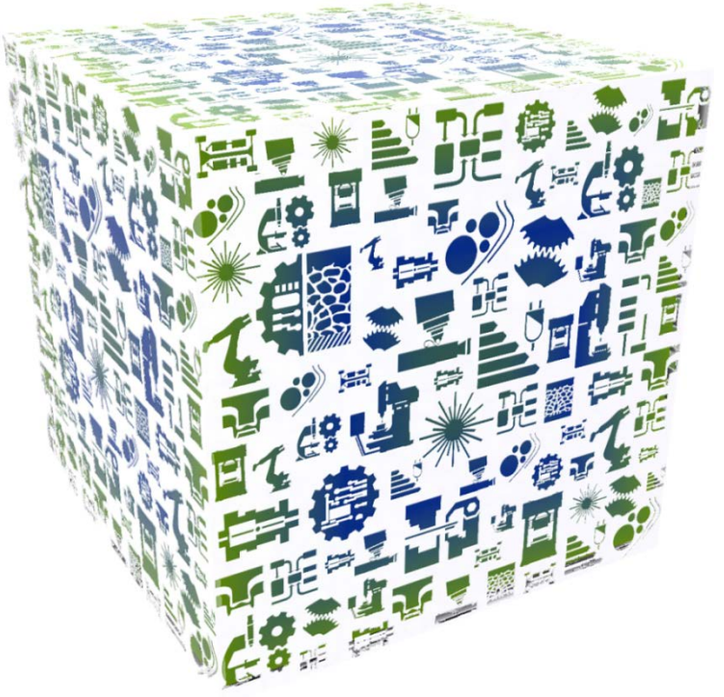
ALUMINUM FOAM SANDWICH BATTERY HOUSING FOR ELECTRIC CARS

Dipl.-Ing. Rico Schmerler, EEV Batteries Summit, Berlin, 18-19th June 2019



Havel metal foam

Fraunhofer IWU

AGENDA

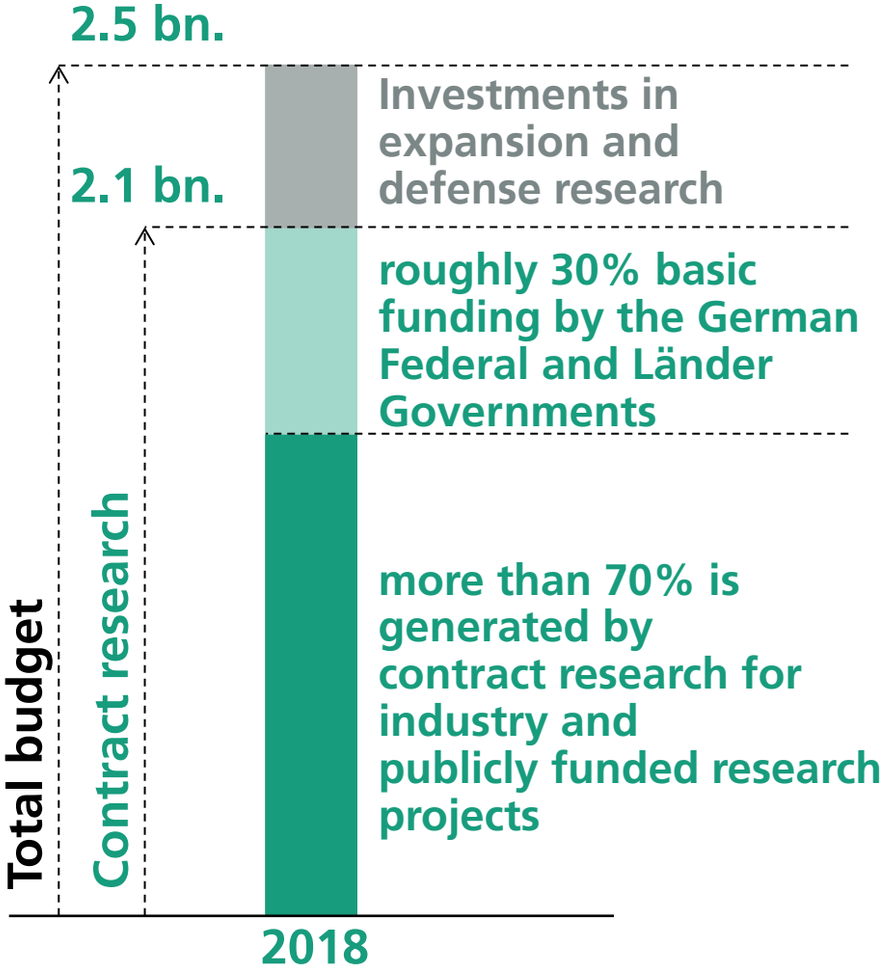
1) Introduction of Fraunhofer IWU and havel metal foam GmbH (HMF)
2) Aluminum foam basics and applications
3) Basics for battery housings of EV
4) Project results for aluminum foam sandwich (AAS) battery housing
5) Basics and new solution for thermal management
6) Further project examples

The Fraunhofer-Gesellschaft
At a glance

Application-oriented research for direct use in the economy and for the advantage of society

26 600 employees

72 Institutes and research units



Profile of the Fraunhofer IWU
Research locations and scientific fields

Chemnitz

Dresden

Zittau

Wolfsburg

IWU Locations

Mechatronics and Lightweight Structures

Forming Technology

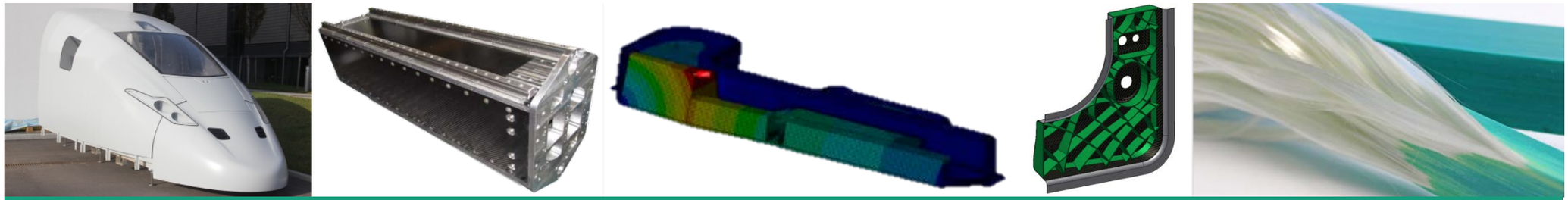
Machine Tools, Production Systems and Machining

Havel metal foam

Fraunhofer IWU

Fraunhofer IWU

Lightweight construction



Enormous potential for lightweight design and functional integration

- Lightweight construction using materials, structures and conditions
- Development and calculations of lightweight structures
- Design/application of metal, polymer, FRP and metal-fiber composite hybrid components
- Metal foam: technology, prototypes, small series
- Manufacturing and joining technologies (injection moulding, pultrusion…)
- Functional integration

Havel Metal Foam GmbH

The Company

- Founded in 2013 at the industrial site of Kirchmöser (Brandenburg an der Havel)
- Specialization in the industrial manufacturing of aluminum foam products
- Own series of Havel Lite® products
- Combination of many years of know-how's from science and industry
- Highly innovative lightweight materials for new industry solutions

Series production of aluminum foam products

- Sandwiches
- Panels
- Foam-filled profiles
- 3D formed parts

Processing technologies

- Bending
- Welding
- Milling
- Drilling
- Mechanical processing

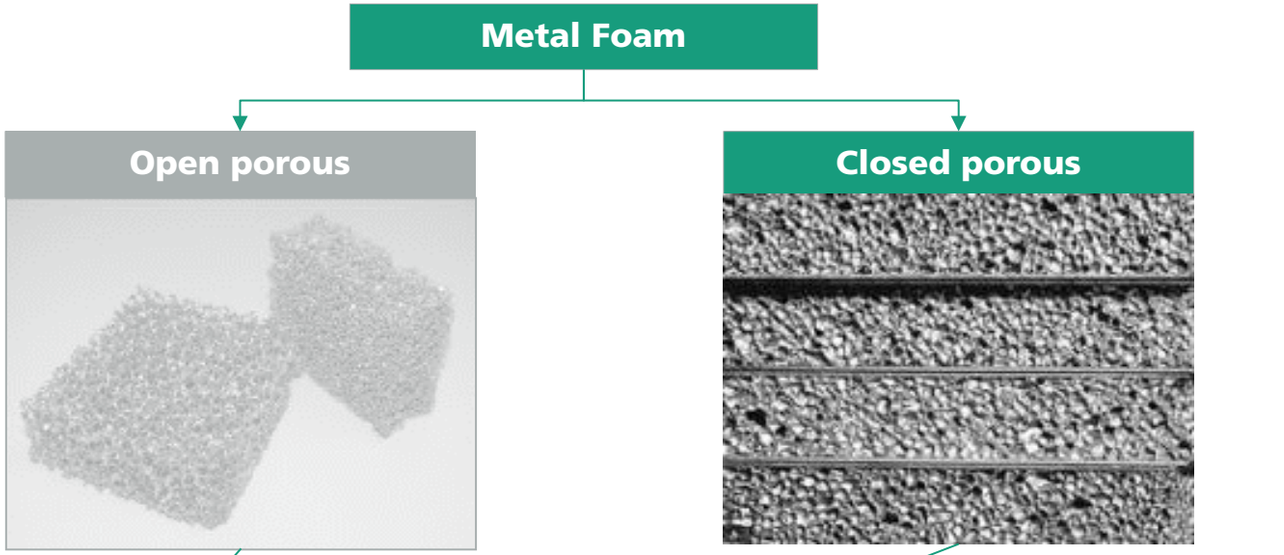
Technical equipment

- Infrared furnaces
- Electrically heated continuous furnace
- Portal milling machine
- Rolling plant

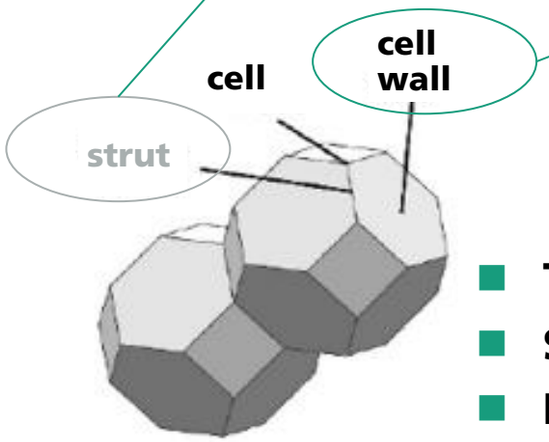
Credentials

DynaEnergetics, MAGNA, Lufthansa Cargo – Networking the world., BOMBARDIER – the evolution of mobility, Webasto – Feel the Drive, SIEMENS, KIRCHHOFF AUTOMOTIVE, indikar, weber, STREIT GROUP, STOOF International, MFOR, FAUN KIRCHHOFF GRUPPE

