EDAG GROUP

BATTERYMODEL FOR FULL VEHICLE SIMULATION

EDAG

FACTS & FIGURES
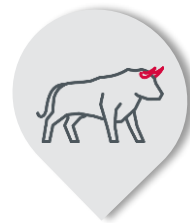
EDAG

| 1969 FOUNDATION | ~ 60 LOCATIONS WORLDWIDE | 19 COUNTRIES | ~ 8,000 EMPLOYEES | 33 SHOW CARS | 2015 IPO | ~ 5 % TRAINING RATE | 650 MILLION REVENUE | ~ 2-3% CAPITAL EXPENDITURE ON REVENUE |

EDAG WORLDWIDE

Europe:
- Germany
- United Kingdom
- Italy
- Netherlands
- Poland
- Sweden
- Switzerland
- Spain
- Czech Republic
- Turkey
- Hungary

Asia:
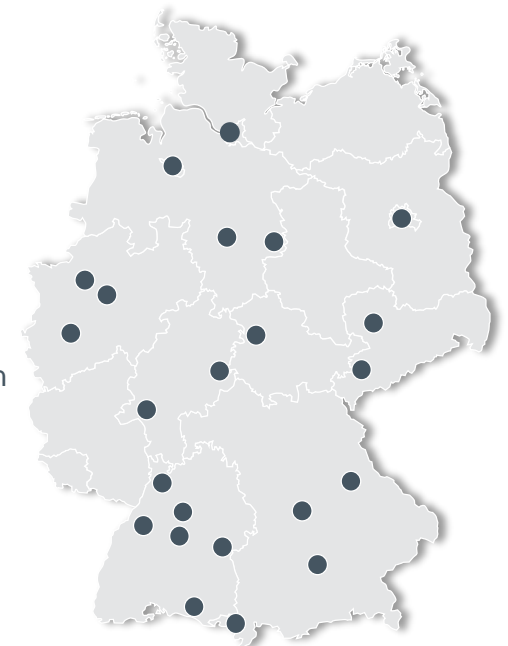- China
- India
- Japan
- Malaysia
- Russia

North & South America:
- Brazil
- Mexico
- USA

EDAG GERMANY

- Berlin
- Bremen
- Dortmund
- Eisenach
- Friedrichshafen
- Fulda
- Hamburg
- Hannover
- Ingolstadt
- Karlsruhe
- Köln
- Leipzig
- Lindau
- München
- Neckarsulm
- Recklinghausen
- Regensburg
- Stuttgart
- Ulm
- Weinheim
- Wiesbaden
- Wolfsburg
- Zwickau

OUR
RANGE OF SERVICES

Vehicle Engineering
- Complete vehicle: Development & Management
- Vehicle Integration
- Body in White
- Chassis
- Interior & Exterior
- Drive Train
- Low-volume Series & Edition

360° VEHICLE ENGINEERING

Software & Digitalisation
- Mobility Software
- Connected Services
- Smart City
- Smart Factory

