Sandwich structures as underbody in electric vehicles

Protection of the battery, crash, heat balance

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What can you expect?

- In short introduction of product and company
- Classic applications in the vehicle underbody
- Surroundings of the battery in e-mobility today
- Unwanted loads on the underbody (battery protection)
- Thermal balance

Overview of the state of our developments / investigations
Metawell GmbH – the company

- **Company data**
  Owner-operated company
  approx. 170 employees
  in business since 1984

- **Portfolio**
  Development and production of
  - Aluminium sandwich panels
  - Lightweight components with sandwich technology

Company site Metawell GmbH
Schleifmuehlweg 31 / D-86633 Neuburg/Donau
Metawell® – semi-finished sandwich panel

Metawell® aluminium sandwich panel

- Production in a continuous process
- Corrosion protection applied industrially in a coil coating process
- Proven process, in use for over 30 years
Sandwich panel as underbody protection?

Use of a sandwich panel as underbody

- **High weight-specific bending stiffness**
  Weight saving by increasing the moment of inertia

- **Increasing the torsional rigidity of the vehicle frame**
  Not only around the longitudinal and transverse axis, but also as a thrust field

- **Extremely flat underbody**
  Very good flow conditions (drag coefficient)
  Danger of jamming of objects much less than with beaded structure

- **Support of the frame during crash**
  Higher kink stability of the sandwich compared to beaded structures
Sandwich panel as underbody

Increasing the torsional rigidity of the vehicle

Field sizes: up to 850 x 2200 mm, once divided diagonally

**Metawell® panel Alu hl 05-02-05 hl / H6**
- Cover sheet: 0.5 mm EN-AW 5182 H48
- Cover sheet: 0.5 mm EN-AW 5182 H48
- Total thickness: 6 mm
- Weight: 3.8 kg/m²

Mercedes O350 Tourismo
Sandwich panel as underbody

Extremely flat underbody

Experience with sporty vehicles

**Metawell® panel Alu hl 05-02-05 hl / H10**

- Cover sheet: 0.5 mm EN-AW 5182 H48
- Cover sheet: 0.5 mm EN-AW 5182 H48
- Total thickness: 10 mm
- Weight: 4.4 kg/m²
Sandwich panel as underbody

Support of the frame during crash

Gumpert Apollo / Arrow

Metawell® panel Alu hl 10-03-10hl / H11.5

cover sheets EN-AW 5754 H48
Li-ion batteries

- High energy density
  Optimal efficiency 18-25°C
- Risk of „thermal runaway“
  due to overheating or mechanical deformation
- Pack the battery in cotton wool....
  Thermal balance?

The battery must be thermally and mechanically protected

E-mobility – battery

Position of battery in the vehicle

- High weight
- High volume
- Low centre of gravity
- Integrated in chassis
- Exposed to the street (large exposed area)
- Directly beneath passengers „Ride on a powder keg...?“

E-mobility – battery protection

High effort for mechanical protection of the battery, Tesla

Skateboard-chassis Tesla model S and X

Additional battery protection model S

E-mobility – battery protection

Audi e-tron

High effort for protection

- Mechanical
- Thermal

Source: floor structure of Audi e-tron Image: Audi/press-inform
Specified requirements for the protection system

- **Actually no space!**
  (very limited installation space)

- **Support during crash**
  Here, a sandwich can support the frame, not replace it.

- **Planar protection to the road**
  - Static loads: setting down / lifting the vehicle in the wrong position (stamp test)
  - Dynamic loads: impacts of objects from the road

- **Protection against overheating**
  - Good heat dissipation
E-mobility – protection of underbody

Static load: Lifting the vehicle in the wrong position (stamp test)

- Stamping load by lifting: 1 ton (10 KN)
- Field size of the underbody panel: 1200 mm x 2000 mm
- Distance underbody panel to the battery: 10 mm (Bottom of the vehicle to battery: 25 mm)

FEM simulations: Required E-module with 15 mm panel thickness: $E_{\text{min}} = 73500 \text{ N/mm}^2$

Converted to a solid plate: 15.3 mm aluminium = 100 kg or 10.6 mm steel = 200 kg

-> Load for a large field too big, fields must be subdivided
E-mobility – protection of underbody

Subdivision of the entire area into individual fields

A rigid sandwich panel allows to increase field size / reduce cross-struts
Criterion 10 CN stamp: 4 compared to approx. 30 fields (other criteria not taken into account!)

Connection of the underbody protection to the frame of the battery in the Tesla model S

Crash-path structure in the Audi e-tron source: Audi/press-inform
Sandwich panel as underbody

Dynamic load: impacts from the road
- Example gravel spatter underbody in high-speed trains

© Siemens AG
Impact of objects from the road

“Average loads” -> No loss of function of the underbody panel

- Impacts on the highway (Speed 130 km/h)
  Assumption: rockfall of 100 g
- Impacts Off-Road / dirt road (Speed 60 km/h)
  Assumption: rockfall of 470 g

Extreme loads -> No damage to the battery
- 7 times of average loads (rockfall with 700 g at speed 130 km/h)

Impacts at different angles of impact
Bombardment of underbody

Study with a drop down unit

- **Simplified assumption of same impact energy**
  Kinetic energy balance: $E_{\text{kin}} = 0.5 \times m \times v^2$
  **Average loads**: Kinetic energy $= 65.2$ J
    - 100 g at 130 km/h or 470 g at 60 km/h
    - 15°, 45°, 90°
  **Extreme loads**: Kinetic energy $= 467$ J
    - 7 times average load
    - 15°, 45°

- **Tests with drop down unit with same kinetic energy**

- **Reproducibility of results**
  Impact of the projectile always at the same angle
  Angle adjustment by rotation of the target plates
Examined specimens

- **Sandwich element with aluminium cover sheets**
  Why only aluminium? Frame structure of the vehicle is often also made of aluminium.