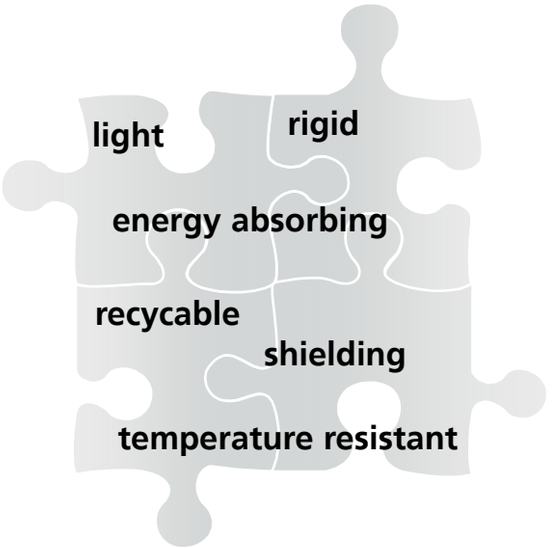
Lightweight design with Metal Foam



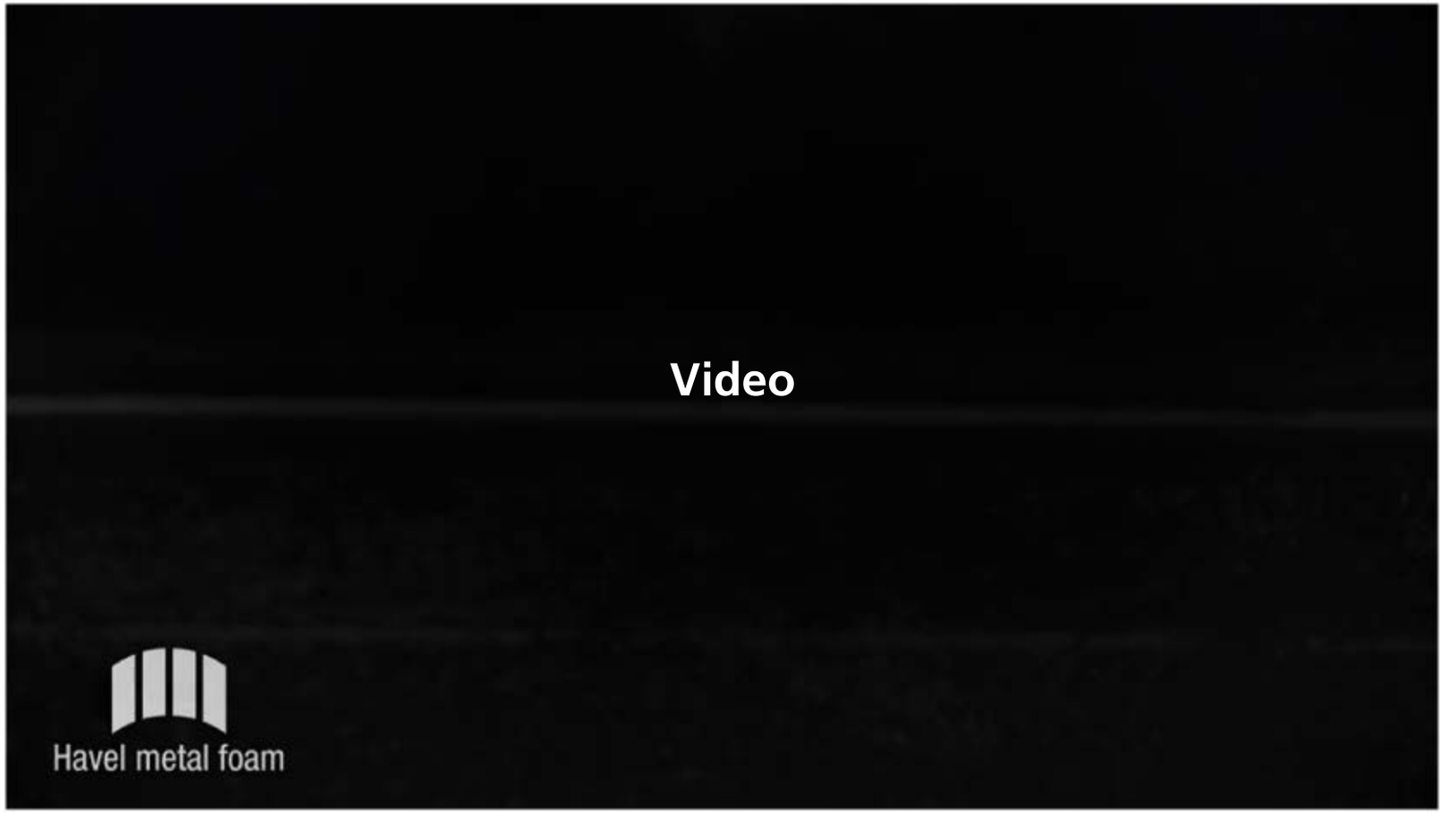
different metals possible,
focus on: aluminum



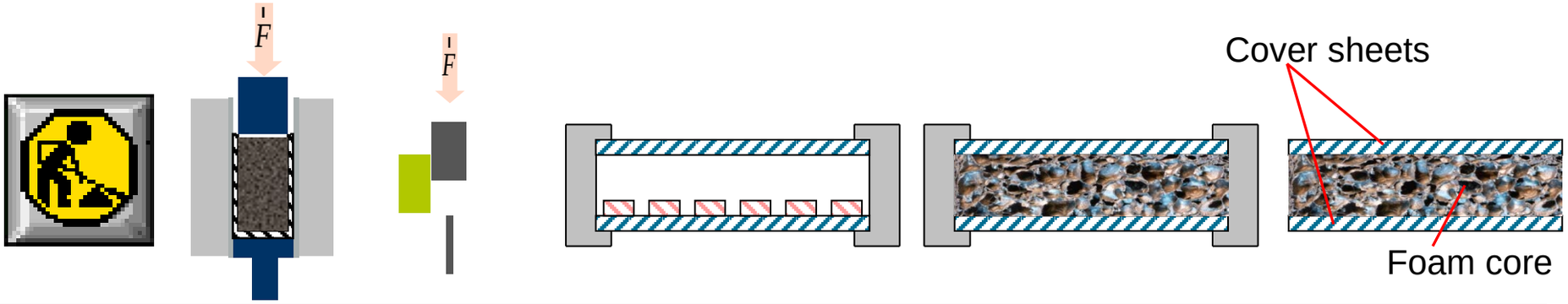
- **Tetragonal dodecahedron**
- **Statistical distributed pores**
- **Density/pore size**



Lightweight design with Metal Foam



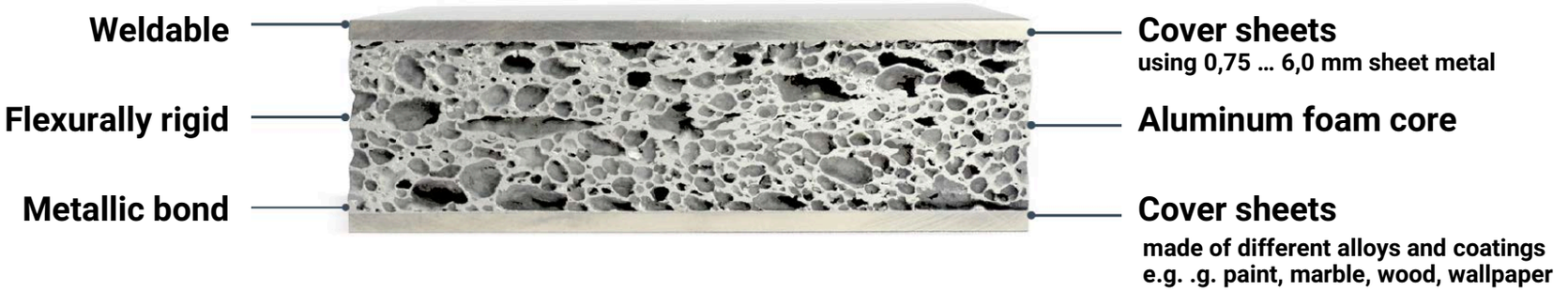
Metal Foam – Powder metallurgical route



Mixing → axial pressing → pressing a rod → input the precursor → foaming → cooling

Foam-able dimension:	
area:	**3000 x 1500 mm²**
max. height:	**50 (70) mm**
Cover sheet thickness:	**0,75 ... 10 mm**

Sandwich application example:

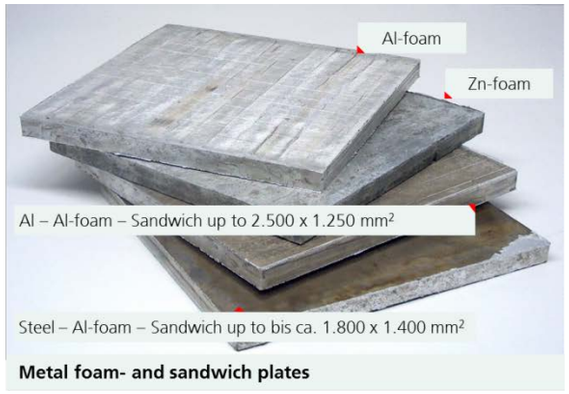


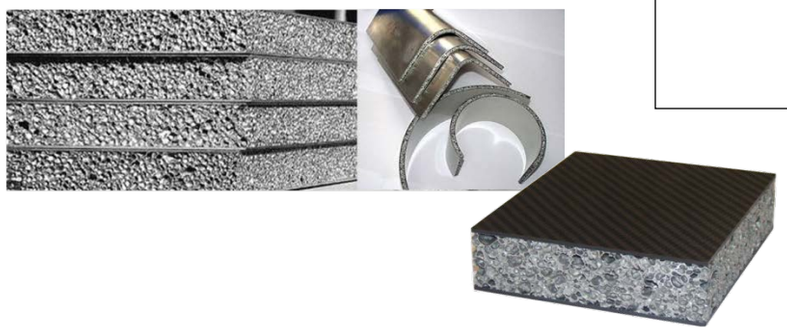
Properties of aluminum foam - material characteristics

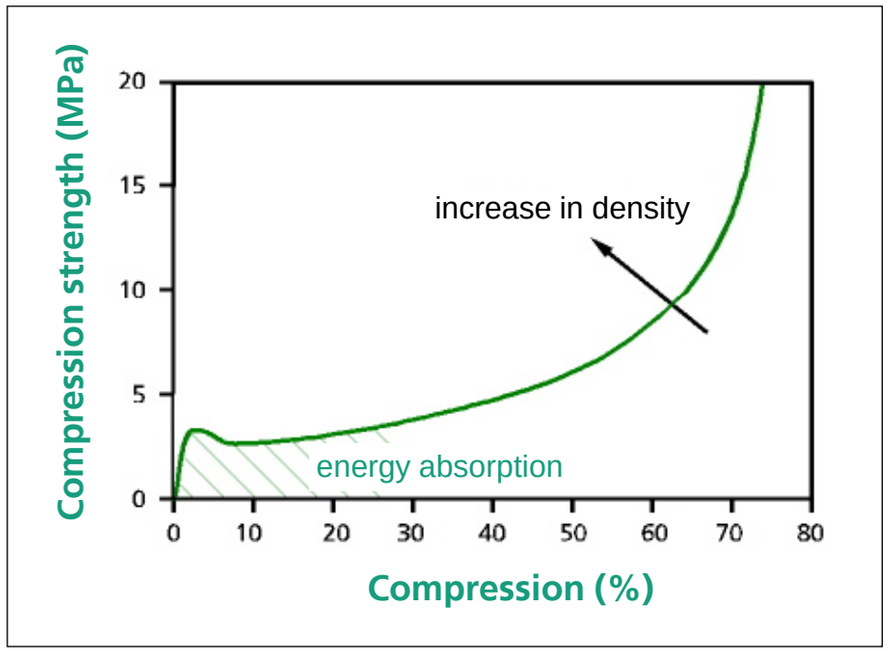
Density	**0,5 - 0,9 g/cm³**
Transverse contraction compression	**~ 0**
Compression strength	**2 - 15 N/mm²**
Thermal conductivity	**2 - 20 W/m·K**
damping capacity (0,7 g/cm³)	**ca. 4,5·10^{-3}**