Electrics / Electronics
- Vehicle Electrics & Electronics
- eDrive & Energy Systems
- Comfort & Body Systems
- Autonomous Drive & Safety
- Connectivity & User Experience
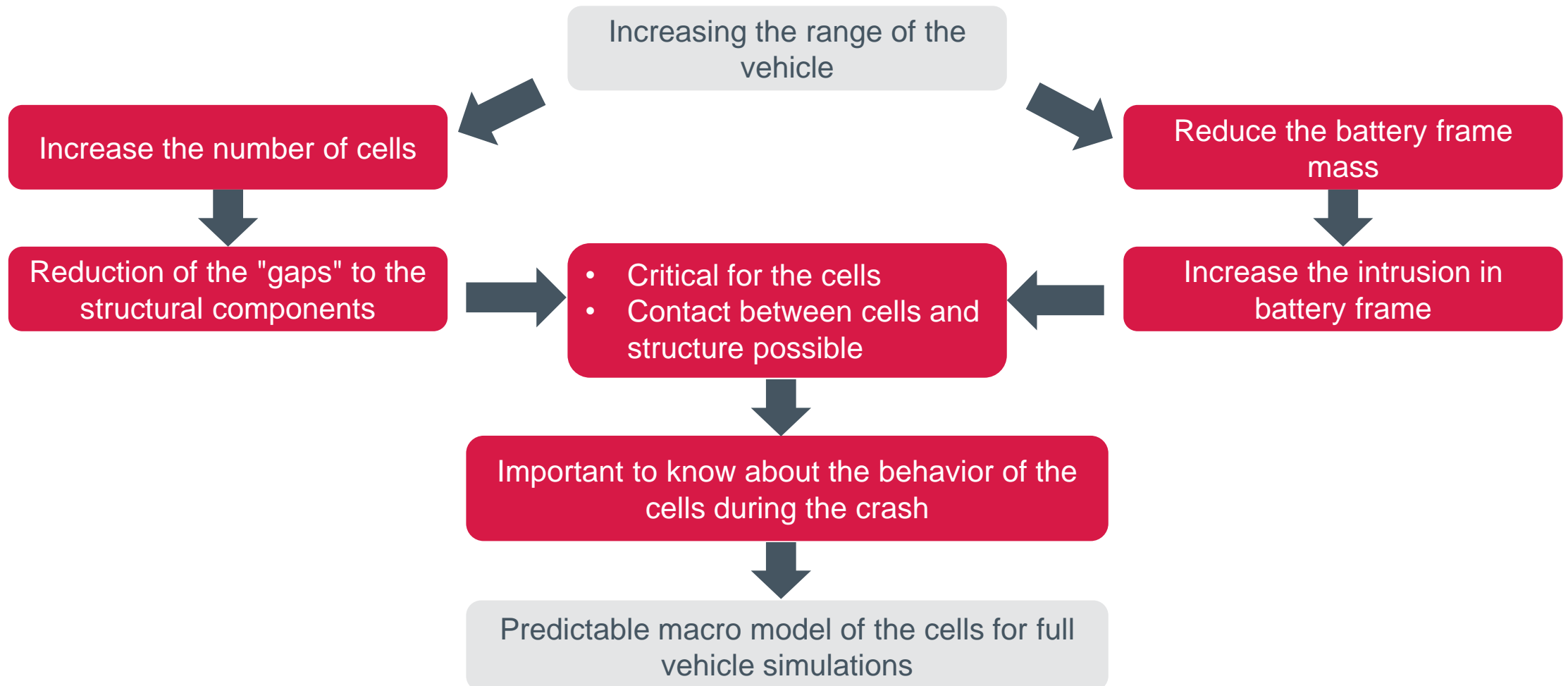
360° PRODUCTION ENGINEERING

Production Solutions
- Feasibility Analysis
- Production Planning
- Systems Engineering
- Fixture Technology
- Plant Automation
- Production Optimisation
- Safety Engineering Services

Increasing the range of the vehicle

Increase the number of cells

Reduce the battery frame mass

Reduction of the "gaps" to the structural components

- Critical for the cells
- Contact between cells and structure possible

Increase the intrusion in battery frame

Important to know about the behavior of the cells during the crash

Predictable macro model of the cells for full vehicle simulations

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BATTERYMODEL FOR FULL VEHICLE SIMULATION
BASIC INFORMATION

- Coupling of mechanical and electrical solvers
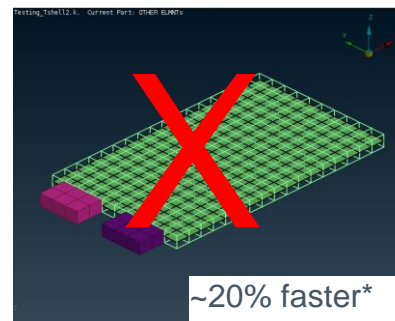- Use of a Randles Circuit for cell simulation
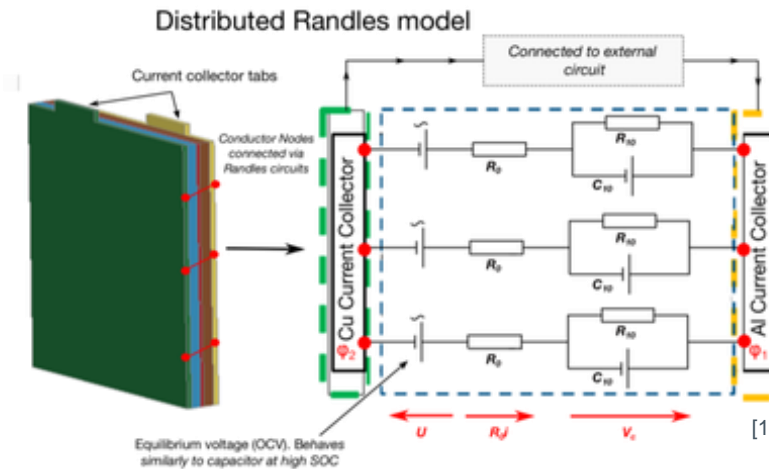
- Simulation of cylindrical, prismatic and pouch cells possible
- We are using a Randle BatMac model to keep the simulation time in acceptable limits
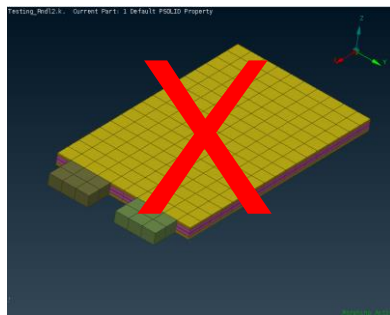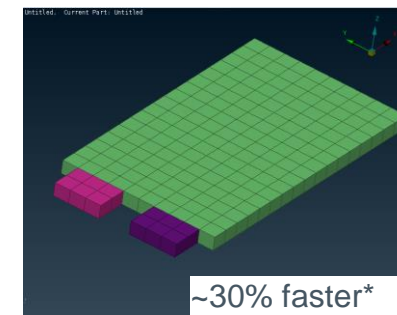
Randles Solid	Randles T-Shell	Randles BatMac

