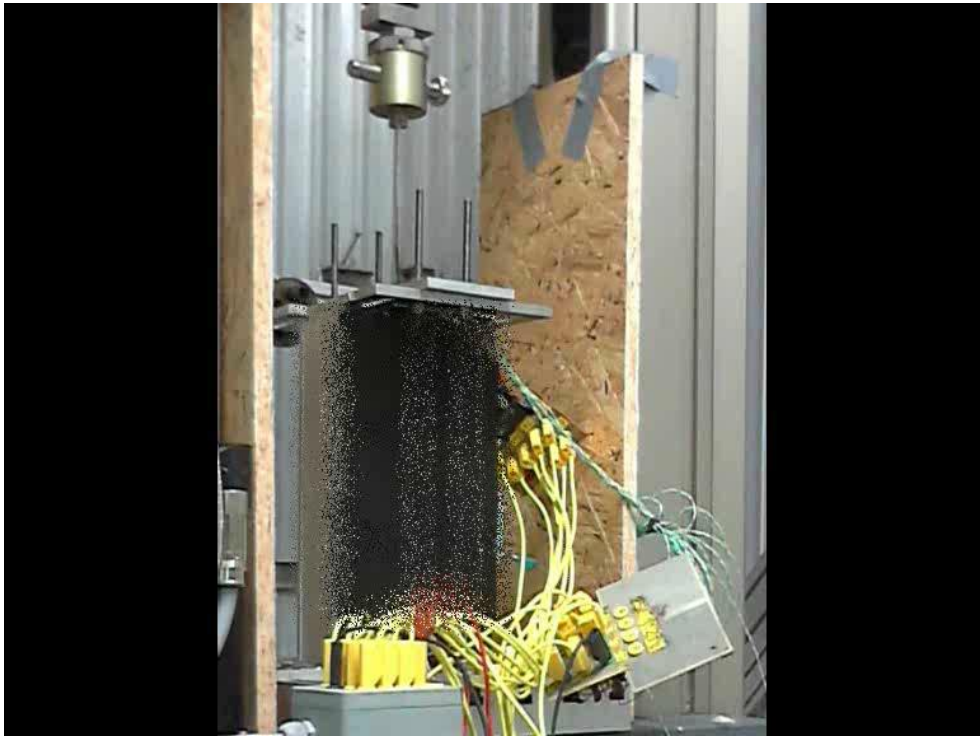
Design objective for battery impact protection

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

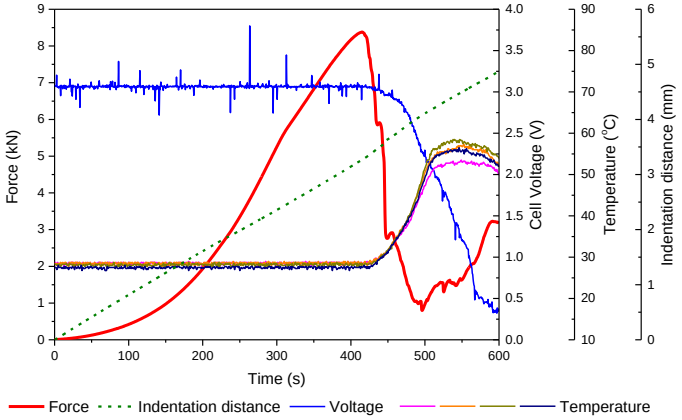
Impact deformation
- → Damage
  - → Short circuit
    - → Heat accumulation
      - → Thermal runaway (fire)



Nail penetration test on Lithium-Ion Battery cell (2005)

