Precisely Developed

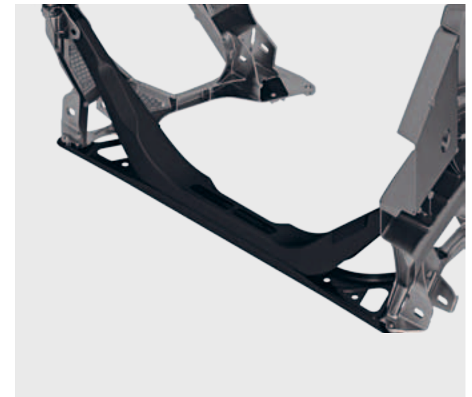
Hybrid cross member made of fiber-reinforced plastic

By Markus Hofmeister and Andreas Tegtmeier

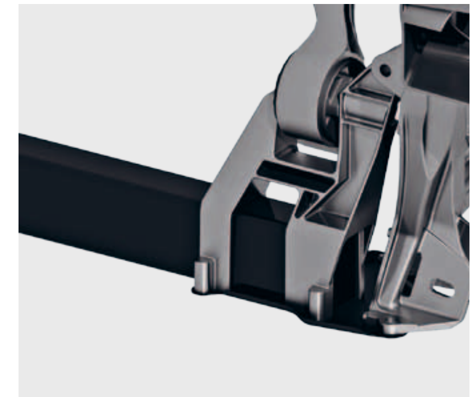
____ Lightweight construction and electrification of the drivetrain are important objectives in modern vehicle development. In combination, they present development engineers with new challenges that call for innovative solutions. Porsche Engineering employs intelligent development methods to meet those challenges. One example is the creation of a structure-stiffening suspension component with composites.

In 2012, Porsche took the lead in the e-Generation (see info box on page 16) research project with the Volkswagen Group research division as a consulting partner. In the project, leading German companies and renowned universities are developing a new generation of components for electric vehicles.

The platform for integrating these groundbreaking components was the current Porsche Boxster, whose basic structure as a mid-engine sports car makes it especially suitable for a purely electric-powered concept car. Over the course of development, nearly all of the car's combustion engine components were removed to make space for other components. Among other elements, a structure-stiffening suspension component in the area of the rear axle was developed. The task of the reference component slated for replacement was to increase the torsional rigidity of the rear as well as the connection stiffness of the rear-axle wishbone to the body. The newly developed component is also subject to other requirements. The developed hybrid cross member made of fiber-reinforced plastic (FRP) is also used to mount the motor of the electric drive unit and serves as torque support.



Reference component



Mount for the power unit carrier

The development of this component, which was led and largely shaped by Porsche Engineering, ranged from the concept phase to design, optimization and simulation as well as production and testing.