~20% faster*

~30% faster*

* simulation of 1 cell compare to randles solid

[1] Dyna Examples: https://www.dynaexamples.com/em/battery

BATTERYMODEL FOR FULL VEHICLE SIMULATION
ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

B154 x L248 x H12

44Ah

- Cell model: LC-44 Litacell

- Electrochemical impedance spectroscopy every 10% State of Charge (SoC)

  - Test sequence of discharge cycles (from 100% to 10%) and rest phases

- Determination of the characteristic values for the equivalent circuit diagram

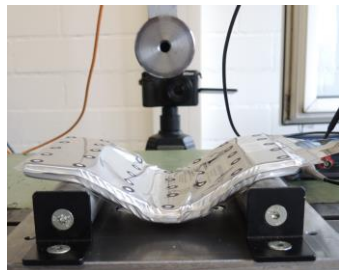 - Characteristic values were subsequently adjusted using a curve fitting method in Matlab
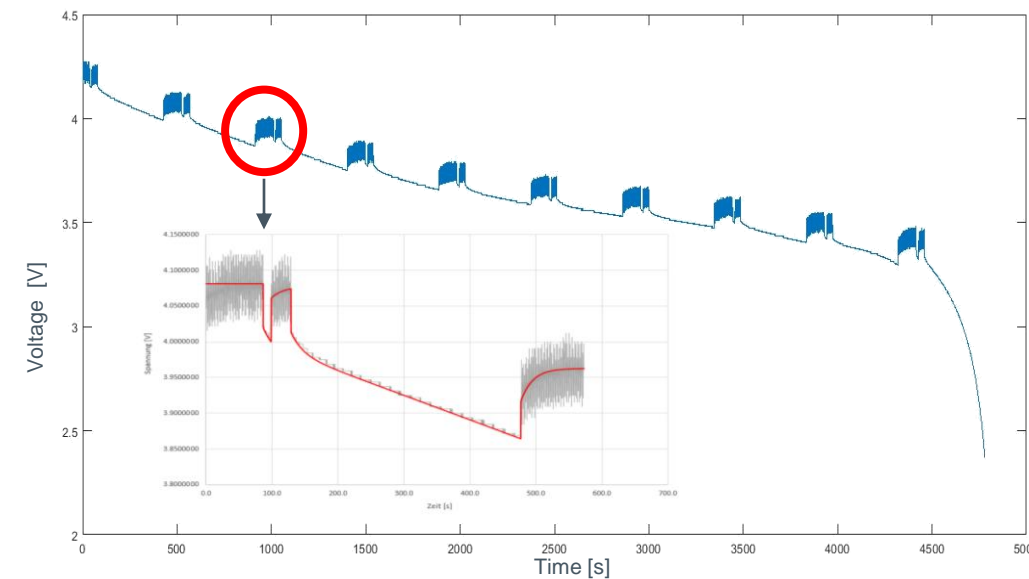
BATTERYMODEL FOR FULL VEHICLE SIMULATION
TESTS FOR VALIDATION