⇨ most technical application

$Variable_{Foam} = Variable_{Solid} (\rho_{Foam}/ \rho_{Solid})^{n}$, n = 1,7 bis 2







Havel metal foam
Fraunhofer IWU

Advantages of aluminum foam and industry application businesses

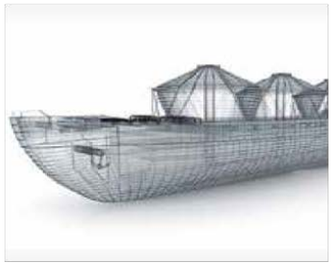
Lightweight construction	⇨	**Lightweight core in filigree hollow structures and sandwiches:** **task: stiffening structures and spacer**
Damping	⇨	**High damping coefficient:** **task: conversion of vibration energy**
Energy absorption	⇨	**high energy consumption in terms of deformation work:** **task: crash absorber**
Fire protection	⇨	**Temperature resistance up to 500 ° C:** **task: building panel for fire protection**
Design	⇨	**aesthetic value of the foam structure:** **task: design element**

Railway industry

Safety & Protection

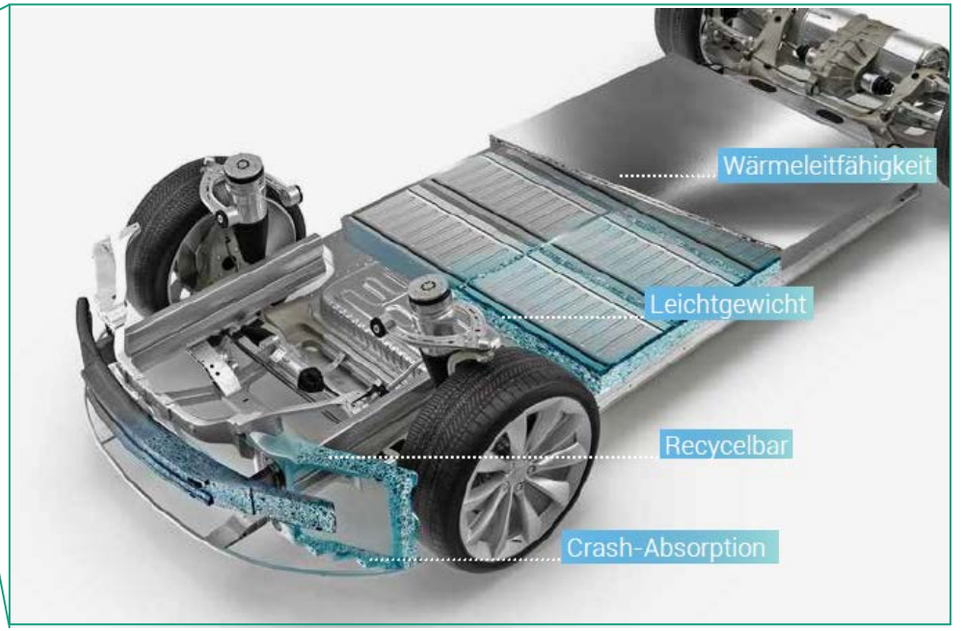
Automotive

Energy sector



Shipbuilding

Mechanical engineering



Applications of closed cell aluminum foam in different fields

Series: 200.000 pieces/year

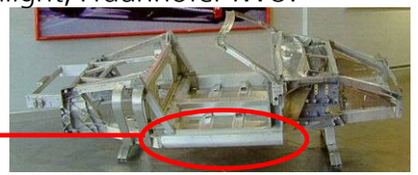
metal foam-crash absorber in a baggage net of Audi Q7.

Source: Alulight; Fraunhofer IWU.

Source: Alulight; Fraunhofer IWU.

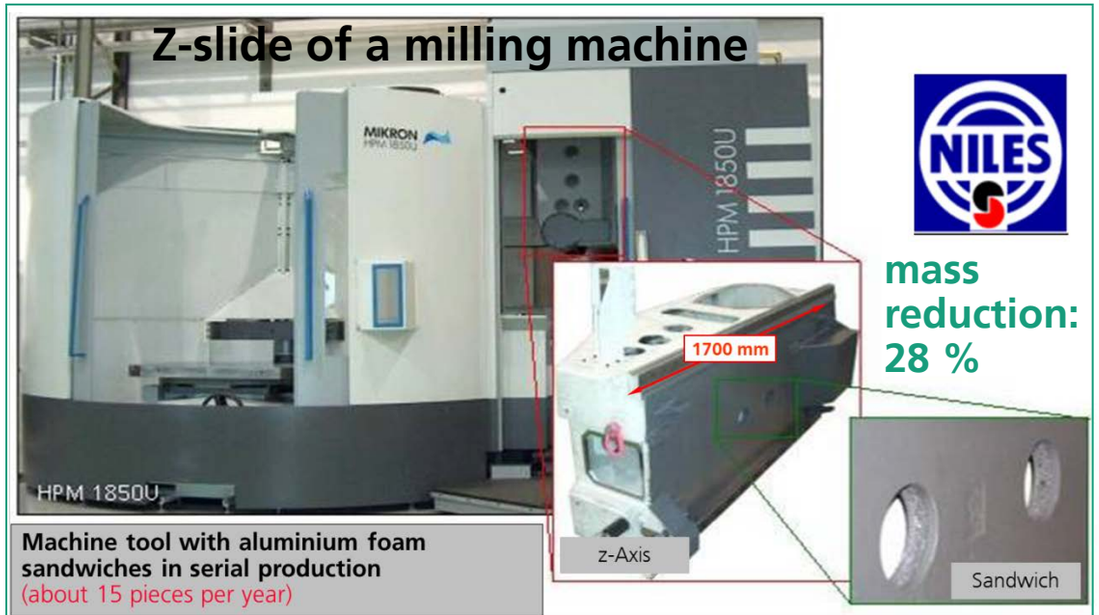
Series: 3.000 pieces/year

+ car-body stiffness



reinforcing element of metal foam in a side-sillboard of Ferrari Spider 430.

Z-slide of a milling machine



Machine tool with aluminium foam sandwiches in serial production
(about 15 pieces per year)

mass reduction: 28 %

front cabin of an ICE

Railway industry & infrastructure

reduction of parts and sub assemblies

reduction of joining operations

improving tolerance chain

Havel metal foam

Fraunhofer IWU

Motivation for application in battery housing








Specifications for battery housing of EV

- low weight
- low production costs
- low production time
- scaleability

mechanical specifications

- crash protection (side, front test)
- intrusion protection (stones, bollard)
- vibration performance
- battery module fixing
- interface safety (body mounting)

general specifications

thermal specifications

- thermal management
- fire safety
- thermal runway
- thermal isolation
- thermal conductivity

safety of batteries against environment

specifications of production

- production-orientated construction
- assembly orientated construction
- tolerances
- maintanence and repair

safety of environment against batteries

- water und gas tightness
- fire resistance
- corossion resistance
- electromagnetic compatibility

Battery housing designs/materials

aluminum
BMW i8, Daimler EQC, VW iD., Audi e-Tron, Golf GTE, Toyota Prius

fiber reinforced plastics (FRP)
concepts, research, prototypes, sports/racing

steel
VW e-Up, Nissan LEAF, Daimler E18-2evo, Chevy Bolt

3D-printed
concepts, research

polymer
Samsung SDI (12V / 48V)

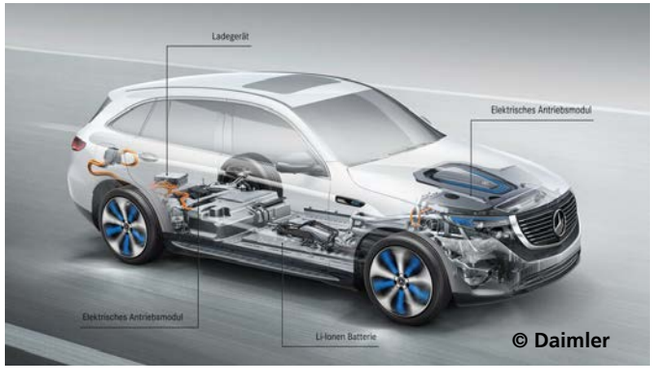
New aspects of mechanical loads for EV

- critical crash load case of EV depends on position of HV-battery
- newest and future EVs → batteries in the floor panel
- beside front and side crash scenarios the **bottom penetrations test** becomes extremely important for

→ damage protection of battery system

→ passenger safety

VW ID.



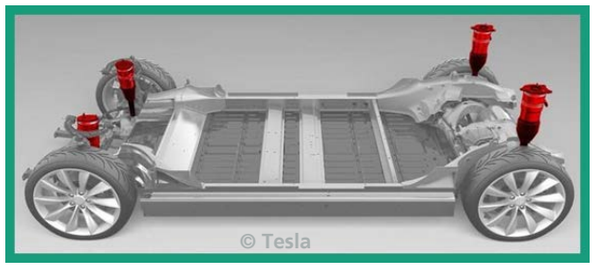
Daimler EQC

BMW i3

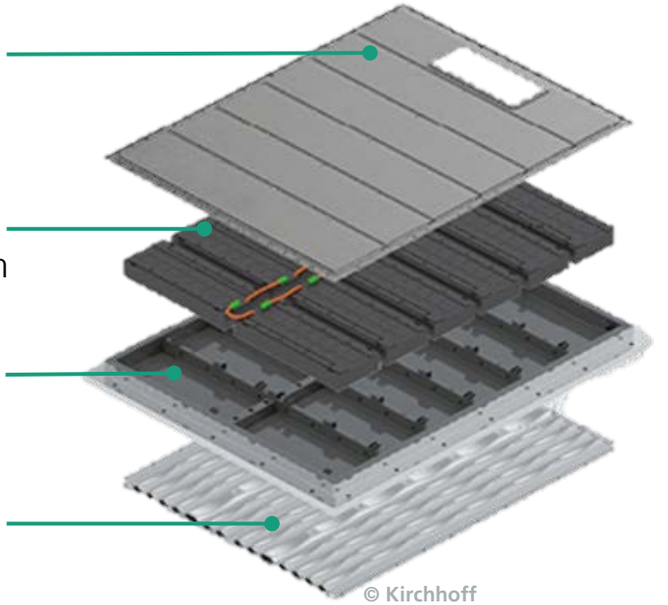
Construction and CAD-design battery housing

- functional integration: underbody protection as integral part of battery box / bottom
- box concept 1: without cross stiffeners
- box concept 2: with cross stiffeners, design space for a battery module of 12 prismatic cells
- battery box dimensions: 1000 x 500 x 150 mm³ (L/W/H)
- outer dimensions fix, sandwich thickness variable
- housing cover: main task is isolation (tightness, EMV), no structural support → neglected