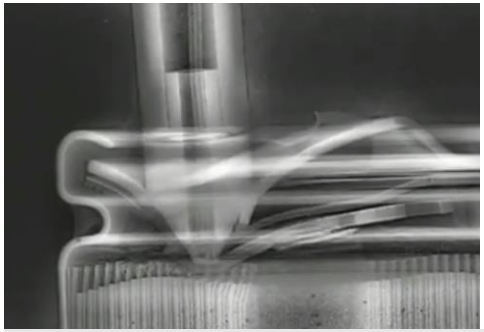
Li-ion battery – Cell integrity

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



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

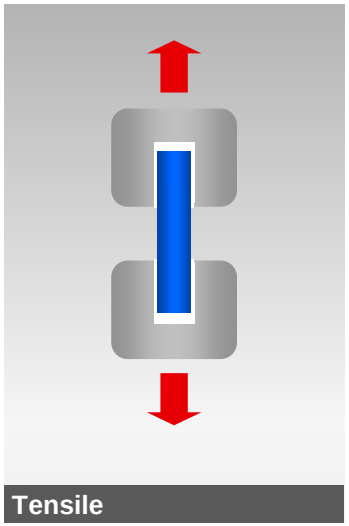
- ✓ indentation increase
- ✓ force peak
- ✓ voltage drop
- ✓ temperature rise

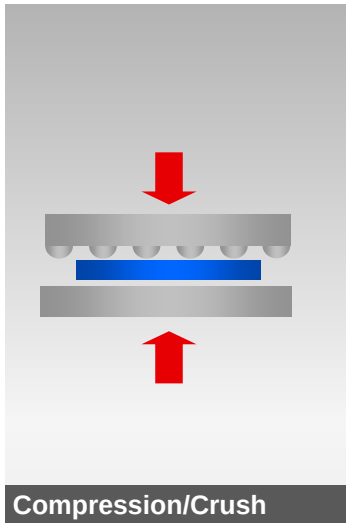


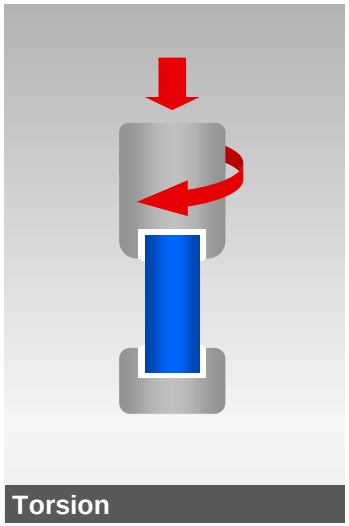
Tracking Internal Temperature and Structural Dynamics during Nail Penetration of Lithium-Ion Cells
Donal P. Finegan,a,b Bernhard Tjaden,a Thomas M. M. Heenan,a,* Rhodri Jervis,a
Marco DiMichiel,c Alexander Rack,c Gareth Hinds,d Dan J. L. Brett,a and Paul R. Shearinga,z

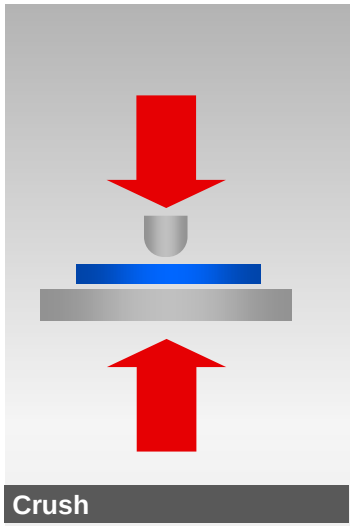
Mechanical testing solutions from ZwickRoell

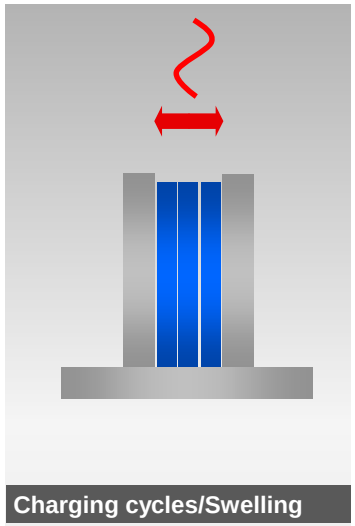
Main mechanical tests for cell components, cells, modules and systems