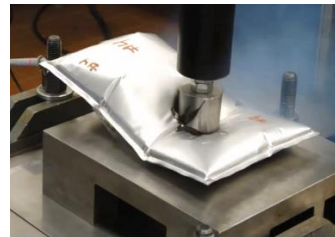B154 x L248 x H12

44Ah

Pouch cell

21700

5000mAh

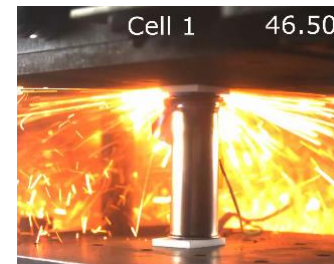**Cylindrical cell**

3 point bending test

Flat stamp

Sphere

Axial

Radial

Round bar

Cell 1   46.50

Cell 4   37.1

Cell 2   35.73
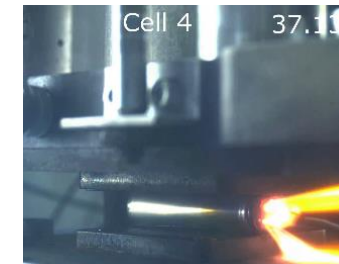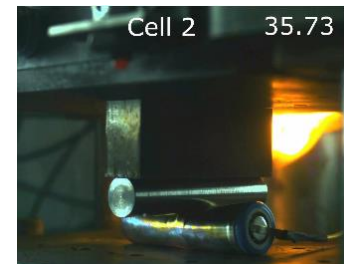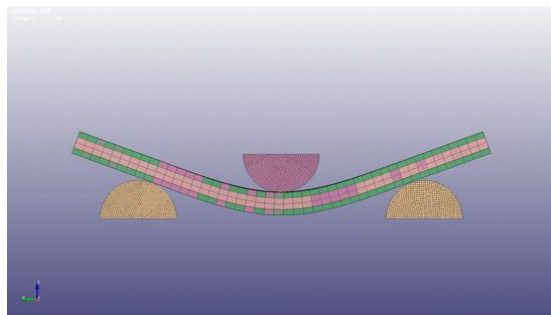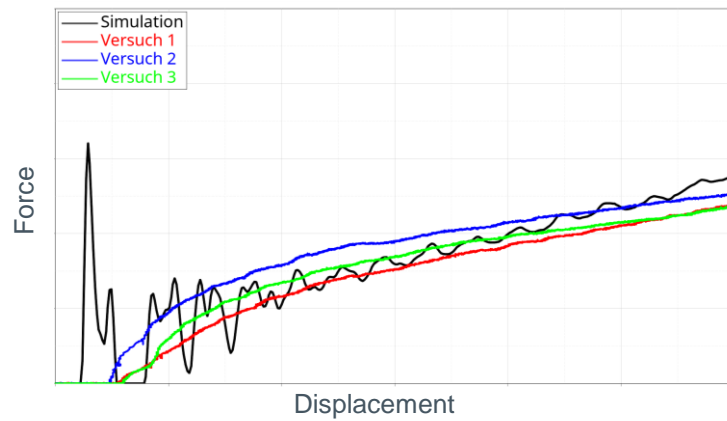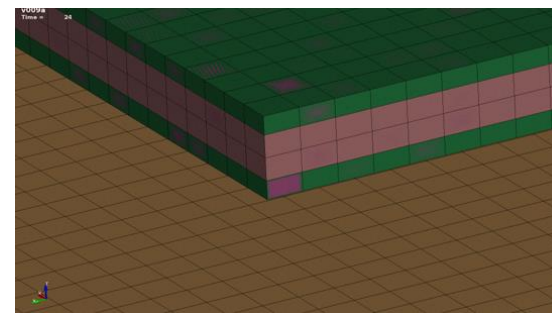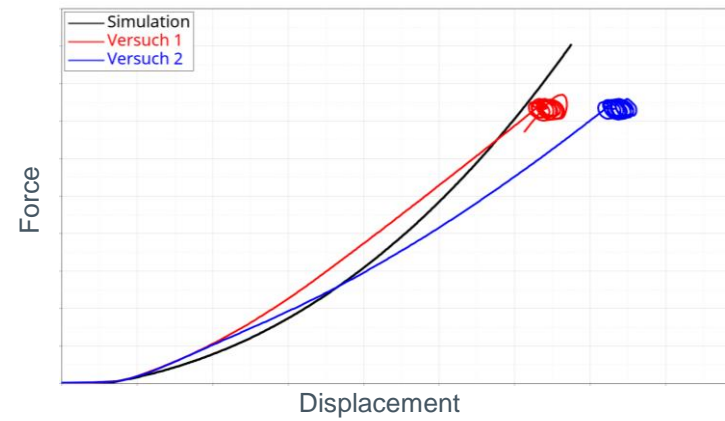
BATTERYMODEL FOR FULL VEHICLE SIMULATION
POUCH CELL