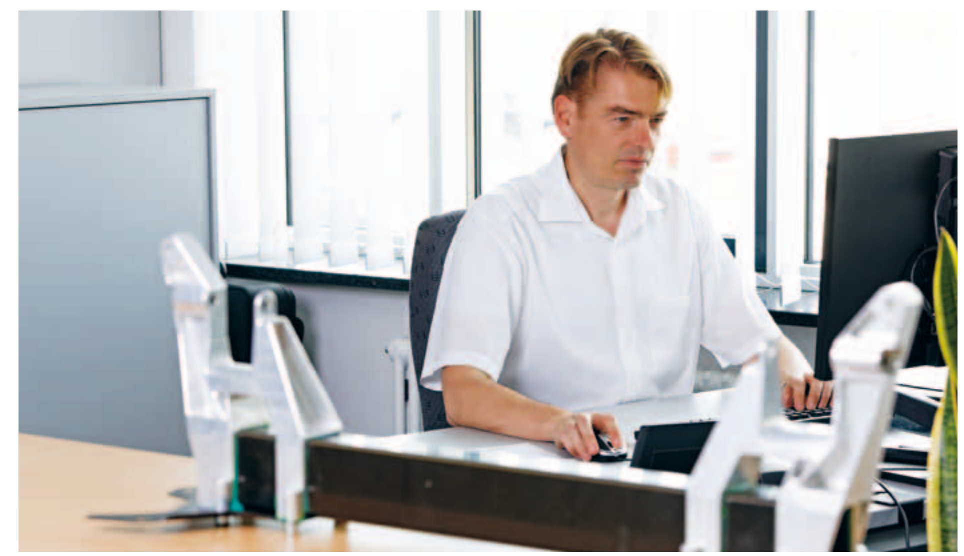
The development methods

In the development of the innovative cross member, the aim, beyond achieving the defined requirements, was to use as little material as possible. The cost angle was also a consideration from the outset with the potential for series production in mind. To achieve these objectives, the engineers at Porsche Engineering employed state-of-the-art development methods for the design and material selection processes.

By selecting the Porsche Boxster mid-engine sports car as the base vehicle, the usable construction space for the design and the defined force-transmission points in the body were pre-determined. A topology optimization in the construction space did, however, enable the creation of a new basic design optimized for the load flow.

As with the optimization of the topology, the virtual assurance of the component to be developed was conducted in part with specialized finite element (FE) programs and the components were calculated by the developers together with software experts. This involved the use of software for linear predesign of the component as well as simulation of the tensions while taking into account non-linear considerations.

As the properties of fiber-reinforced composites strongly depend on the orientation of the fibers, they have to be aligned in a load flow-appropriate manner to exploit their full potential. Thus the orientation of the composite fibers was optimized through simulation and designed to maximize the material properties. ›



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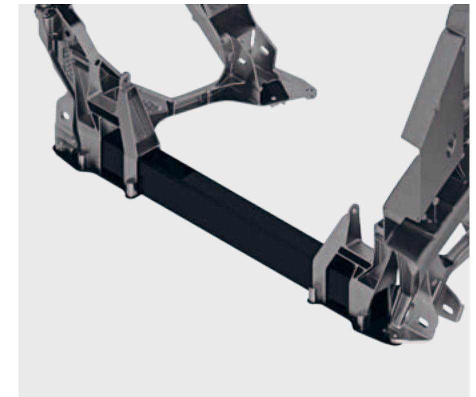
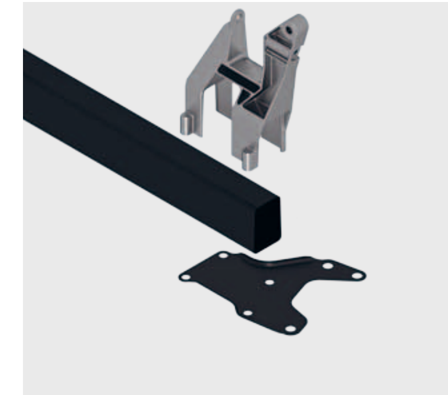
COMPREHENSIVE VEHICLE DEVELOPMENT


Structure optimization of the construction space


Areas with different characteristics


FRP hybrid cross member


Individual parts of the cross member

Requirements and material selection

Over the course of initial research, it became clear that the welded sheet-metal construction used in the reference component was not ideal under the new conditions. Weight was the primary consideration in the development of a new component. Every kilogram saved enables increased range, either through decreased driving resistances or by allowing a larger battery.

Material selection is the decisive factor here. Aluminum alloys, high-strength steels and fiber-reinforced composites form a ground floor for components with this purpose in mind. It is very important, however, to select the right material as needed for the right area of application. Useful in this context is a comparison of the materials available for selection with regard to the specific stiffness, i.e. the relationship of the E-module [N/mm²] and the density [g/cm³].

The results for the future component revealed three different areas, all with rather different requirements profiles:

1. A flat area that is determined by the surrounding components; it is imperative that this part be capable of handling the major shear forces that can be expected to emanate from the wishbone.

