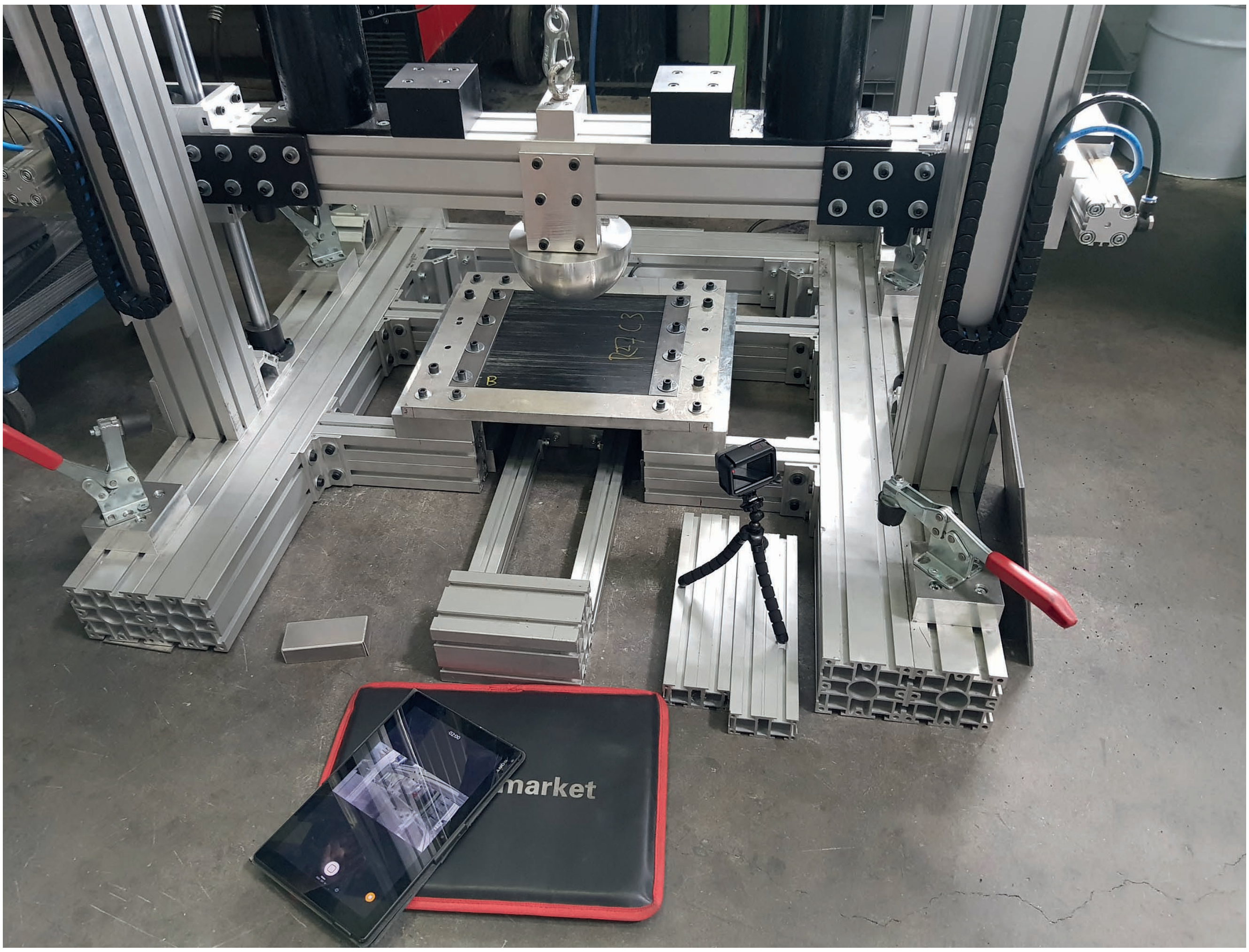
Polypropylene Beats Aluminum

Underbody Protection for Batteries in Electric Vehicles

Batteries in electric vehicles must be specially protected to counter the risk of fires. Battery trays made from aluminum frequently offer insufficient protection. The automotive supplier ElringKlinger has therefore developed underbody protection manufactured from glass fiber-reinforced PP.