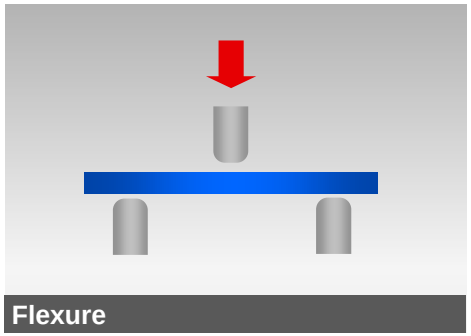

Tensile

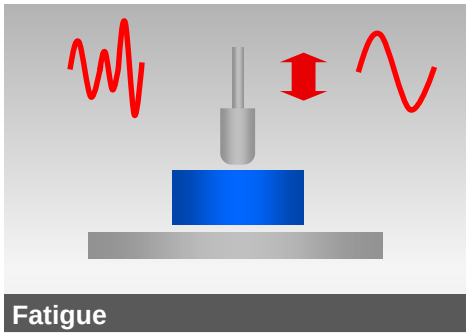

Compression/Crush

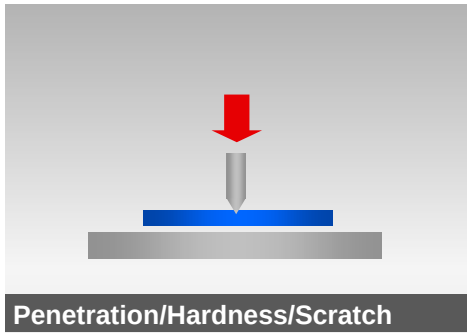

Torsion

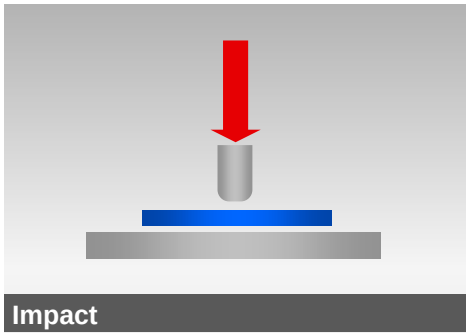

Crush


Charging cycles/Swelling


Flexure


Fatigue


Penetration/Hardness/Scratch


Impact

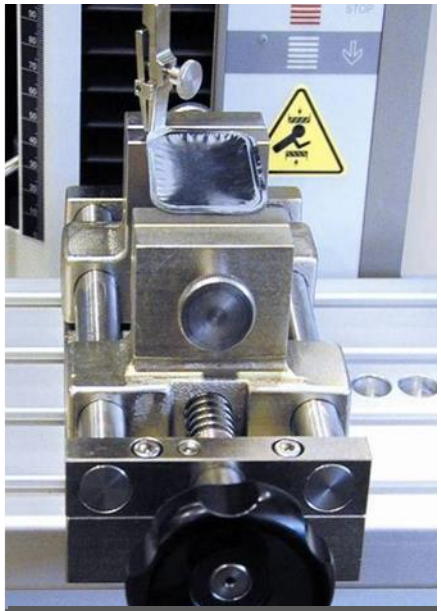
Li-ion battery – Cell materials

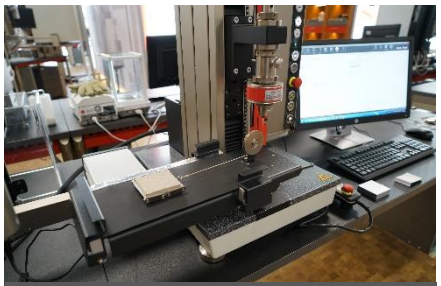
Various standard testing solutions fulfill the requirements for better characterization of battery cell materials