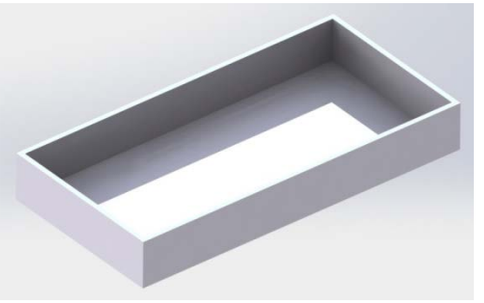
decapsulated system vs. structural integration

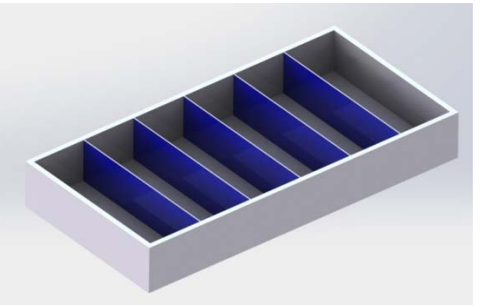


sub systems of battery housing



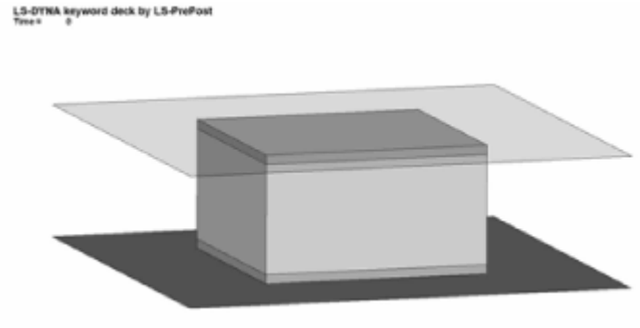
final box concepts



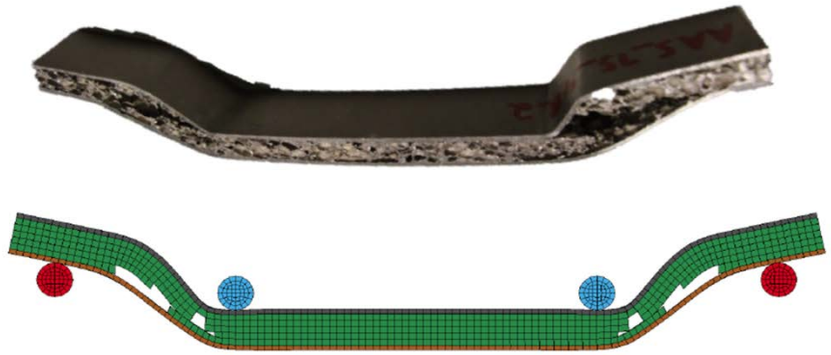


Material characterization tests on specimens

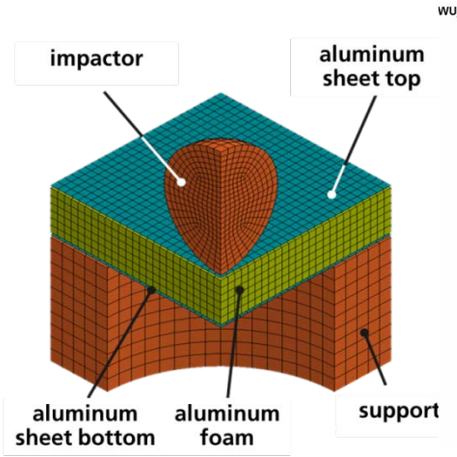
pressure test

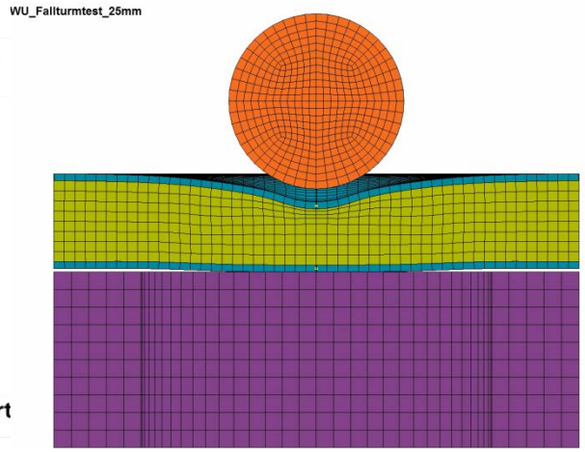


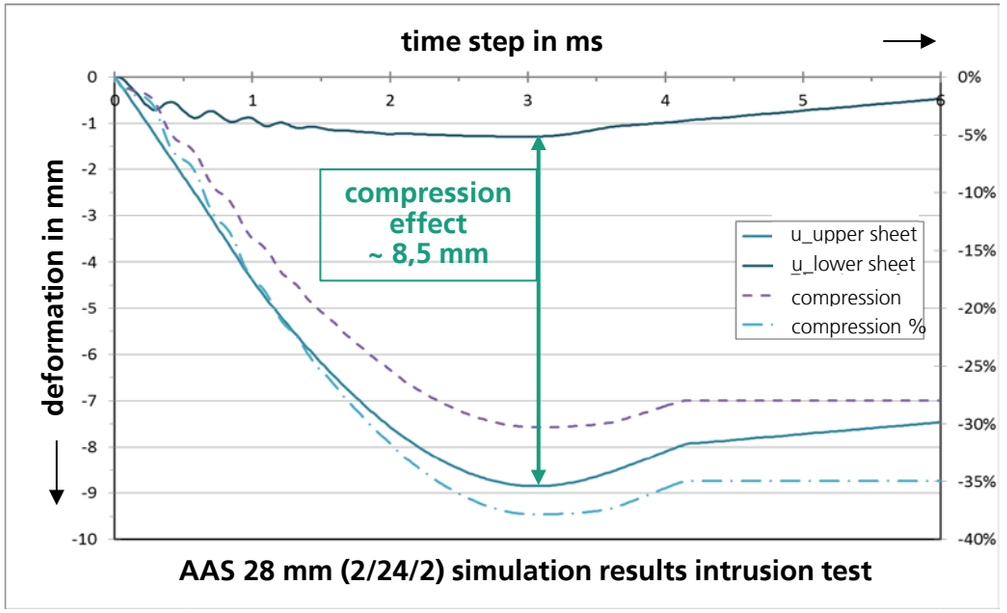
4-point-bending test



intrusion test

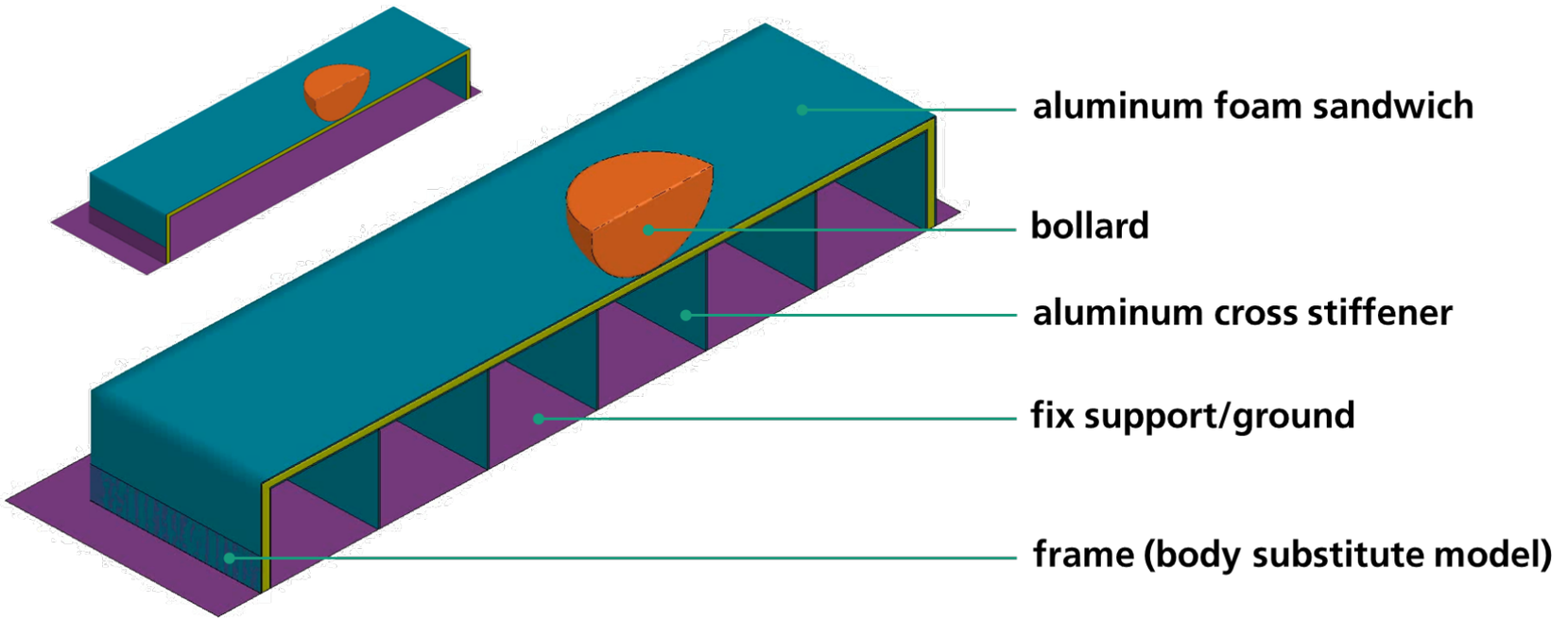






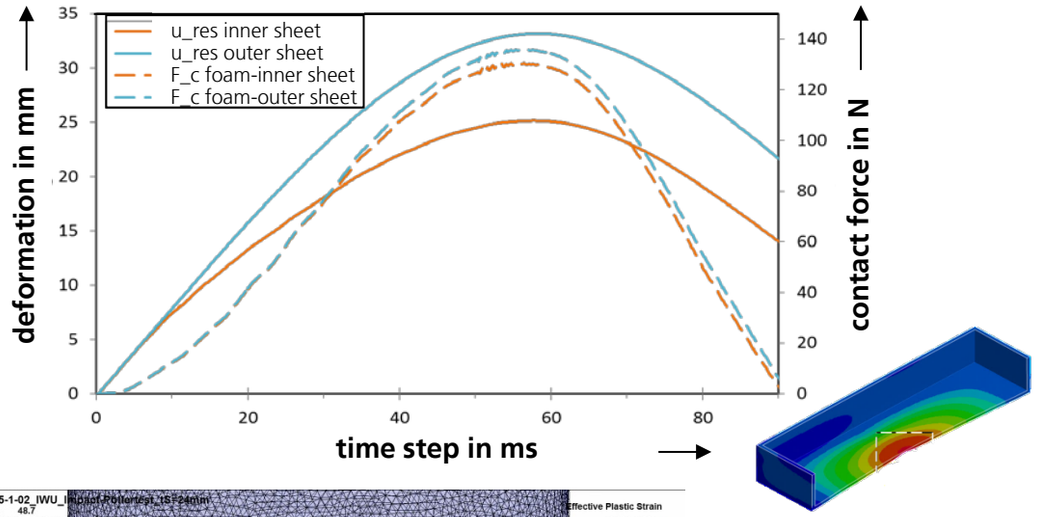
Simulation of the battery housing
Boundary conditions