To be suitable for the underbody protection of electric vehicles, a material must first pass a bollard test (© ElringKlinger)

Until now, battery trays for electric vehicles have been produced mainly from aluminum. Recently, however, a number of vehicles have caught fire after objects lying in the road were flung up at high speed against the battery trays. These components were designed to resist low-speed impact stresses and could not withstand this ballistic impact. As a result, the objects pierced the trays and damaged the batteries, which then began to burn.

ElringKlinger AG, Dettingen an der Erms, Germany, therefore developed a ballistic-impact-resistant battery tray system. It had to weigh no more than an aluminum component and incur no significant extra costs through the use of expensive materials such as aramid fibers or titanium. In the interest of sustainability, the aim was to achieve the greatest possible recyclability of the materials used and the finished battery tray.

The battery trays in electric vehicles are primarily underbody systems designed to protect the batteries from impact stresses arising from the road.

These are simulated in the development process by a bollard test with defined energy input. From the available installation space, mounting system, and selected material, the possible component thickness, weight, and costs can be calculated.

The behavior of different fiber composites under impact stress was tested by ElringKlinger using the puncture impact test as per standard ISO 6603–2. The matrix systems tested were polypropylene (PP) and an epoxy resin, while the reinforcing materials used were glass and carbon fibers. The tests showed that in a direct comparison, glass fiber-reinforced PP recorded the highest maximum forces and energy absorption (**Fig. 1**). The following material properties and mechanisms are responsible for this:
- Ductility of PP in contrast to brittle epoxy resin,
- high elongation at break of glass fibers (5 %) in comparison with carbon fibers (0.5 %),
- high energy transfer through fiber pullout due to limited adhesion of the polar glass fiber surface to the non-polar PP.

As the results show, laminate structures based on unidirectional (UD) tapes achieve the highest test values. The UD tapes developed in-house with 80 wt. % and 60 vol. % glass fiber content not only have improved maximum force and energy absorption but also significantly increased stiffness. Currently available UD tapes with 70 wt. % glass fiber content have a tensile modulus of approximately 34 GPa. Through the increase in fiber content, the value could be increased to 47 GPa. This is a step in the right direction for creating a system with an installation space similar to that of the aluminum tray. But it is still not enough, since the elastic modulus of aluminum (70 GPa) is considerably higher. So installation space equivalence can only be achieved by increasing the structural stiffness of the battery tray.

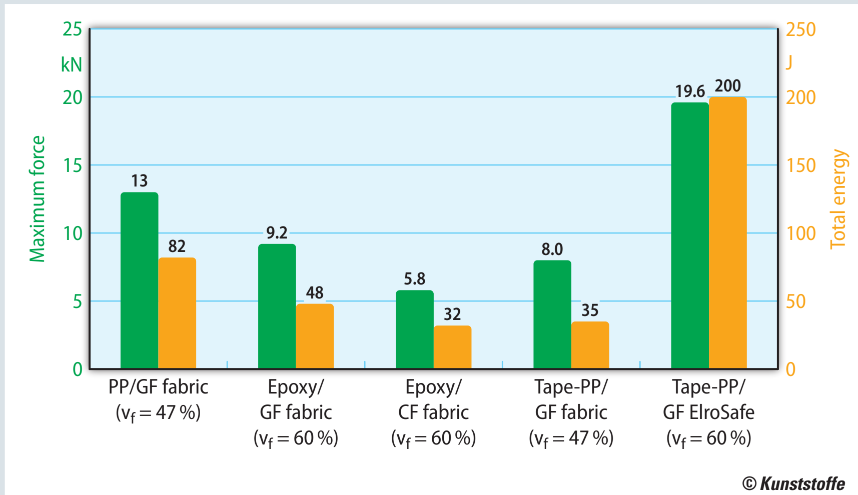


Fig. 1. UD tapes made from PP with a high glass fiber content had much higher values than the other materials tested (source: ElringKlinger)