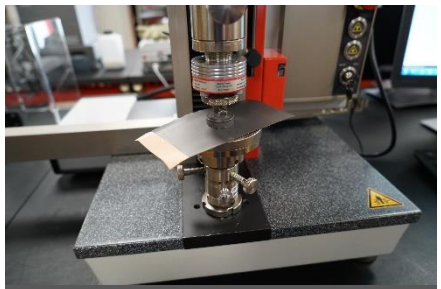

Tensile


Puncture

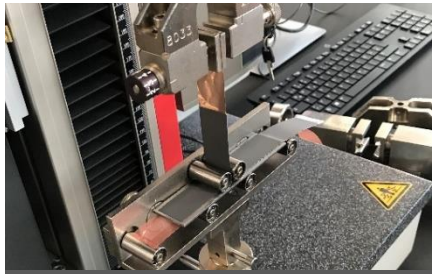

2-point flexure

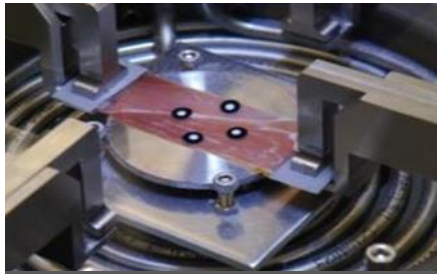

Tab weld

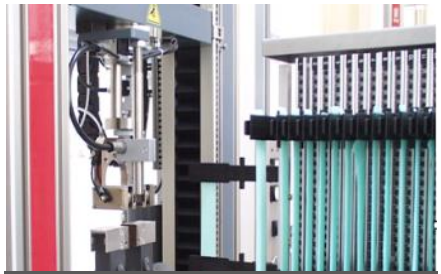

Friction


Coating compression


Tensile/Compression creep in bath


90° Peel / Delamination

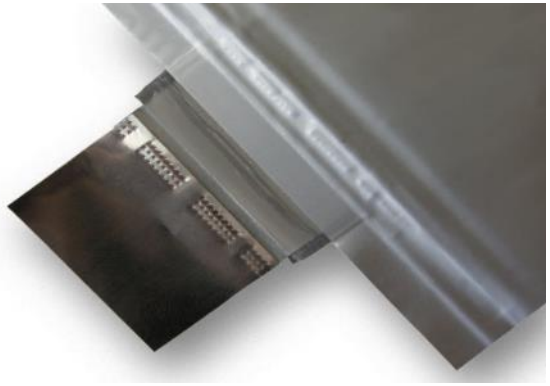

Bi-axial test in bath


Automation

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°/+100°C)
  - Humidity
  - Chemical influence
  - Mechanical damage
  - Etc…

Li-ion battery – Cell materials

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

Z-direction tensile test on cathode coating

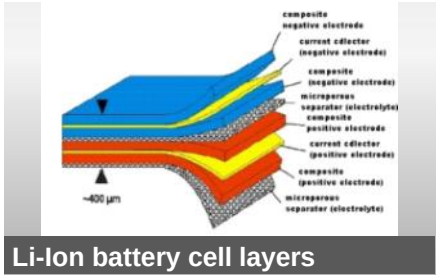
Description:

determine the surface adhesion forces of electrode coating

ZwickRoell solution:

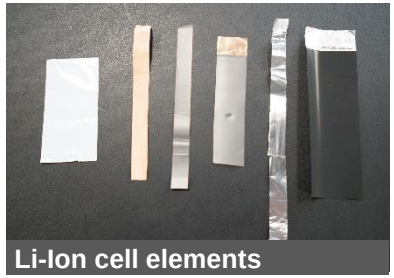
- Machine: Z010 Allround-Line with fast (2 kHz) synchronous measured-value acquisition
- Special Z-direction tensile fixture to measure coating adhesion forces
- High repeatability and throughput due to up to 5 tests in one setup