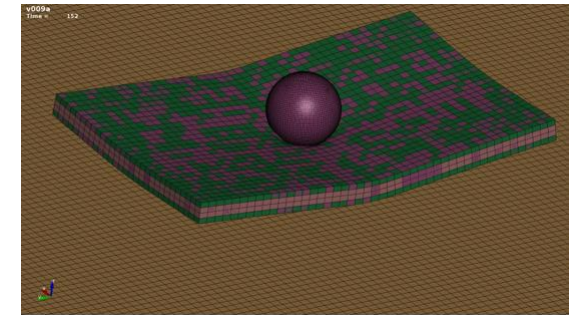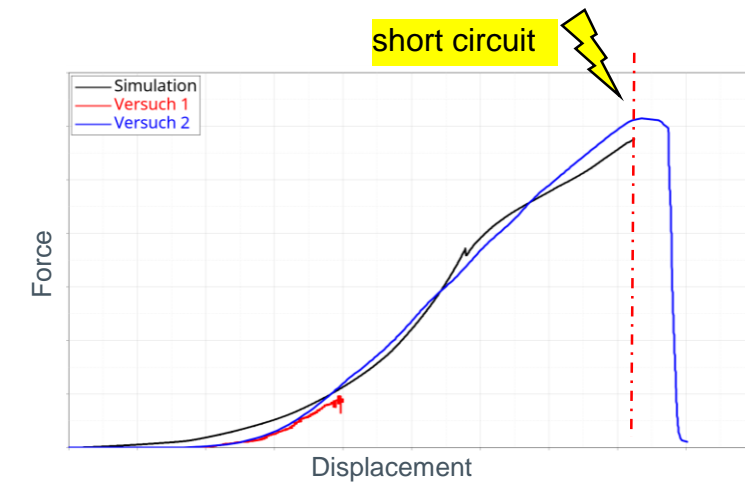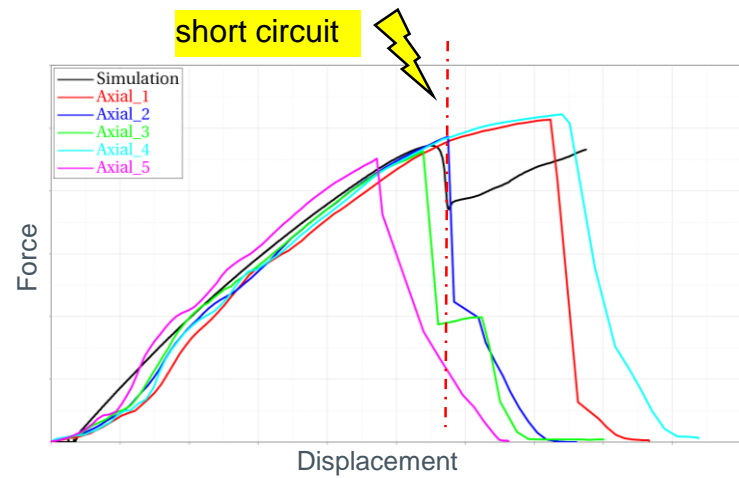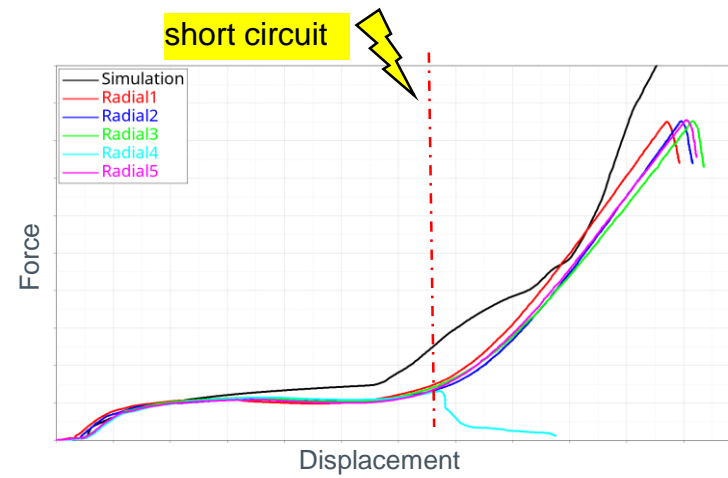**Bending**

