Audi introduced the Audi Space Frame (ASF) into mass production in 1994 (© Audi)

Multi-Material Mix Gets a Carbon Fiber Twist

Vision Becomes Reality for Mass Production of Torsionally-Rigid CFRP Components

Steel, aluminum, magnesium and carbon-fiber-reinforced plastics are combined in the new Audi A8 for a lighter weight, higher performing car body. This multi-material mix solution combines the best structural properties at a lower weight. Contributions from Voith and Dow helped enable mass production of a carbon fiber rear wall.

Automotive lightweight design continues to play a key role in driving innovation that addresses CO_2-emission and fuel consumption reduction in combustion engine vehicles as well as offsetting battery weight to increase driving range for electronic vehicles. Heat-treated steel, aluminum, magnesium and other lightweight metal alloys have traditionally been integral to vehicle weight reduction – along with high-strength polymeric materials. Carbon-fiber-reinforced polymer (CFRP) has long been used in aerospace, aviation and high-performance racing vehicles. However, using it in high-volume manufacturing operations has proved challenging – due to both cost and molding process constraints. Three companies – Audi AG, Ingolstadt, Germany, Voith Composites GmbH & Co., Garching, Germany, and Dow Automotive Systems, Auburn Hills, MI/USA – have collaborated to engineer efficiencies that make mass production of high-performance CFRP components possible.

Enabling CFRP Technology

Audi is at the forefront of lightweight design, utilizing a multi-material mix to achieve optimal performance. The spaceframe for the new A8 is a good example. Along with hot-formed steel, aluminum and magnesium components, Audi has engineered an ultra-high-strength, torsionally-rigid CFRP rear panel (**Fig. 1**) to become the largest structural component of the occupant cell of the new A8. This panel contributes to an overall 24 % percent torsional stiffness gain over the previous generation.

The CFRP technology is made possible through several factors supported by an appropriate composite-based design that transfers and optimizes CFRP principles from sports car to mass production platforms. This integral design reduces the structure to a single component with integrated function. Preform technology from Voith comprises direct fiber placement that decreases expensive CF scrap and facilitates optimal component design. The design is complemented by a robust, automated and linked manufacturing process that includes new Ultra RTM Technology that enables low mold pressures with faster cycle times. Finally, epoxy resin and adhesive bonding technologies from Dow complete the cost-effective composite solution package.

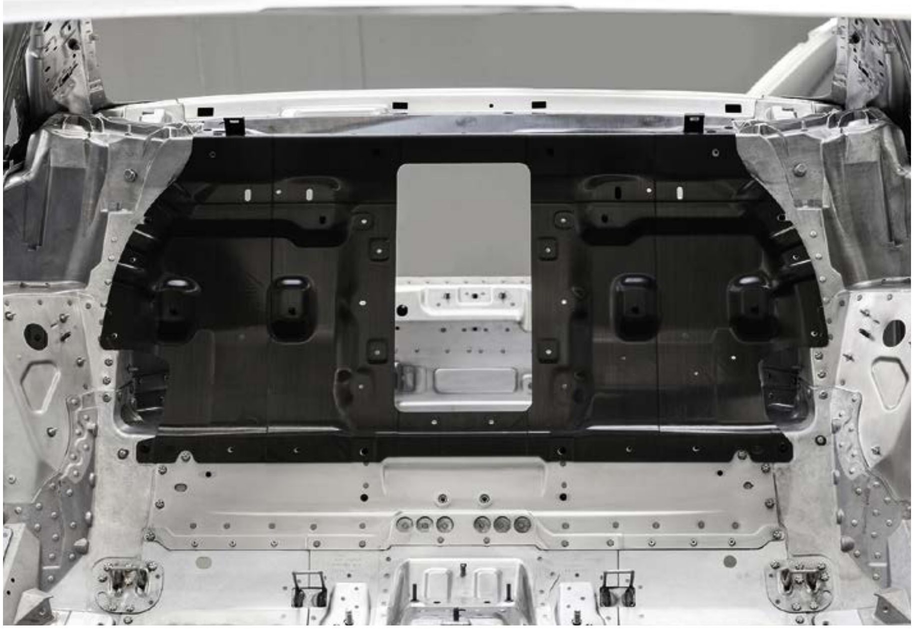

Fig. 1. Together with their partners, Audi developed mass production and assembly of the structural CFRP rear wall. It weighs 50 % less than its predecessor and is mounted to the vehicle body with a fast-cure adhesive from Dow (© Audi)

Component Construction

Building competence for the use of CFRP in high-volume platforms required time and breakthrough technologies developed at the Audi Lightweight Center. This resulted in Audi's integral component design and supplier selection that enabled the serial production process for the A8 rear panel structure.

One of the key factors that supported component construction was advanced technology from Voith that includes fully automated fiber processing through direct fiber placement (**Fig. 2**). While standard preform preparation with carbon fiber stacks/layers of non-crimped fibers is an accepted process, direct fiber placement has a high potential to improve component manufacture. This new procedure eliminates expensive semi-finished products, reduces process steps and allows for a completely digitalized production process. Voith's ability to apply this technology to create a complex preform that utilizes direct fiber placement of 6 to 19 optimized layers with localized load paths was important to the project's success (**Fig. 3**).