Coating after test



Li-Ion battery cell layers

Typical Li-Ion battery cell

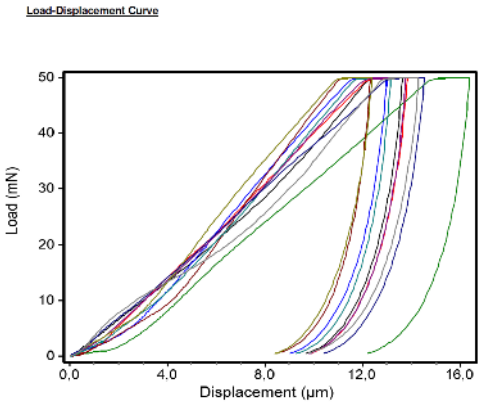


Li-Ion cell elements

Li-ion battery – Cell materials

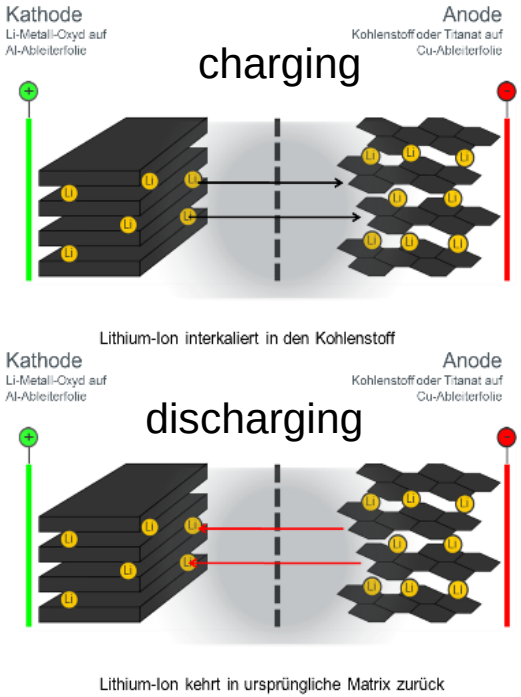
Improvement of mechanical fatigue properties of electrode composites of lithium ion battery cells during charging cycles.

Nanoindentation hardness tester for the determination of mechanical properties of different electrode coatings at various ageing stages (mechanical, thermal, electrochemical).



Force-Deformation curve of a Carbon coating on Cu-anode

ZHN, Nanoindentation tester with flat punch fixture



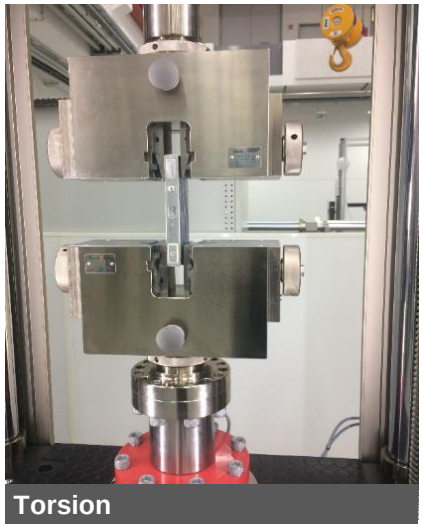
Movement of lithium ions during charging cycles
Source: Prof. Schreiber

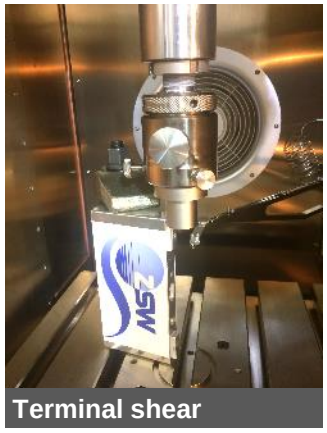
Li-ion battery – Cell integrity

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

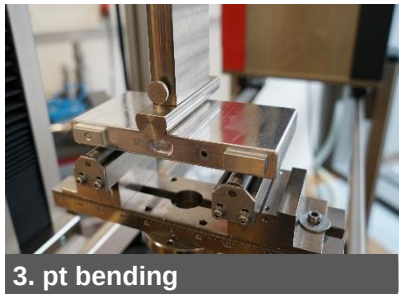
- Mechanical tests at different states of charge and environmental conditions:
  - Tensile, Torsion, (Static and Fatigue)
  - 3-/4-point bending (Static and Fatigue)
  - SOC Inflation/Deformation
  - Forced short-circuit (Nail penetration test)
  - Crush
  - Drop *
  - Impact
  - …


Nail penetration


Torsion


Terminal shear


Inflation/Deformation


3. pt bending

* not in ZwickRoell portfolio

Li-ion battery – Cell integrity

Examples of mechanical tests on lithium-ion pouch cells


Impact


Puncture


Flat crush


Edge crush


Terminal Shear

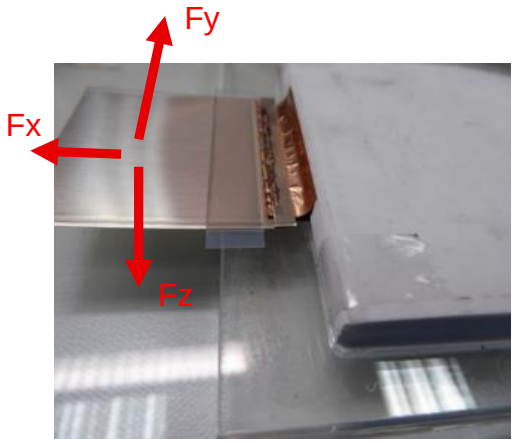
*Cardboard sample to be replaced by pouch cell