Sandwich Structure with UD Tapes

The technical solution lies in a sandwich structure known as ElroSafe. This uses UD tapes for the outer layers, because of their lower density, and a direct long fiber thermoplastic (DLFT) as the core material. In this way, through higher wall thickness, the required structural stiffness can be obtained for the same areal weight. Comparative calculations and validation tests show that with a 5 mm-thick sandwich comprising 1.5 mm outer layers made from UD tapes and a 2 mm core made from a DLFT with 30 wt. % glass fiber content, an installation space equivalent to that for a 3 mm-thick aluminum sheet (comparative material: EN AW-5754 H22) is obtained. Installation space equivalence here means the same component thickness plus deformation under defined load. Testing was carried out using application-appropriate geometry with a free bending length of 254 mm. In the testing instrument, a standard bollard with a diameter of 180 mm and weighing 100 kg was dropped from a height of 85 mm onto the 340 x 290 mm test panel (**Title figure**). This corresponds to an energy input of 84 J. Deflection over time was measured on the underside of the test panel.

Table 1 compares test panels with different glass fiber contents in the UD tapes of the outer layers and a 3 mm-thick aluminum sheet. These results, taken together with curves shown in **Figure 2** (left aluminum, right ElroSafe), lead to the following conclusions:
- Only with a UD tape having a glass fiber content of 80 wt. % can installation space equivalence with aluminum be obtained.
- The ElroSafe sandwich transfers the input energy fully elastically. This is possible due to the high tensile strength of the tape (up to 1000 MPa) and the high elongation at break of the composite (>2.5 %).
- The aluminum sheet deforms plastically in the form of a permanent bulge of 12.2 mm (**Fig. 3**) due to its low yield strength of about 100 MPa.

It is assumed that damage events of this type and intensity rarely or never happen in a vehicle's life. Nevertheless, when driving off paved roads or descending from a curb, such damage events may possibly occur. A battery tray produced from ElroSafe effectively prevents damage to the battery in these cases. Even after repeating »

Material (outer layers/ aluminum type)	Fiber content [%]	Deformation [mm]	Wall thickness [mm]	Installation space [mm]	Permanent Deformation
UD tape PP/GF	70	19.6	5.0	24.6	0.0
UD tape PP/GF	80	16.9	5.0	21.9	0.0
Aluminum (EN AW-5754 H22)	--	18.9	3.0	21.9	12.2

Table 1. Results of the bollard test on UD tapes with different glass fiber contents and an aluminum sheet (source: ElringKlinger)

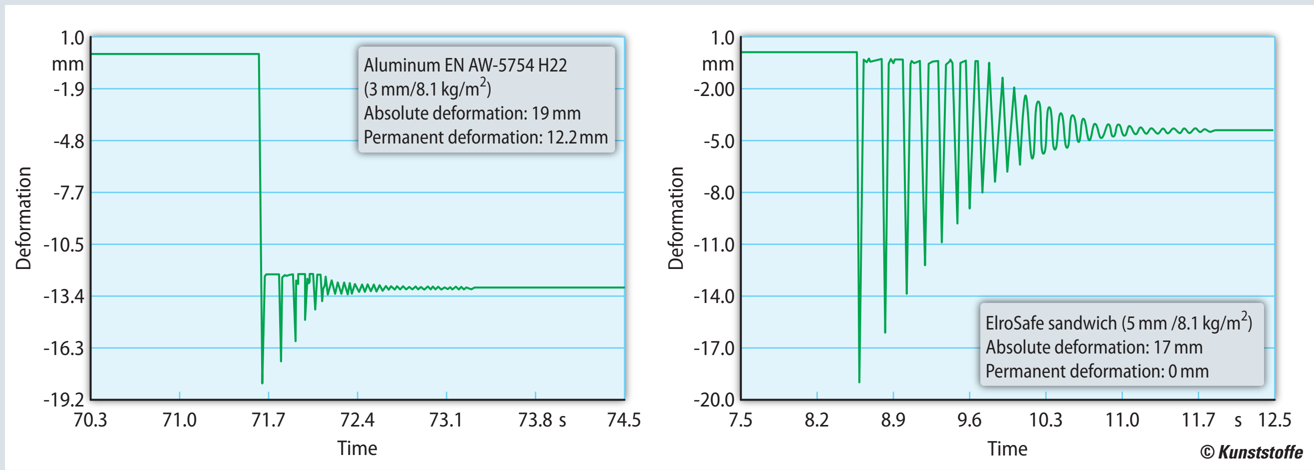


Fig. 2. Deflection under load (180 mm diameter, 100 kg, 84 J): in contrast to aluminum, the PP sandwich structure transfers the energy fully elastically (source: ElringKlinger)