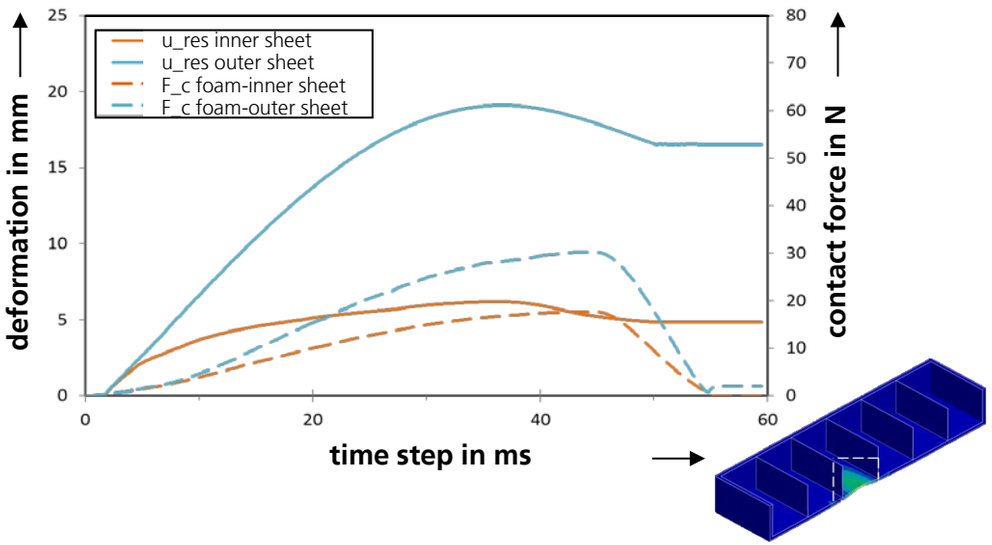
- impact in-between cross stiffeners / center of housing
- kinetic energy of bollard: 370 J
- aluminum foam sandwich (AAS)
  - 2 mm aluminum cover sheets AW EN-6082
  - aluminum foam density: 0.44 g/cm³, max. compression of foam: 16,2 %

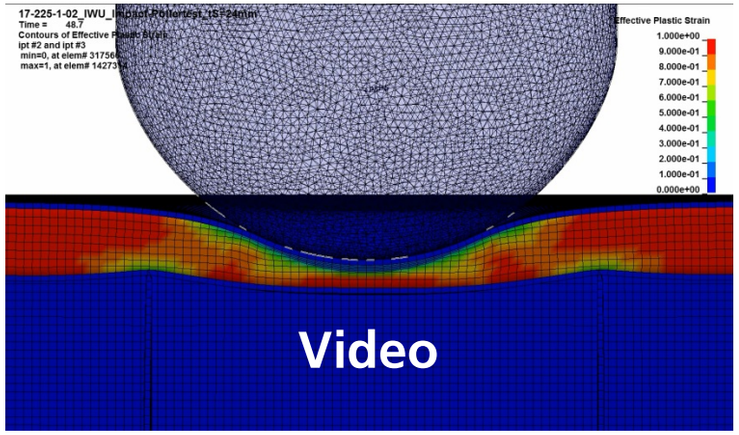


Simulation battery housing
Results aluminum foam sandwich (AAS) 15 mm (2/11/2)

- without cross stiffeners: high global deformation, foam potential not completely used
- with cross stiffeners: high local deformation, foam energy absorption efficient
- designs without inner side deformation possible!

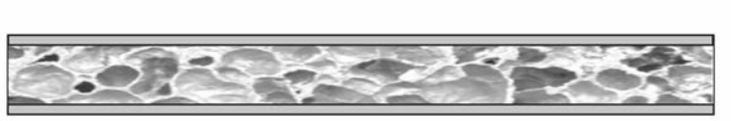




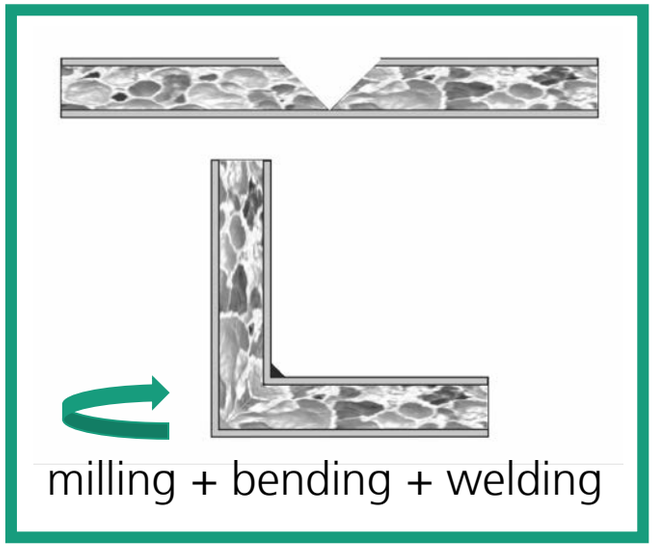


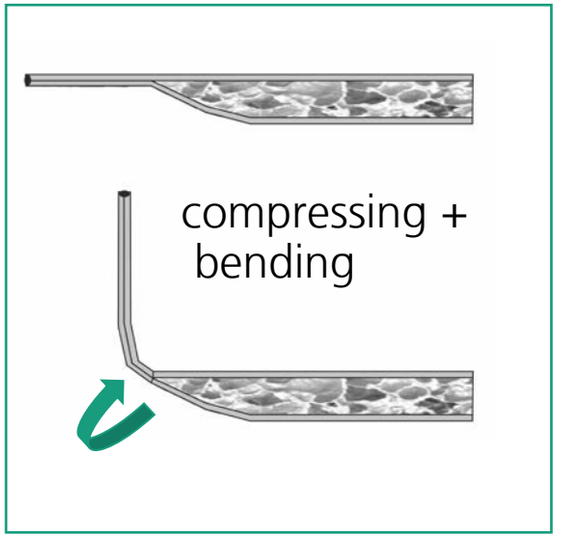
AAS 15 mm (2/11/2) cross stiffeners	no	yes	Δ
deformation inner side [mm]	25,1	10,5	- 58,2 %
deformation impact side [mm]	33,2	19,8	- 40,4 %
compression [mm]	8,1	9,3	+ 14,8 %

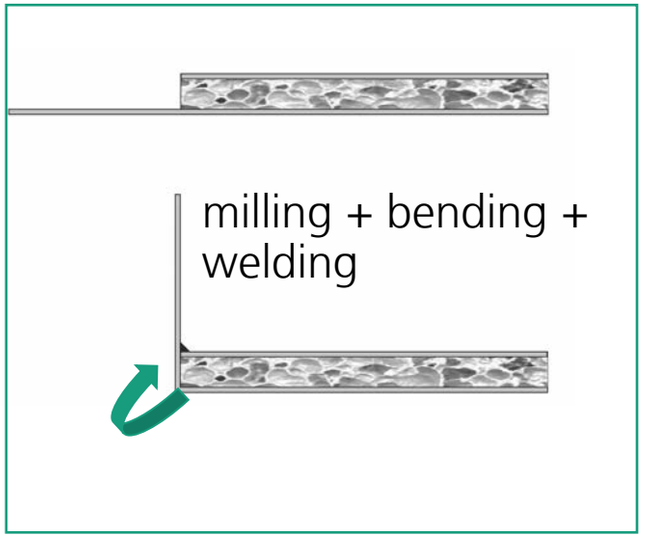
Demonstrator production
Conception of manufacturing