Li-ion battery – Cell integrity

Objective: Validate safe electrode welds of large format lithium ion cells against themo-mechanical cyclical fatigue

Linear drive system LTM with flexible sample fixture for Fx, Fy, Fz determination.

Typical loading cycle for conductor



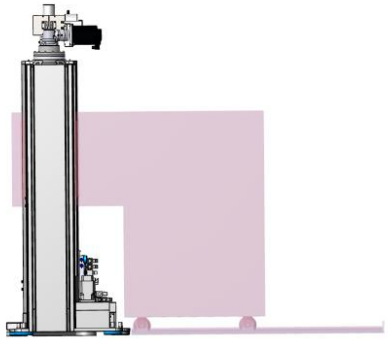
Loading axes for a pouch cell conductor

LTM 1, 1 kN Linear drive test system

Li-ion battery – Cell research

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

- 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 set for future cell design
  - Integrated with room safety equipment

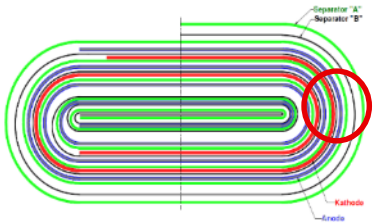


Universal Testing Machine equipped with safety temperature chamber

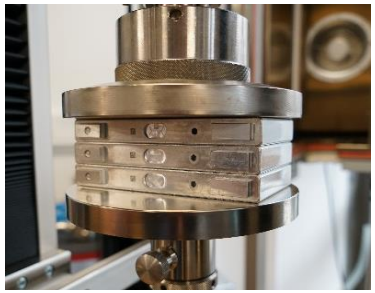
Li-ion battery – Cell research

Design improvement of cell structures of larger scale Lithium-ion batteries through measurement of mechanical loading and deformation during charging cycles (swelling).

- Servohydraulic test machine (100 kN) for the determination of swelling effects of lithium ion cells during charging cycles.
- Machine can be equipped with temperature chamber for simulation of environmental conditions (-80°C - +250°C).
- High risk of fire requires special protection chambers (Hazard Level 6).



Schematic drawing of a wound cell



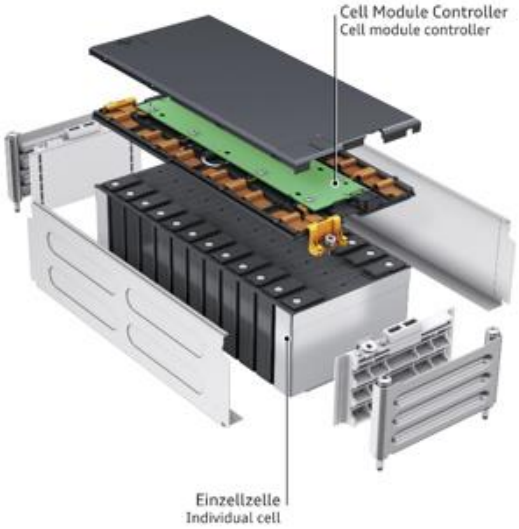
Compression tool for active and passive compression tests on lithium-ion cells

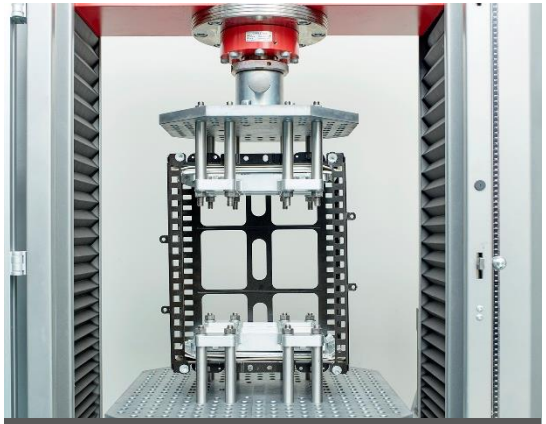
HA 100, 100 kN testing machine prepared for integration of a temperature chamber (HL6)