2. A middle area with a high flexional resistance generated from the connection points with the body.

3. A section that can handle the significant forces of up to ten kilonewtons from the power unit mount.

In the first area, steel is the perfect material owing to the low available construction height of just a few millimeters. It is the best-suited material for passing on the high shear forces without buckling or warping.

For the second section, a design was selected that would enable maximum stiffness at the lowest possible weight. The choice was a profile made of carbon fiber-reinforced plastic. This was perfect for increasing the stiffness of the rear.

To best handle the loads in the third section and support surrounding components, aluminum was selected. In this application, aluminum guarantees high specific stiffness while offering great freedom to shape the material.

A two-component adhesive was used to connect these different materials optimized for their respective tasks. Thus three in themselves essentially optimal subcomponents were combined to form a single component. In short: the best of three worlds.

Characteristics and production-appropriate design

All elements of the cross member were also designed with a mind to subsequent series production. The production method therefore also influenced the design. Common processes in series production were taken into account.

The first area, also known as the closing panel, was manufactured out of ›

e-Generation

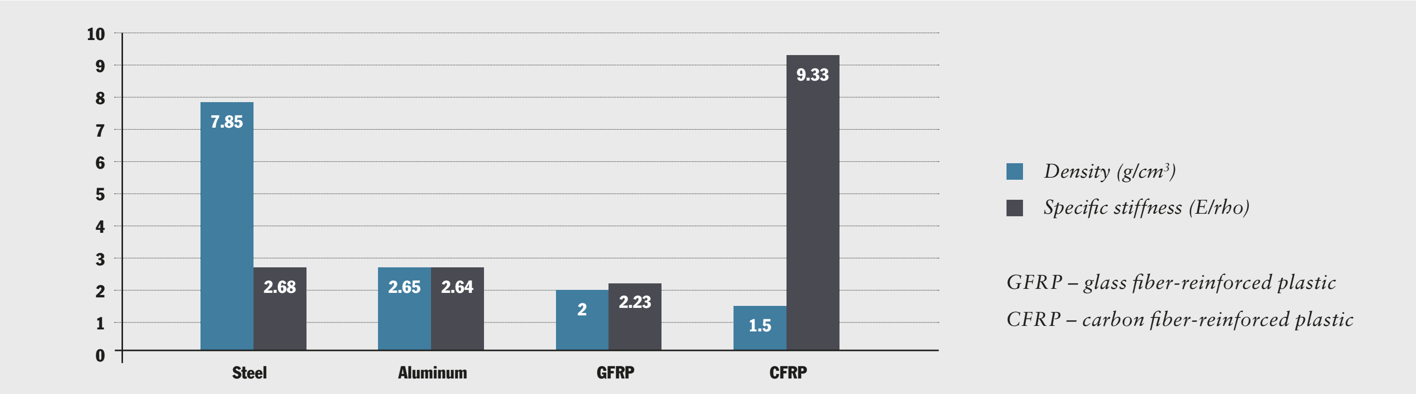
In the current environmental and climate situation, new solutions in the field of vehicle-based mobility are urgently needed. Leading German companies and renowned universities and research institutions joined together to advance the cause of e-mobility as part of the e-Generation project sponsored by the Federal Ministry of Education and Research (BMBF).

The joint project supports the goal of the federal government to establish Germany as a leading market in the field of electro-mobility with the aim of improving the range, cost, and day-to-day usability of the vehicles.

Electric vehicles are currently still significantly more expensive than conventional vehicles. In spite of the many innovations that electric vehicles require, potential customers expect a good and easy-to-use vehicle. To increase the market appeal of electric vehicles, the costs of the requisite e-mobility components and systems must be reduced drastically. With this in mind, the project is examining the possibility of a module for electric drivetrains.

To increase the range, the use of energy resources must be optimized. Beyond the fundamental reduction of consumption, research efforts in this area also focus on new means of vehicle air conditioning. Reducing the overall weight also contributes to increased ranges, which is why lightweight construction and efficiency-focused measures are also being examined. New generations of drive components coordinated with other components in the overall vehicle composition should result in new potential for greater efficiency as well.