- **Different aluminium alloys and hardness conditions**
  Impact on the penetration depth

- **Surface coating**
  Effects of low-friction surfaces at impacts below 45°

- **Reinforcements of aluminium layers by fibre materials**
  Multi-shell construction to stabilise the lower cover layers
Bombardment of underbody

Exemplary test results of the shelling tests

Metawell® standard panel Alu hl 10-03-10 hl / H11.5

\[
\begin{align*}
\text{t}_1 & \quad \text{cover sheet} & \quad 1.0 \text{ mm EN-AW 5754 H48 (with slide primer)} \\
\text{t}_2 & \quad \text{cover sheet} & \quad 1.0 \text{ mm EN-AW 5754 H48 (with slide primer)} \\
\text{t}_w & \quad \text{core material} & \quad 0.3 \text{ mm corrugated sheet EN AW 5182 H48} \\
\text{H} & \quad \text{total thickness} & \quad 11.5 \text{ mm} \\
\text{weight:} & \quad 7.2 \text{ kg/m}^2 \quad (\text{corresponds to approx. 2.7 mm solid aluminium sheet})
\end{align*}
\]
Bombardment of underbody

**Shelling with average load 65.2 J**
Lower cover sheet slightly deformed,
Upper cover sheet (side of battery) uninfluenced.
Function remains entirely in tact
(except for very limited local loss of stiffness)

**Metawell® Alu hl 10-03-10 hl / H11.5**
Bombardment of underbody

Shelling with extreme load 467 J
Lower cover sheet severely deformed,
Upper cover sheet (side of battery) at 45° hardly any deformation.
Function restricted, lower cover sheet immediately prior to tearing

Metawell® Alu hl 10-03-10 hl / H11.5
Reinforced sandwich panel

Reinforcement of sandwich with protection layer

- Reinforcement of the lower cover sheet with fibre materials (Kevlar® or Nomex® fabric)

- Slight improvement, especially for extreme loads

- Results dependent on alloy and surface

Standard-panel
Alu hl 10-03-10 hl / H11.5

Fabric fibre
+ 0.5 mm aluminium
Influence of surface and alloy

Fibre-reinforced sandwich 
same design, different alloy and surface.

Bombardment: average load, 45°
Due to anti-friction coat (slide primer) and greater strength, the projectile bounces off the test piece 9B (right), while "burying" into the surface at 3B. The probability of a crack is much higher at 3B.
Influence of surface and alloy

**Fibre reinforced sandwich**

same design, different alloy and surface.

**Bombardment: Extreme load, 45°**

In the case of extreme load, there are very clear advantages due to the anti-friction surface coating (slide primer) and the higher-strength alloy.
**Added benefit of Metawell® as underbody**

**Heat balance: battery cooling**

**Material**  
Aluminium has very good heat conduction

**Air cooling**  
Consistent air flow due to extreme evenness

**Fluid cooling**  
Benefit of the corrugation channel of the Metawell® panel as a cooling channel

Cooling system in Audi e-tron Audi/press-inform
Added benefit of Metawell® as underbody

Heat balance: Battery preconditioning (heating)

Tesla (Press release 2018-01-05):
“When the temperature gets close to freezing, pre-air conditioning heats your battery to increase the driving and charging power. To reduce the loss of charge, we recommend that you plug in the charging cable and turn on the pre-air conditioning about an hour before you leave, as it may take a while for the battery to warm up in cold weather”

Heated Metawell® panels
Metawell® panels are ideal for gluing heating foils thanks to their even surface.
- Very good heat conduction
- Almost no extra space
- Proven heating systems with Metawell®
**Electromagnetic compatibility EMC**

**Aluminium as a shield**

E-Mobility has high demands for EMC  
Test standards: CISPR 25 / ISO 11452-2

Aluminium provides a good shielding to ensure EMC.

- Metawell® panels are made of aluminium  
- Large components (= few connection points) contribute particularly to EMC  
- A large Metawell® underbody is ideal
Summary

**Metawell® sandwich panel as underbody and battery protection**

- Fabrication of the sandwich panel in industrial and continuous production
- Proven product with long-term experience in vehicle construction
- Reinforcement of chassis by bending and torsion resistant panel
- Low weight
- Even surface (low air resistance)
- By multilayer construction also the standard panel has a good protection function
- Reinforcement of lower cover sheet for extreme loads through fibre fabric possible .... necessary?
- Good heat conduction -> air cooling
- Corrugation channels could be used as a cooling channel -> active battery cooling
- Pre-treated, smooth surfaces can be easily heated -> preconditioning
- Large aluminium sandwich supports EMC
- Easy recycling of aluminium