From this point, the main challenge became infiltrating the part with ultra-fast cure resin that would perform at low cavity pressure with excellent mold release capability. Voraforce epoxy resin systems from Dow were selected not just because of its excellent speed but because of its overall processing benefits such as ultra-low viscosity and high reaction latency resulting in excellent fiber impregnation and outstanding part quality. That profile of characteristics allowed the ability to use high-fiber-volume content layup fabrics or preforms of carbon or glass fibers. This accommodates the manufacture of very complex geometries with varying thicknesses and enables integration of added functions – all with ultra-fast-cure molding cycles of less than 120 s with no post cure. Voraforce works compatibly with resin transfer or wet compression molding processes (**Fig. 4**) and integrates an internal mold release agent to ease mass production and reduce cleaning downtimes. This also helps minimize equipment wear and maintenance.

Fig. 2. View into the Voith production facility at Garching, close to Munich, Germany. There, the Audi A8 CFRP rear wall structure is processed in a fully automated manufacturing process utilizing the patented direct fiber placement technology by the Voith roving applicator (© Voith Composites)

Manufacturing and Assembly Considerations

Automated processes are essential to high-volume manufacturing of composite components. Voith created an industrialized process chain that accommodates every step from fiber placement »

Hybrid Car Body

High strength steel, cast aluminum, magnesium and CFRP: The following video illustrates how each component and material is used in the Audi A8 spaceframe:
- www.audi-technology-portal.de/de/karosserie/aluminiumkarosserien/audi-space-frame-asf

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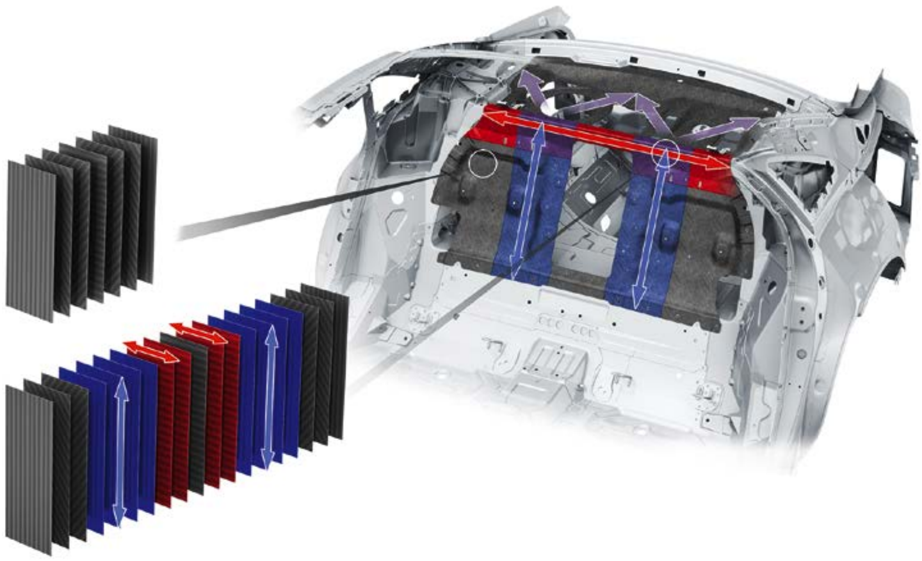

Fig. 3. An isotropic base structure is prepared with a six-layer carbon fiber buildup that is then reinforced up to 19 layers indicated by the red and blue load paths (© Audi)

through sub-assembly of the rear panel structure. This includes:
- Fiber placement,
- 3D forming,
- 3D cutting,
- Ultra RTM,
- CNC milling,
- cleaning, and
- assembly.

The process chain is supported by fully digitalized fiber placement on an industrialized production line with automated quality control and handling. This enables the high production rate Ultra RTM process (**Fig. 5**) that operates with low injection pressure and curing times less than 120 s utilizing Voraforce 5300 epoxy resin from Dow. The resin contains an internal mold release technology that provides the ability for pre-assembly surface cleaning with just water and no mechanical pre-treatment for assembly steps. Lastly, the rear panel sub-assembly is bonded with fast-curing Betaforce 9050 structural adhesive from Dow.