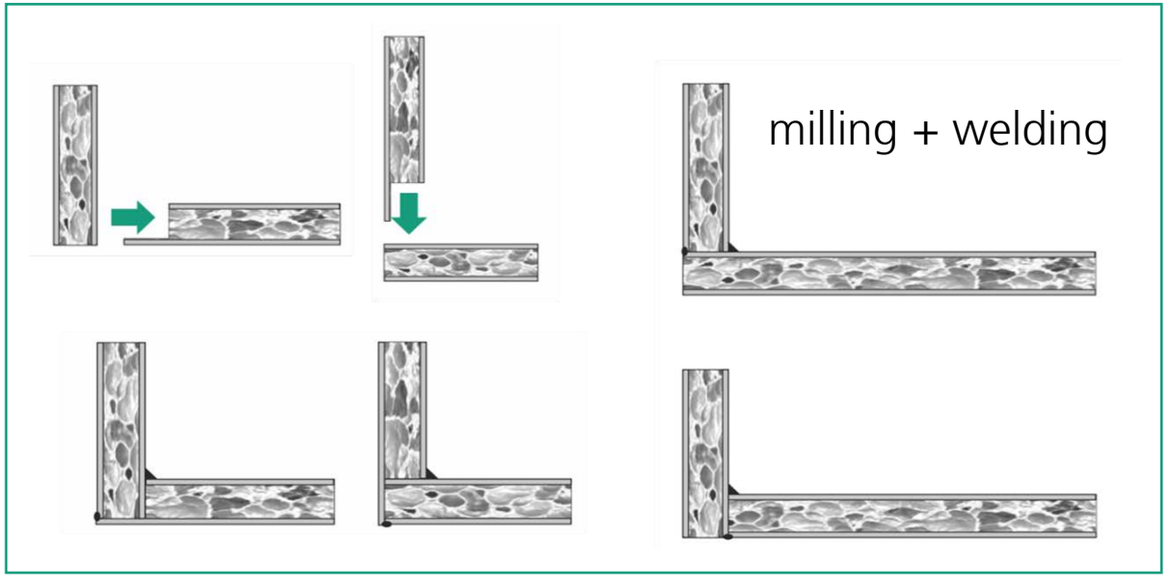


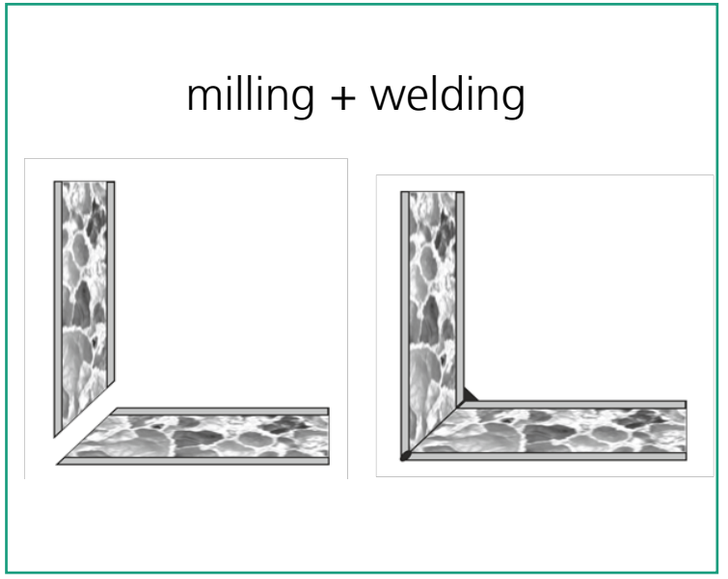
basic material











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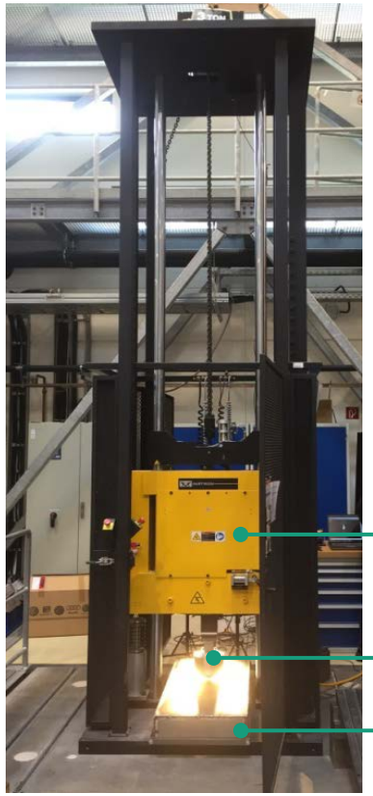
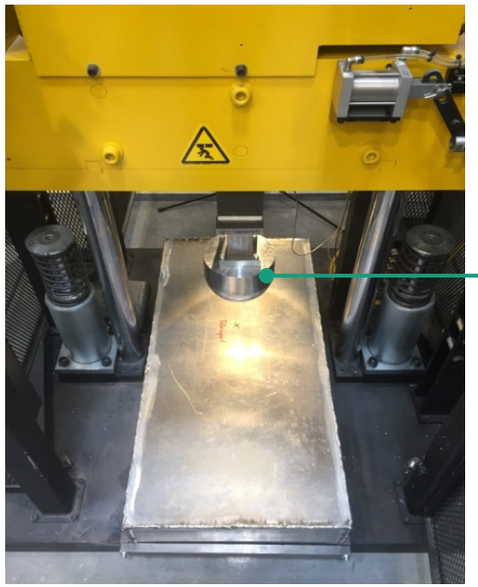
Demonstrator production
Aluminum foam sandwich battery boxes

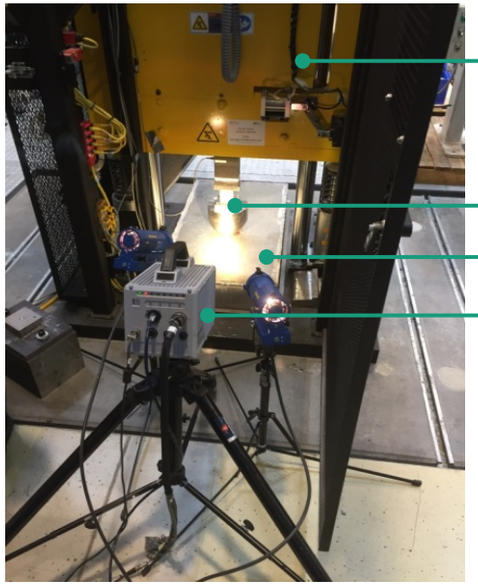
- 2 demonstrators have been built:
  - 22 mm thick AAS-sandwich weight ca. 18 kg
  - 28 mm thick AAS-sandwich weight ca. 20 kg

Demonstrator – Bollard test
Experimental setup

- impact in-between 2 cross stiffeners

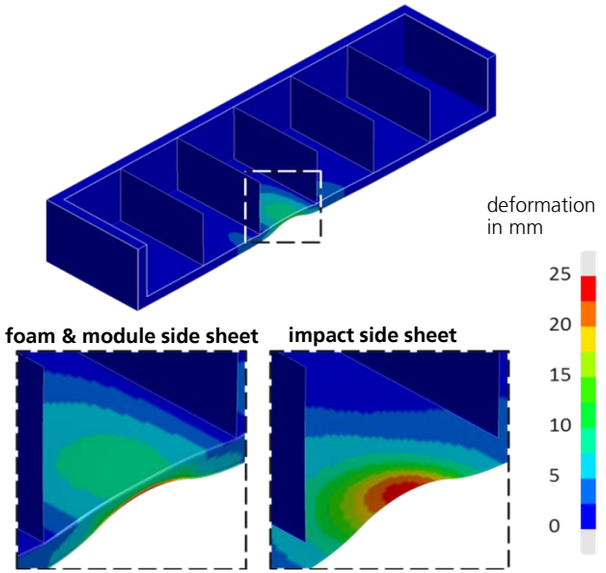






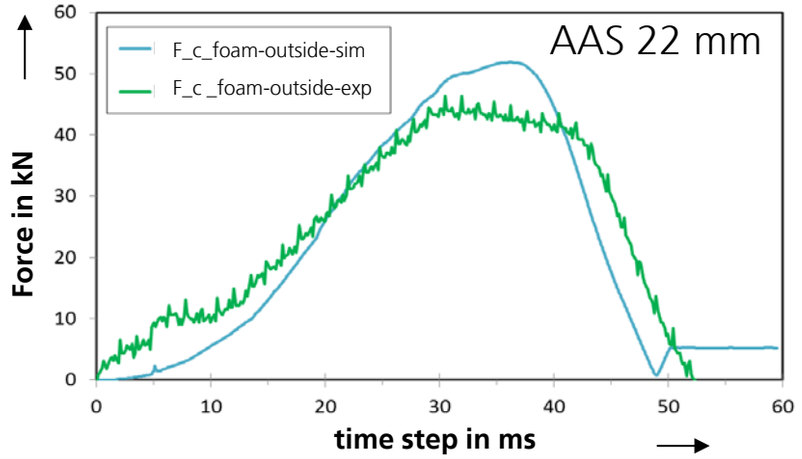
Demonstrator – Bollard test
Experimental results

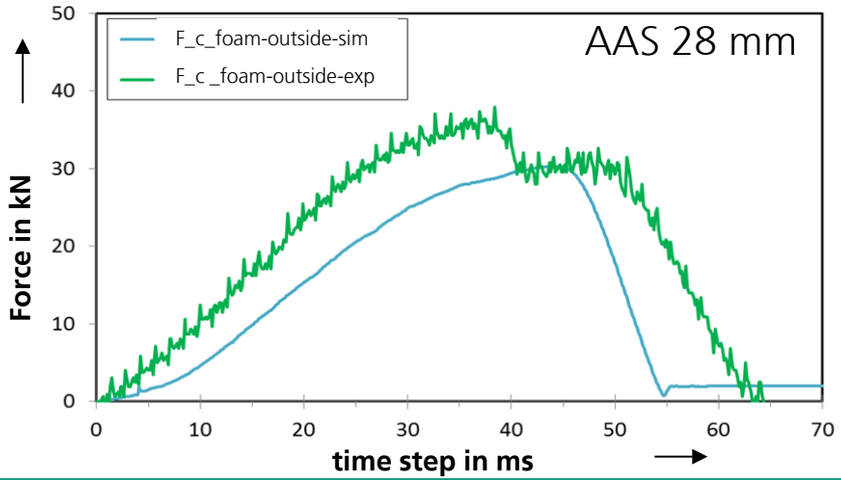
- deformation mostly concentrated in-between cross stiffeners on the inner side
- tightness of the inside box was realized
- good agreement of experimental with simulation results of inner side deformation and force-time curve
- higher deformation and with this compression of impact side in experiment



AAS 28 mm (2/24/2)	Simulation	Experiment	Δ
deformation inner side [mm]	14,6	15,3	4,6 %
deformation impact side [mm]	21,0	28,1	25,3 %

→ optimization options: impact test tolerances (friction, bollard height or rather speed), foam and cover sheet material data from quasi static to dynamic





Havel metal foam
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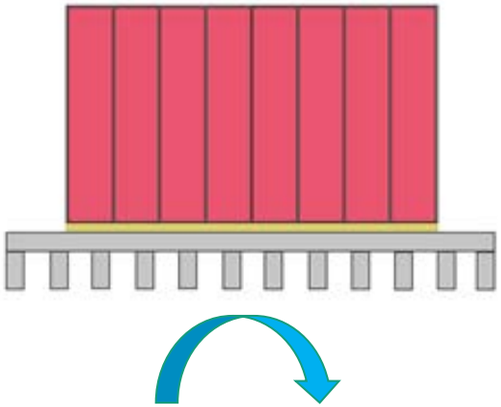
Demonstrator – Bollard test
Next steps

- material characterization
  - quasi static
  - dynamic
- implementing new results into material data sheet
- optimization material model
- topology optimization system (box, cross stiffeners)
- application and test for real industry specifications (design space, interfaces…)
  → project partners are welcome!
- integration of functionalities into the sandwich core/foam:
  - thermal management functions
    → integrating cooling/heating tubes, direct joining during manufacturing process
    → integration of passive cooling system

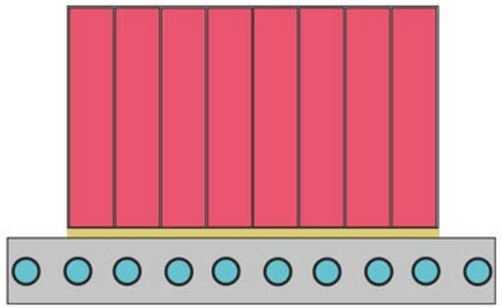
Thermal management of EV-batteries

- current main strategies of thermal management of EV-batteries

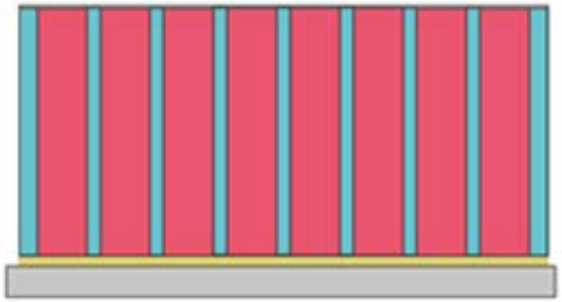
air cooling: plate with heat distributer



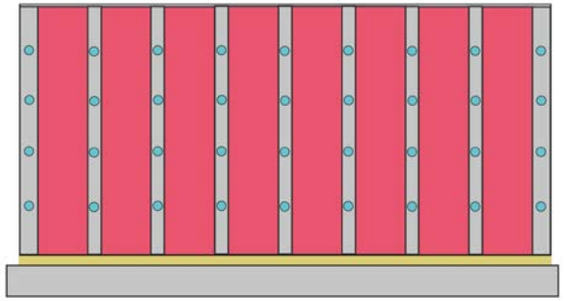
cooling plate with flow channels and cooling liquid



direct cell cooling with liquid (dielectrics)

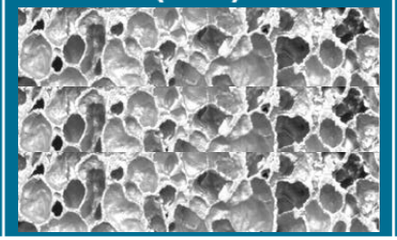


direct cell cooling with cooling plates



Infiltration of metal foam with PCM

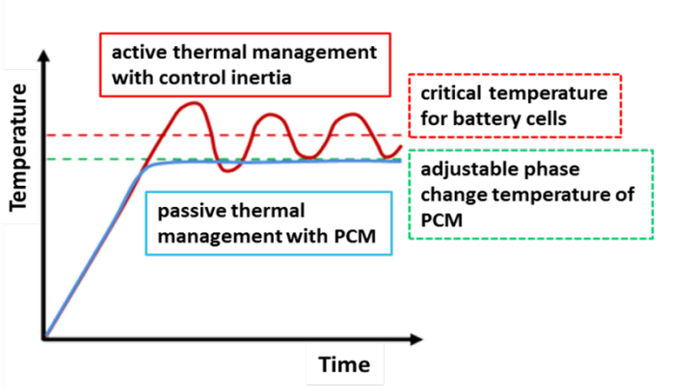
+ state of aggregation is a reversible process
+ adjustable melting range
+ physiologically harmless