the bollard test ten times on the same sandwich panel with an energy input of 84 J, no permanent damage can be seen. Following these tests, the drop height was gradually raised in a type of increasing-load test. The first visible sign of damage, a ductile failure on the compression side, occurred at a drop height of 785 mm. At 735 mm, which corresponds to an energy input of 721 J, there was still no damage. ElroSafe can therefore withstand very high loads without damage but requires additional deformation space for this.

Following the battery fires occurring as a result of running over objects in the road, ballistic impact tests were conducted on behalf of a German auto manufacturer. In these tests, 5 kg steel projectiles were fired onto various materials at 110 km/h and an impact angle of 15°. Only the ElroSafe sandwich, in the described overall thickness of 5 mm, withstood the test without penetration. There was only slight linear abrasion of the outer glass fibers on the side hit by the projectile. In this case, too, the input energy was fully converted into elastic deformation.

In accidents between a gasoline or diesel vehicle and a battery-powered vehicle, spilt fuel can ignite under the battery vehicle. It is therefore important to ensure that batteries do not catch fire before the passengers of the battery-powered vehicle have been rescued. Standard ECE180 defines a suitable test for this. A trough of burning gasoline with a flame temperature of 700 to 800 °C is slid under the component being tested or a significant section of it. It remains there for 130 s. During flame exposure, the component must not lose its structural integrity. In addition, the temperature on the inner side of the component must not rise so high as to ignite the battery.

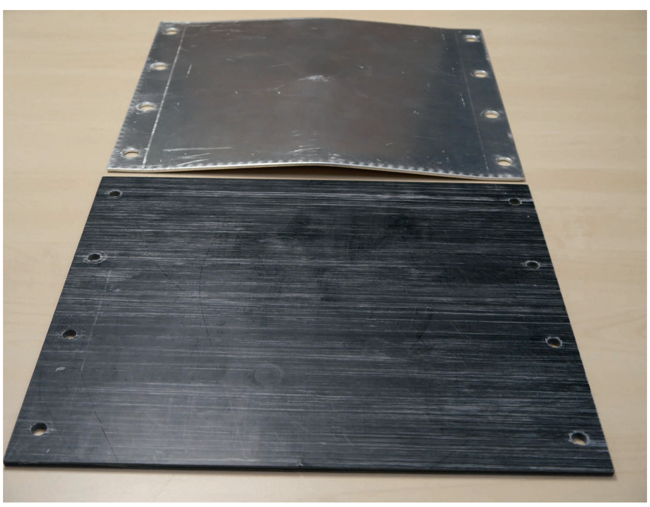


Fig. 3. After three repetitions of the bollard test, the aluminum sheet had significantly deformed by 12. 2 mm, whereas the ElroSafe sheet was undamaged (© ElringKlinger)

Underbody also Protects against Fire

The fire test rig can be seen in **Figure 4**. On an ElroSafe sheet measuring 695 mm x 695 mm, aluminum profiles were fitted all round, simulating the construction of a current battery tray. The tray was sealed on top with fire-resistant gypsum plasterboard. On the outside of the profiles, two thermocouples were laterally mounted and another was passed through the plasterboard to the inner side of the ElroSafe sheet.

Figure 5 shows the temperature curves measured on the profiles (yellow and green). These curves represent the combined temperature of the flames and the aluminum profiles. The red curve shows the temperature curve on the inner side of the ElroSafe sheet. Because of the low thermal conductivity of the thermoplastic fiber composite, a temperature of only 100 °C was reached there. The high fiber content leads to extremely dense packing of the unidirectional glass fibers, which prevents oxygen reaching the deeper layers. For this reason, only a very thin matrix film burns on the side exposed to flame. The weight loss of the sheet was only 14 g.