Flat stamp

Sphere

short circuit

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EDAG

Axial

Radial

Round bar

short circuit

short circuit

short circuit

Roundbar was not our objective

BATTERYMODEL FOR FULL VEHICLE SIMULATION
EM SIMULATION OF BATTERY PACK

EDAG SCALEbat

- Design of a battery with 100 electrically simulated prismatic cells
- Use of the Randles Batmac Model
- Model size ~1,500,000 elements for the electrical cells
- Parameters determined by electrochemical impedance spectroscopy
- Mechanical behavior from pouch cell abuse tests
- Computing time ~ 10h for 80ms on 96 CPU strongly dependent on EM time step

➢ Successful detection of the short circuit

Example from EDAG SCALEbat

Top View

Example from EDAG SCALEbat

SOC [%]

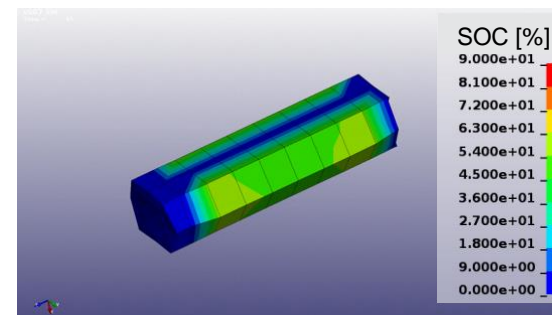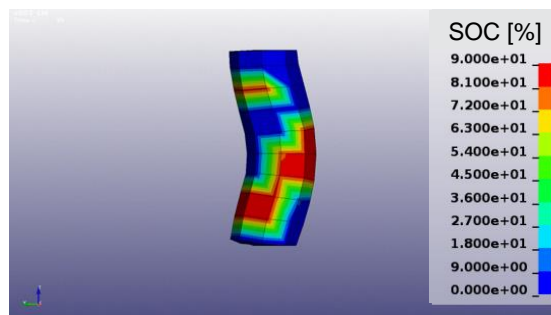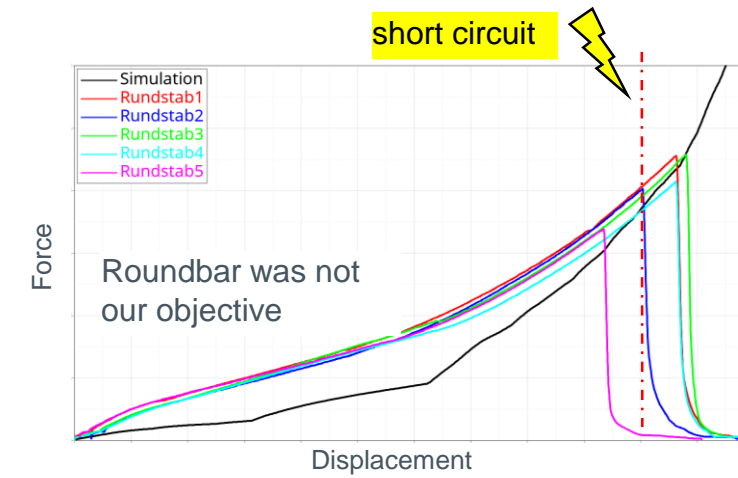| |
|---|
| 9.000e+01 |
| 8.100e+01 |
| 7.200e+01 |
| 6.300e+01 |
| 5.400e+01 |
| 4.500e+01 |
| 3.600e+01 |
| 2.700e+01 |
| 1.800e+01 |
| 9.000e+00 |
| 0.000e+00 |