Finally, during the sub-assembly and assembly processes, structural adhesives were important to retain the integrity of

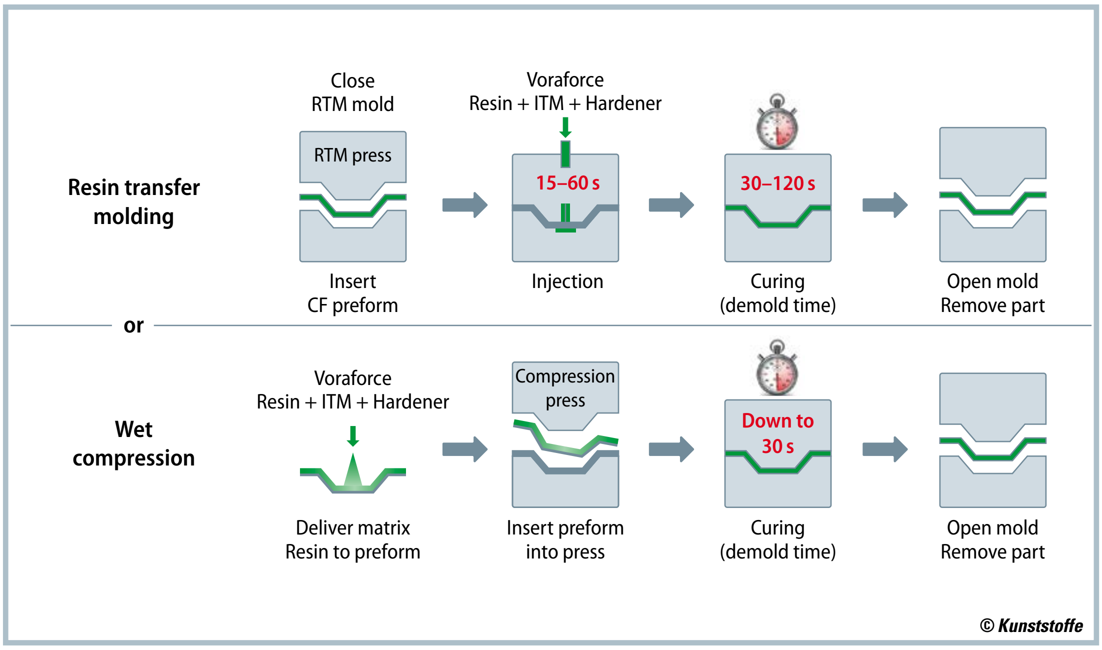

Fig. 4. Process benefits of Voraforce 5300 epoxy system. It is well suited for either RTM or wet-compression molding. Ultra-fast curing times coupled with an efficient internal mold release agent, accelerate the mass production (the properties shown are typical but not to be construed as specifications) (source: Dow)

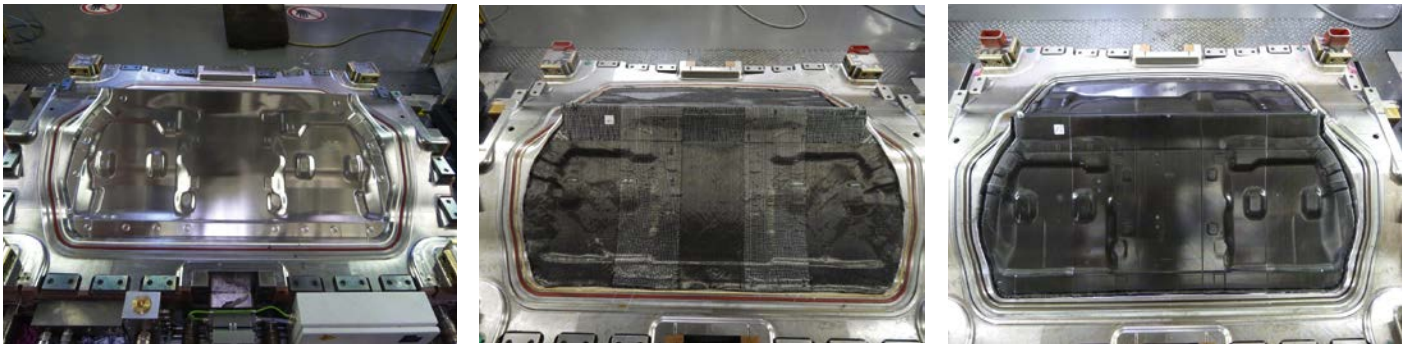

Fig. 5. CFRP rear wall in the Ultra-RTM process. From left to right: view of the lower mold surface, mold with dry preform incorporating the reinforced load paths, cured epoxy injected part prior to demolding (© Audi)

the CFRP rear panel. This joining technique helped achieve the torsional stiffness improvement and contributes to part stiffness. Betaforce 9050 was applied to the sub-assembly through a fully-automated process at Voith and again during final assembly at Audi to bond the rear panel assembly into the vehicle body.

Selecting an adhesive that could undergo heat-accelerated cure without compromising adhesion performance was essential to this application. The ability to accelerate cure results in shorter cycle times and allows for a significant reduction in tack times which is important on the assembly line where speed is of the essence. In addition, fast cure assists in efficient part logistics as end-cure properties are reached approximately one hour after manufacturing, enabling reduction of storage prior to shipment.

Collaboration Is Essential

In conclusion, collaboration is essential to drive innovation. Design, automated processes and material selection have been combined to create a scenario where mass production of CFRP components is possible. The resulting A8 rear wall structure weighs 50 % less than the previous generation, significantly increases torsional rigidity and optimizes driving and handling characteristics. This success opens a new avenue for CFRP as a viable consideration for lightweight material selection for high-volume manufacturing. ■