Material Reduces Energy Requirement

The low increase in temperature on the inner side of the ElroSafe sheet shows the good thermal insulating effect of ElroSafe. Since these batteries only work optimally within a certain temperature range, their temperature must be controlled. When outdoor temperatures are low, a by no means negligible amount of energy is required for this. The energy demand is higher the more energy is lost to the environment as a result of thermal conduction. In this respect, a battery tray made from ElroSafe achieves a substantial improvement over aluminum with its very high thermal conductivity and so also extends the vehicle driving range.

The initiation and progression of a sound event arising as a consequence of an external stimulus such as a stone strike are characterized by measuring the acoustic impedance. Here, the pulse height, i.e. the sound volume, and the decay behavior of the pulse over time are measured. Even in this regard, a battery tray made from ElroSafe has considerable advantages over its aluminum counterpart. The sound pulse is lower and decays faster. This is particularly important with high-end vehicles.

Fig. 4. The material must withstand temperatures of up to 800 °C in the fire test. This ensures that the battery does not catch fire (© Warringtonfire)

The tests during the development process clearly show that ballistic-impact-resistant battery trays can be produced from ElroSafe. Besides the crucial safety aspect, such trays have very good suitability for everyday use because small impact stresses do not cause lasting damage. The trays also offer good protection from fires under the vehicle and are very good thermal and acoustic insulators. On account of these technical advantages and the low costs, a number of development projects with this material have already been started. Serial production is expected to follow in 2022 or 2023.

ElroSafe can also be used in lightweight design applications with thermoplastic fiber composites, which until now have been held back by high system costs. Possible applications include rear seat backs, bulkheads, and rear bumper beams. These components require additional functionalization in the form of ribs or mounting elements, which can be readily pressed from the DLFT core or produced in a subsequent injection molding process in the compression mold.

The starting materials for ElroSafe consist solely of PP, glass fibers, and commonly used additives such as carbon black for coloration, stabilizers, and adhesion promoters. All waste products along the production chain, such as edge trim from tape manufacture, but also reject parts, can be comminuted and used in the production of new components instead of an injection molding masterbatch. The regrind is blended with virgin PP on the injection molding machine to produce PP-GF30 or PP-GF40. This ensures a sustainable material loop, which has been validated by two studies carried out at Rosenheim University of Applied Sciences (TH Rosenheim), Germany [1]. ■

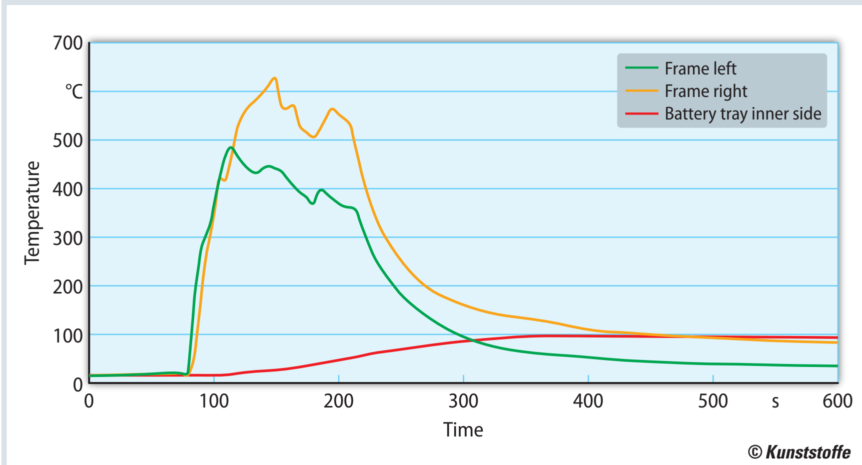


Fig. 5. Temperature curves in the fire test: the temperatures measured on the aluminum frame (green and yellow curves) are initially far higher than those measured on the ElroSafe sheet (red curve) (source: Warringtonfire)

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Service

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