10

BATTERYMODEL FOR FULL VEHICLE SIMULATION
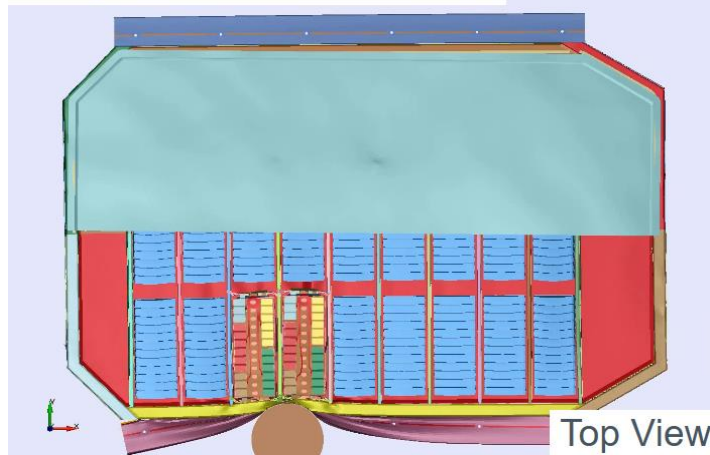## EM SIMULATION OF BATTERY PACK

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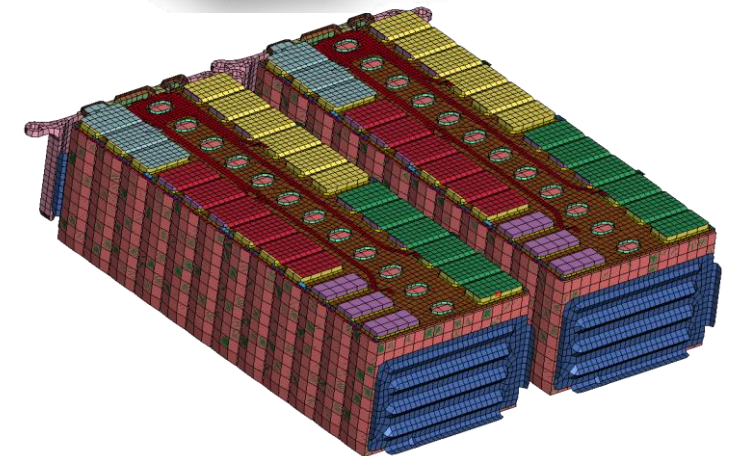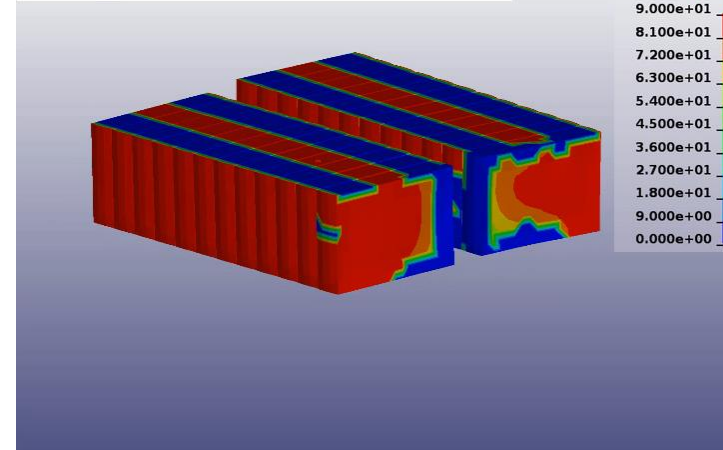
➢ Successful detection of the short circuit

Example from EDAG SCALEbat

Top View

Example from EDAG SCALEbat

SOC [%]

9.000e+01
8.100e+01
7.200e+01
6.300e+01
5.400e+01
4.500e+01
3.600e+01
2.700e+01
1.800e+01
9.000e+00
0.000e+00

Benefits in the Project for a B-Segment car:
➢ Increase Vehicle Range:
  ➢ + 50km WLTP (13%)
➢ Reduce Frame Weight:
  ➢ - 20kg (-33%) on the crash parts of battery frame