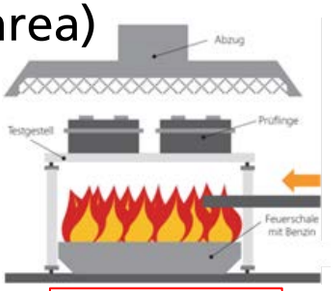
	PCM (RT44HC[4])	Metal Foam (MF)	PCM + MF (ρ_{MS} = 0,5 g/cm³)
			
Density [g/cm³]	0,8 (solid) 0,7 (liquid)	≥ 0,4	0,54
Thermal Conductivity [W/m·K]	0,2	15 **Factor 35**	7
Heat Capacity specific [J/g·K] latent [J/g] latent [W·h/kg]	 2 255 71	 0,7 - -	 0,94 256 71
Bsp.: Heat Capacity [J/g] for heating from 25 °C to 44 °C	287	13 **Factor 21**	272

Infiltration of metal foam with PCM

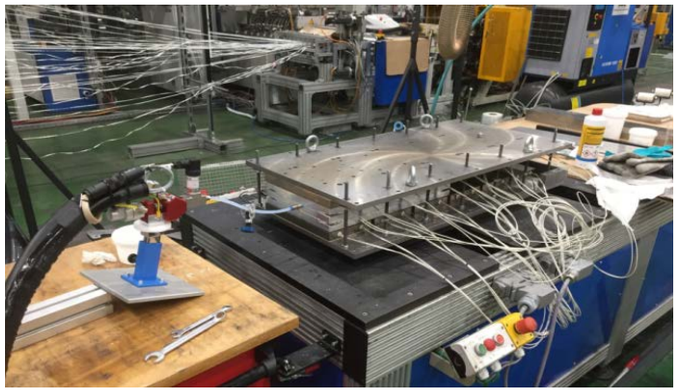
- strategies of thermal management with PCM

1) complete passive thermal management (load case depend, constant temperature area)
2) flatten thermal load peaks
3) increasing of temperature homogeneity
4) preventing / mitigation thermal runway

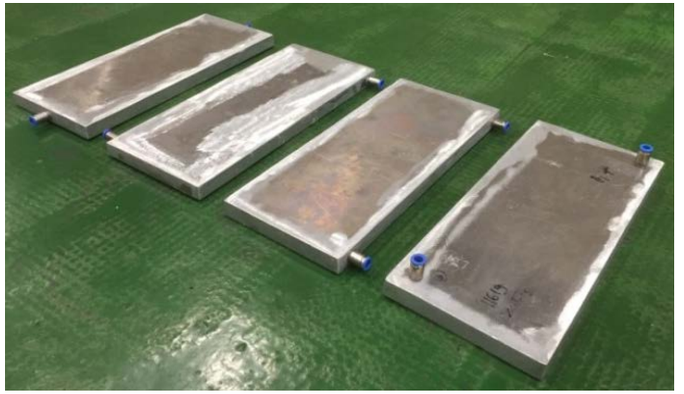




ECE R100 fire test



- mixing and metering unit for infiltration of parts and assemblies at Fraunhofer IWU
- infiltration with pressure and/or vacuum into a mold or direct into a part



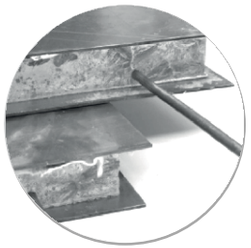
Havel metal foam

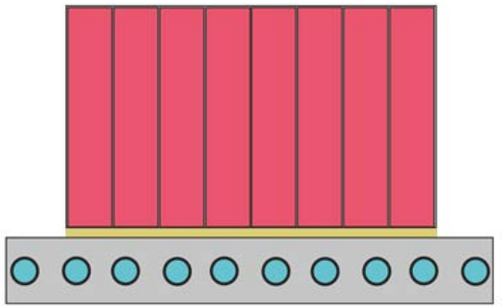
Fraunhofer IWU

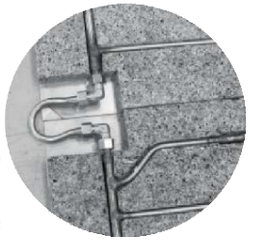
Integration of metal foam/PCM thermal management in EV-batteries

- strategies of thermal management with metal foam and PCM for EV-batteries

metal foam sandwich with integrated flow channels





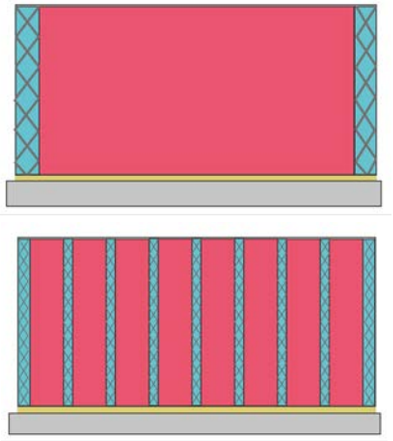


Aluminum foam **s**andwich with integrated steel tubing

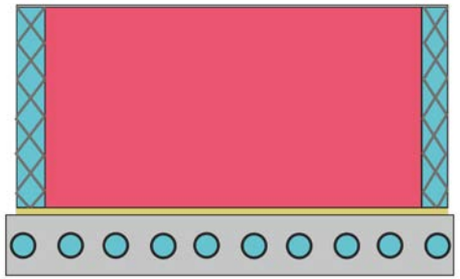
directly integrated during foaming process

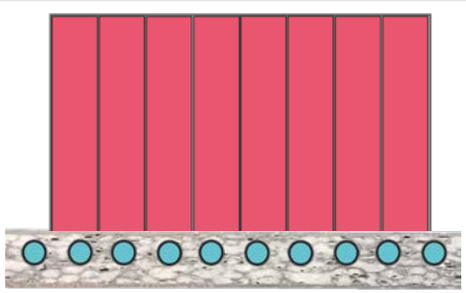
aluminum foam panel (milled) with integrated tubing

passive cooling with phase change material (PCM)



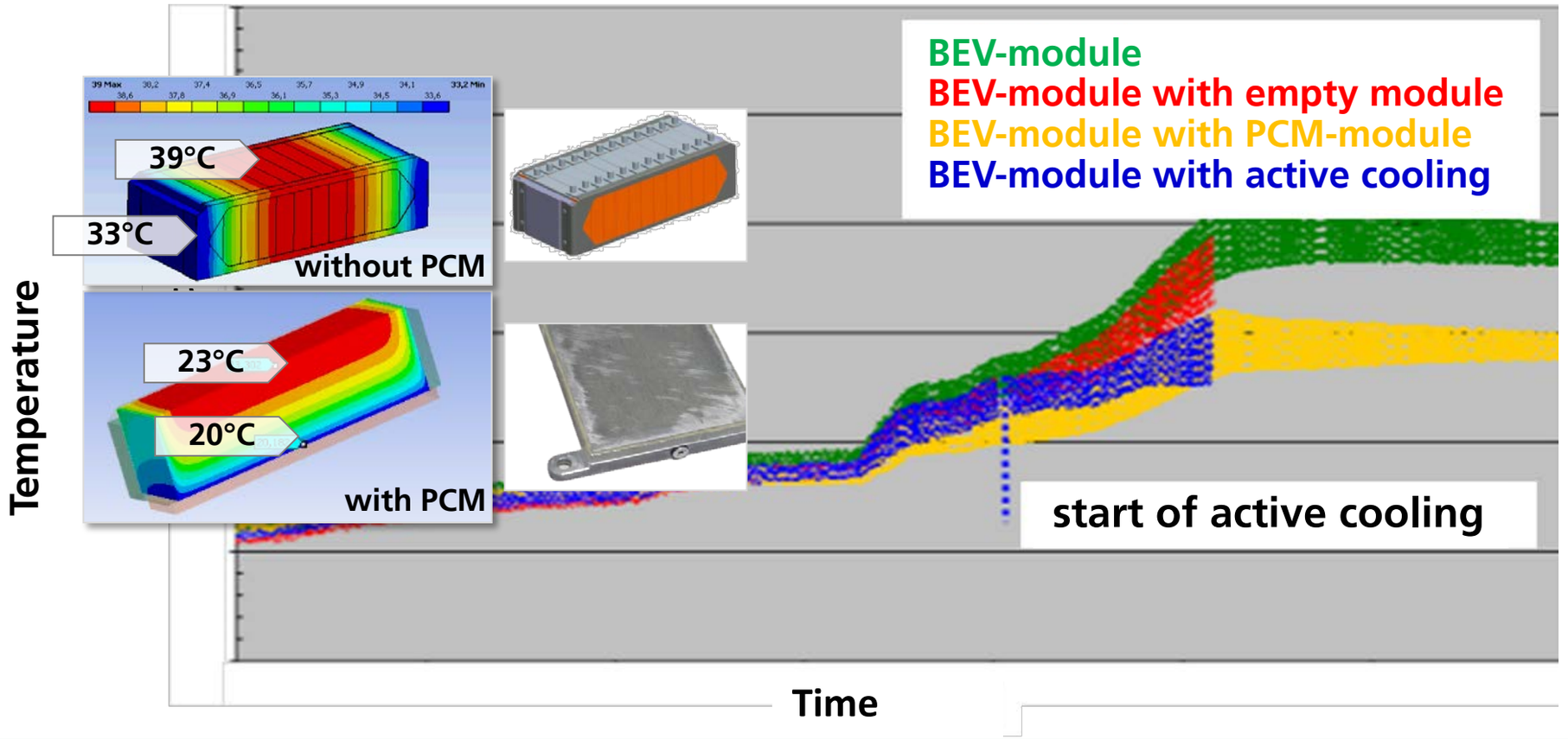
combinations of active and passive strategies