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, connectors
  - Cooling
- Tests:
  - Shock / Impact
  - Crush
  - Environmental
  - Structural
  - Abuse (*)
  - Vibration *
  - Electrical performance *




Structural test

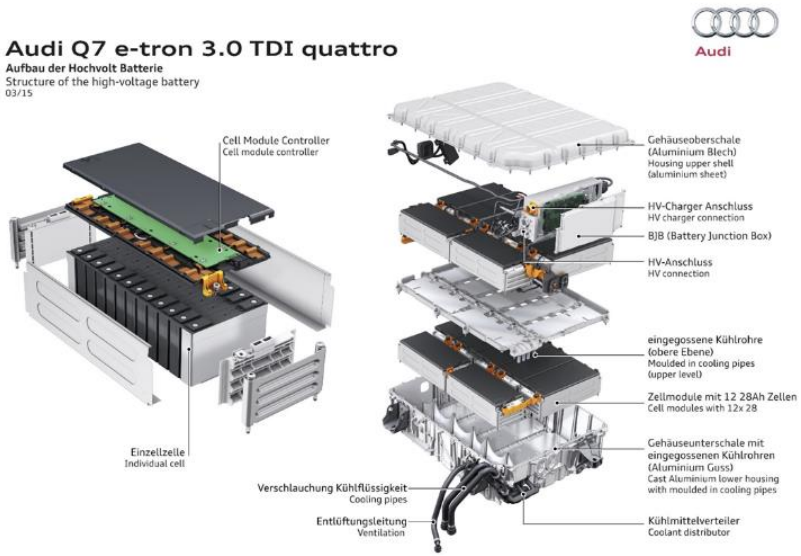
* not in ZwickRoell portfolio

Li-ion battery – System

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

Structural test



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Testing solutions

Through constant innovation, we offer all components necessary for professional material testing.

// Static testing machines

// Fatigue testing machines

// Hardness testers

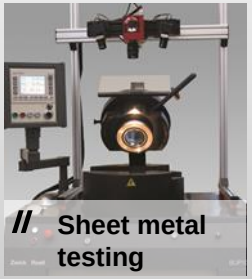
// Software testXpert® III

// Electronics

// Impact Testers

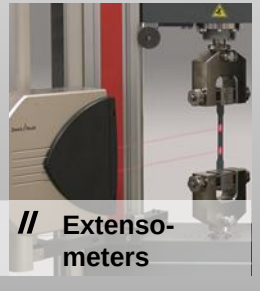
// Plastometers

// HDT-Vicat

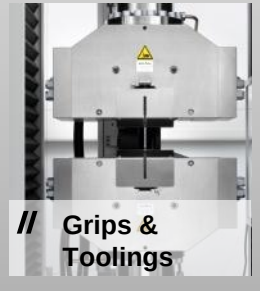


// Sheet metal testing

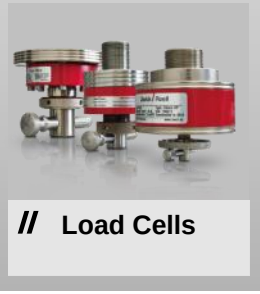
// Robotic testing



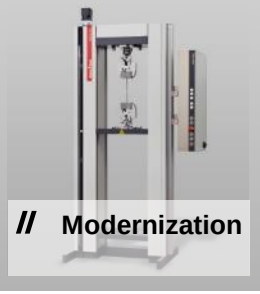
// Extenso-meters



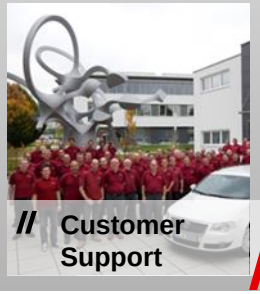
// Grips & Toolings



// Load Cells



// Modernization



// Customer Support

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