BATTERYMODEL FOR FULL VEHICLE SIMULATION
BENEFITS BY USING A BATTERY SIMULATION

Increasing the range of the vehicle

Increase the number of cells

Reduce the battery frame mass

Reduction of the "gaps" to the structural components

Predictable macro model of the cells for full vehicle simulations

Increase the intrusion in battery frame

- Simulate the mechanical behavior of the cell
- Simulate the short circuit

Increase the range of the vehicle ✓
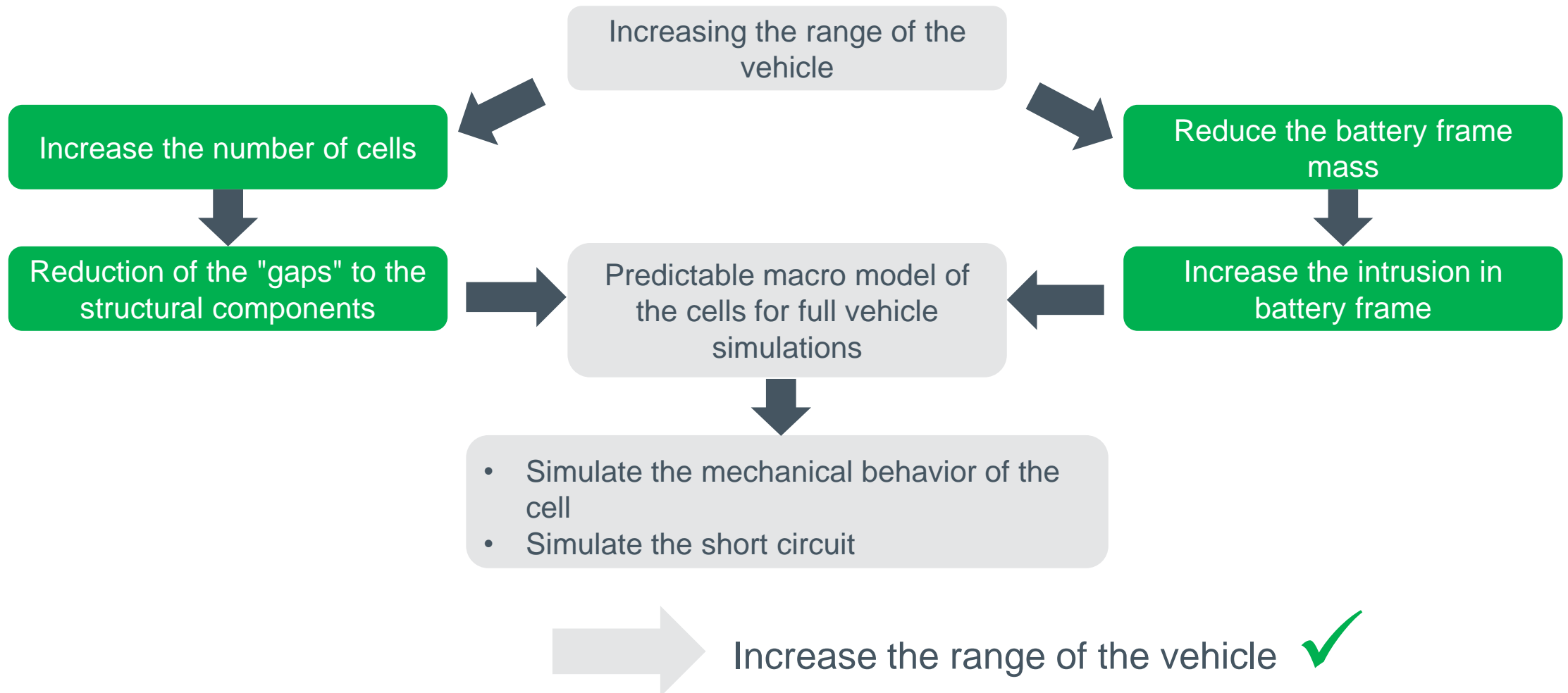
BATTERYMODEL FOR FULL VEHICLE SIMULATION
SUMMARY

- EDAG has a battery macro model for full vehicle simulation

- We are able to support the development of battery electrical vehicles by:
  - Simulate the mechanical behavior of the cell
  - Simulate the short circuit
  - Optimization of the battery frame
  - Increase the amount of cell

  for all common types of cells

  ➤ Increase the vehicle range

➤ The battery design is done in close cooperation with our electrical engineers

➤ Thermal simulations and battery swelling is also a part of our development

Temperatur
>48
46
43
41
39
36
34
32
30
27
<25
No Value

Expansion [mm]
>0.20
0.16
0.12
0.08
0.04
0.00
-0.04
-0.08
-0.12
-0.16
<-0.20
No Value

Displacements scaled by 10x
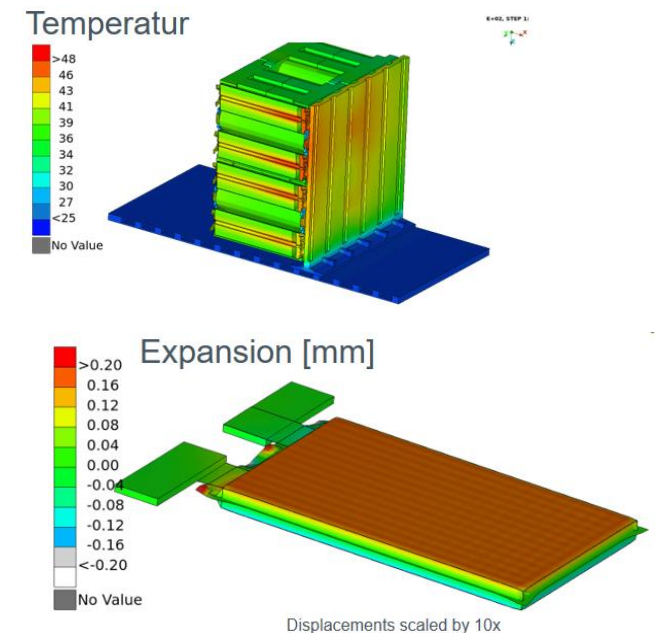
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