Metal foam with PCM for thermal management of EV

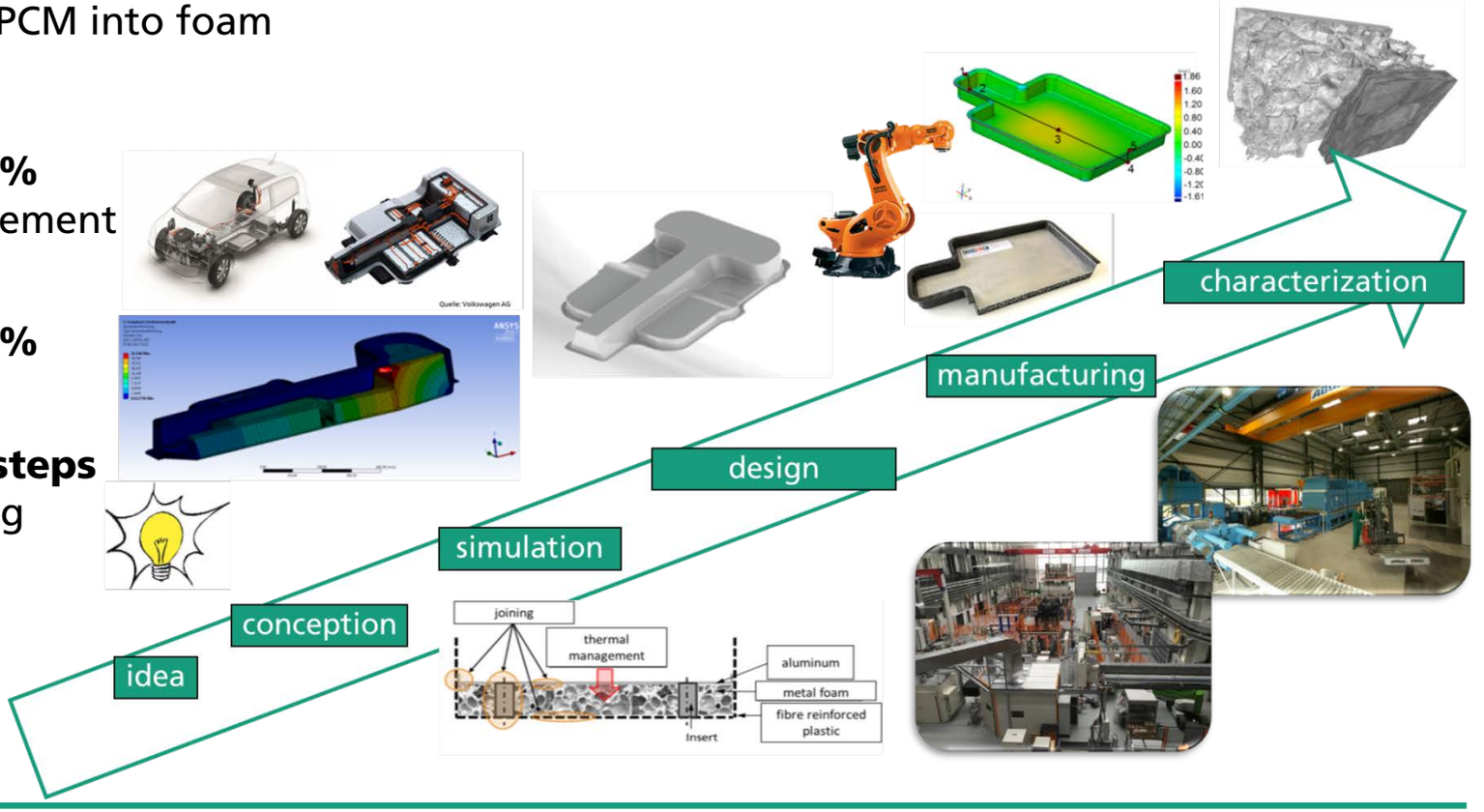
- passive thermal management with PCM-module for BEV-module was successfully realized for defined load case, without exceeding the thermal critical value
- simulation and experimental investigation: test for 1.5 h load case successfully for BEV and PHEV
- temperature gradient $\Delta T < 5$ K



Functionally integrated lightweight battery housing

Covering the process chain from material to components

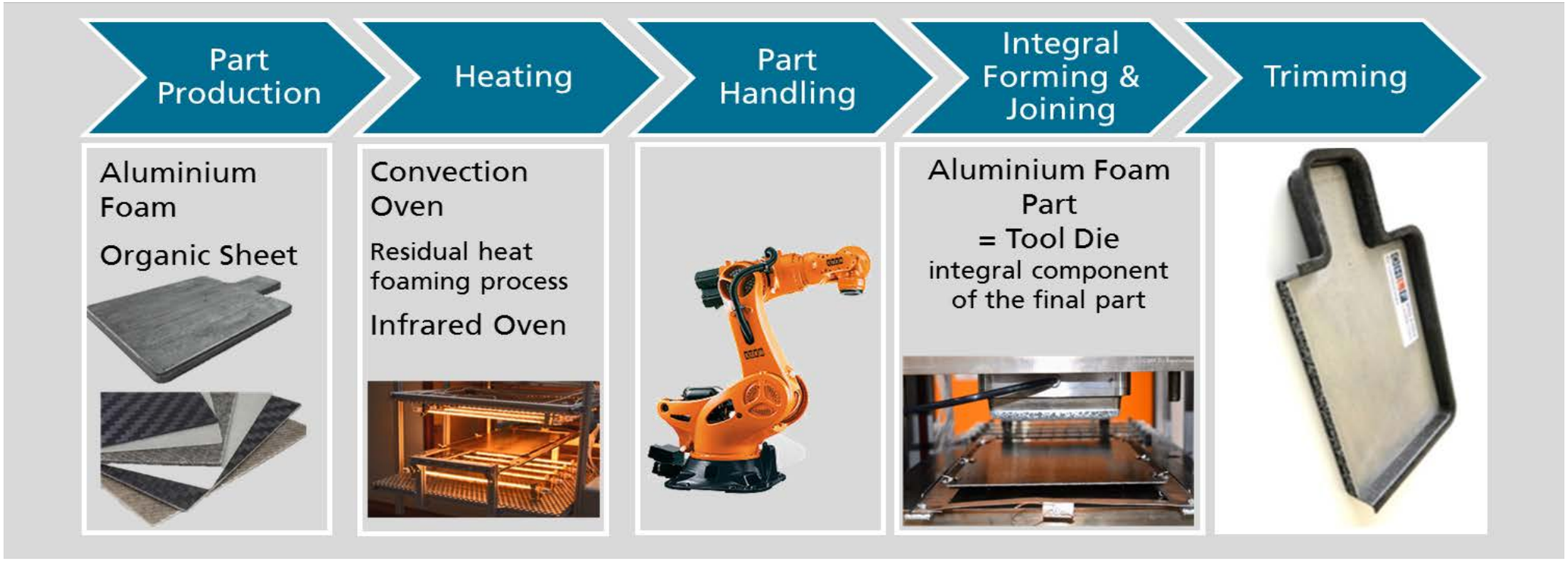
- Motivation: insufficient range of EV, thermal and mechanical functions separated, battery heating during charge and discharge → performance loss and safety issues
- Goals: development of a new concept for a battery housing, combining mechanical and thermal functions in a multi-material-mix, mass reduction, process step reduction
- Approach: sandwich setup with aluminum top sheet, aluminum foam core & FRP outer shell combining, optional integration of PCM into foam
- Results:
  - **mass reduction of 29 %** without thermal management (38,2 kg → 27,1 kg)
  - **mass reduction of 12 %** including PCM
  - **reduction of process steps** through integral forming and joining process



Functionally integrated lightweight battery housing

Manufacturing process

- hybrid components: complex process chain
- developed process: reduction of process steps
- integral forming and joining



Functionally integrated lightweight battery housing

Demonstrator and final setup

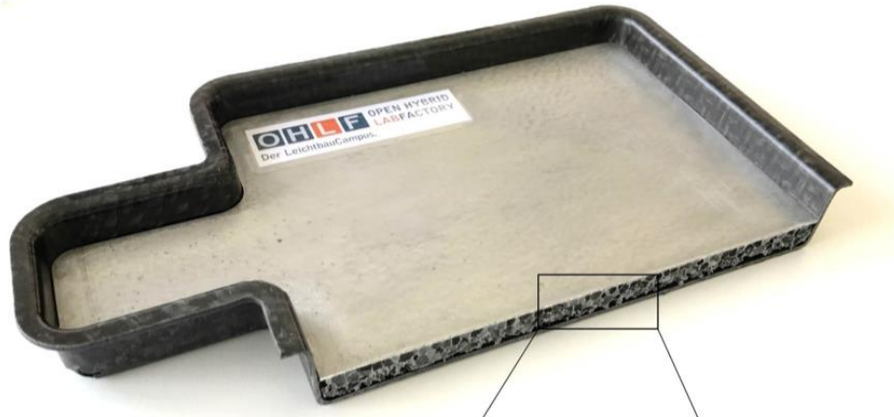
simulation

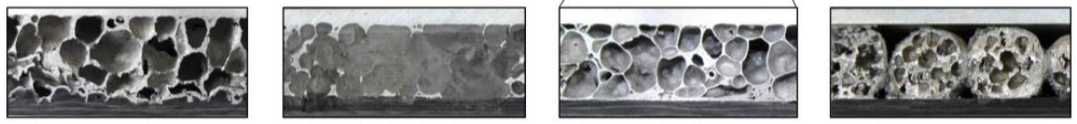
tool design

aluminum foam

forming of organic sheets

inserts



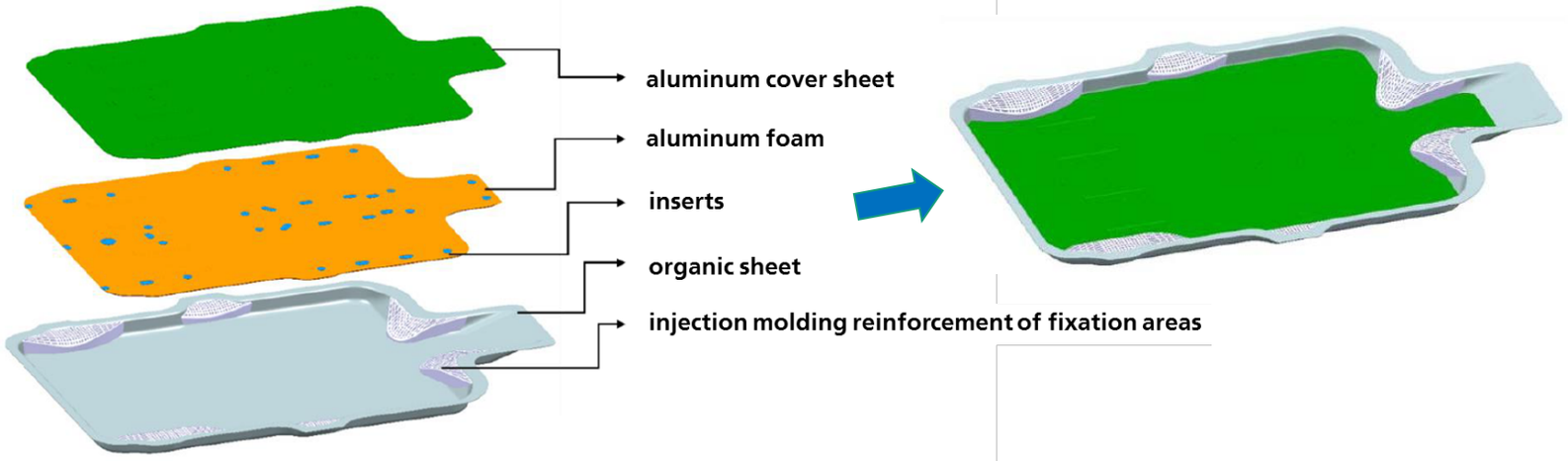


closed cell aluminum foam with open porous structure on one side

closed cell aluminum foam infiltrated with PCM

closed cell aluminum foam with oxide layer on one side

Advanced Pore Morphology (APM) foam with PA12



design for electro mobility

integrated joining process

passive cooling system

Technische Universität Braunschweig

Fraunhofer

Thank you for your attention !

Fraunhofer Institute for Machine Tools and Forming Technology IWU

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