The close collaboration between the vehicle manufacturers and important suppliers and universities ensures the market-relevance of the research results and thus creates the basis for rapid market implementation. The aim of the research results is also to improve the competitiveness of the automobile and supplier industry in conjunction with research institutions in Germany and thus pave the way for Germany to assume a leading role in the global marketplace.



Comparison of density and specific stiffness

cold-forming micro-alloyed high-strength steel and given a cathodic coating to protect against corrosion. A positive side-effect of this is a coated component suitable for adhesive application without further preparation.

This material and coating are frequently used in the automotive sector, which aside from having the desired characteristics, also results in low material costs.

Through two screw connection points, the closing panels form the lower interface to the body.

The consoles—i.e. the third section—are made of aluminum. Die cast molding is preferable for the manufacture of the part because this method, compared to other casting methods, allows smaller wall-thicknesses and a great deal of freedom in shaping. The material was one used in the suspension area for subframes and suspension arms. Each of the aluminum consoles has a fixed mount for the drive unit and together they form the upper interface to the body.

The heart of the cross member is a square profile that emerges as a pultrusion profile via the pullwinding method. The pultrusion method is currently the most cost-effective means of manufacturing fiber-reinforced elements in larger unit numbers. Continuous fibers running lengthwise in the profile direction are shaped through a thermosetting matrix and saturated with an epoxy resin. To incorporate fibers crosswise to the profile direction in the component as well, the continuous fibers are additionally wrapped in fibers at an angle deviating from the pultrusion direction.

This makes it possible to generate almost any fiber orientation or configuration without breaks for joints in the fibers. Thanks to this production method, the profile used in this component demonstrates greater robustness and stiffness than a comparable part made of high-strength steel—at a quarter of the weight.

The subcomponents are joined with a two-component adhesive from the bodyworks. The adhesive procedure was specially developed and tested for this cross member.

The adhesive alone is enough to ensure an absolutely adequate bond between the components. Since suspension components, as in the present case, are usually safety-relevant components, the aluminum consoles are additionally fastened to the closing panels with screws. This ensures that even in the case of a hypothetical failure of the adhesive bond, limited functionality would be assured.

Thanks to the use of modern development and production methods, the cross member that emerged from this process is twice as stiff as the reference component. It also integrates the function of the unit carrier and yet weighs five percent less than the reference component.

Assurance and production

To ensure proper functioning in the vehicle, the cross member and all joining techniques were simulated and evaluated with calculation programs. One particular challenge in this regard was validating the FRP profile and the adhesive connection.

After proving the requisite robustness and calculating the stiffness, initial prototypes of the cross member were created. This was always done with a view to potential series production: even the first components were produced and joined so as to be as similar as possible to cross members produced automatically in any later production process. The aluminum consoles were designed in a cast-compatible fashion and the closing panels were manufactured in line with the envisioned series production method. The process safety of the joining process was also subjected to continuous examination and optimization throughout the process.

Before being used for the first time in the vehicle, the FRP hybrid cross member had to prove its long-term robustness on the test bench. This involved simulating an endurance test at the Weissach testing grounds that approximates the strains of a vehicle lifetime in a very compressed format. The component went on ultimately to pass the test without any significant damage being detected.

To check the cross member after the exacting ordeal on the test bench, various methods of examination were used, including computerized tomography. After all of these assurance measures, all vehicles in the e-Generation project were outfitted with the component.

Evaluation and completion

The development of the FRP hybrid cross member shows what can be achieved with an intelligent material mix combined with new component development methods and established production procedures. This opens up an alternative to the existing more expensive and time-consuming methods such as the ones used in the motor-racing context.

The untapped potential for lightweight construction within the field of hybrid component design opens up the possibility of using innovative development approaches to build lightweight and stable components at relatively low costs. An entirely lightweight construction-oriented design of the cross member could enable additional weight savings of up to 30% without compromising in terms of the requirements. ■

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