The world on a composites diet: How more and more markets are trying to lose weight with reinforced plastics

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That fiber reinforced plastics have a huge potential for making products lighter is stating the obvious. But the reasons why you'd want to shed pounds, kilos or even tonnes can be surprising.

Carbon fiber: not just for supercars anymore

Carbon fiber has been working wonders in the automotive industry for decades now. It is a magic wand. Wave it and not only does a car's weight go down (improving its performance and fuel economy), but also its appeal goes up. Unfortunately, carbon fiber has mainly been limited to production techniques suited to small series.

But the game is changing with manufacturers like BMW using carbon fiber reinforced polymers in its i3 and i8 models. The SGL Automotive Carbon Fiber plant at Moses Lake (a joint venture of BMW and SGL) is in the process of tripling its production to 9000 tons per year. That is employment for 200 people. BMW is not messing about.

How much research and development it takes to bring carbon fiber composites into automotive mass production is demonstrated by the CAMISMA project (carbon fiber-amid-metallic structural interior component using a multi-material approach). It was started in 2012 and is supported by the German Federal Ministry of Education and Research.

In this project Johnson Controls – a global leader in automotive seating, overhead systems, door and instrument panels, and interior electronics – has developed a lightweight carbon fiber seat backrest. Evonik Industries AG, Jacob Plastics GmbH, Toho Tenax Europe GmbH and the RWTH Aachen University's ITA institute were also involved.

In order to benefit from the weight advantage of carbon fibers, the automotive industry has to consider the entire lifecycle. The material is expensive, so a low cost manufacturing process is essential. And the concept has to encompass fiber recycling. If a car is scrapped after a decade of use, it would be wasteful to just burn the carbon fiber parts.

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Mass production of a carbon fiber seatback

The first step was to develop a fully automated continuous process with in situ polymerization to produce the base materials for the seatback. In this process, reclaimed carbon fiber is combined with heated laurolactam (the monomer precursor of polyamide 12) and an initiator.

Out comes a continuous, thin, fiber reinforced thermoplastic tape that can be used for thermoforming later on. There are two types: a tape with unidirectional virgin carbon fibers, and a random nonwoven version made from off spec fibers. For the prototype that carbon is still leftovers from fiber manufacturing. But in mass production this can be replaced by end-of-life recycled carbon fiber.

FIGURE 1

New material manufacturing process for thermoplastic CFRP tapes. Courtesy of Evonik: A Köver, Johnson Control 'Simulation and Manufacturing of an Automotive Part for Mass Production', ITHEC 2014.

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The next step is the actual molding of the seatback. And in automotive mass production this has to be done in a cycle time of around one minute.

So the two tapes are used to make a flat preform of the seatback, considering various fiber orientations. The random nonwoven makes up most of the seatback. The stronger, unidirectional fiber tape is for strengthening.

Metal inserts are placed in the tool at the bottom of the seatback prior to the fiber material; they are for the interface to the lower structure of the seat.

Then the preform is heated and placed into the mold. An overmolding technique is used: after the mold is closed and the preform is pressed into the required shape, extra thermoplastic material is injected into cavities in the mold. This forms strengthening ribs on the inside and a nice finishing edge all around the seatback.

Simulating and optimizing the manufacturing process

It is important to simulate and optimize the manufacturing process. That way you can prevent problems like warping, wrinkling and tearing. For this the ThermoPlastic composite Research Centre (TPRC) in Enschede got involved in the seatback project in 2013.

TPRC originated in 2007 from a collaboration between Boeing, TenCate Advanced Composites, Fokker Aerostructures and the University of Twente. The number of members in that collaboration has since increased to 14. The center does fundamental research for them to enable wider use of thermoplastic composite materials.

'TPRC also works for third parties on interesting projects,' Bert Rietman, senior research associate of TPRC, says. 'In most cases, our job is characterizing the behavior of the material in the process, and then simulating and optimizing a forming process.'

Defects during the manufacturing process depend on the geometry, process definition, and features like: radii, blank shape, and lay-up. In order to successfully predict them, you have to accurately know the most relevant mechanisms, like: intra-ply shear, inter-ply shear or friction, tool/laminate friction and bending. Unidirectional plies, fabric reinforced plies and plies with discontinuous fibers all behave differently. And the interaction between different plies depends on the reinforcement structure (Figs. 1 and 2).

'Before you can run a process simulation you have to understand the behavior of the material,' Rietman says. 'These mechanisms all occur with the matrix in a melted state. So you have stiff fibers sliding in a viscous mass comparable to peanut butter. We made about eighty test pieces from the strengthening tapes and nonwovens, and measured them in different test rigs at high temperature. That gave us the force–deformation curves we need to establish our material models. It's measured at different speeds, temperatures and pressures in order to get generally applicable models. So if Johnson Controls wants a different application for the same material, we don't have to do the measurements again.'

These constitutive models were entered into a draping and forming simulation tool developed by Aniform, Enschede.

'In the simulation we saw wrinkling in the original seatback design,' Rietman says. 'So we used our knowledge to change the structure such that it could be produced without wrinkles, making sure the end product still fulfils the main requirements. In this case, the crash behavior of the product is of major importance. The forming behavior of composites depends on the architecture of the fiber reinforcements. In general, woven fabrics are easy to drape over doubly curved regions. Look at your clothes. However, there are limits. Take your trousers: they'll still crease under the knees. That material just cannot be deformed any more, giving rise to wrinkles. You can improve that by changing the orientations or sizes of the fibers in the base materials. The unidirectional tapes are the most difficult to form without wrinkles. One layer can take a lot of shear. Two crossed layers aren't so bad either. But add a third layer in yet another orientation and things get very difficult. It might help to try to prevent the third layer by choosing a smart set of orientations for the other two.'

As an added bonus, the software outputs the exact contour the flat preform needs to have before it is loaded into the press. That

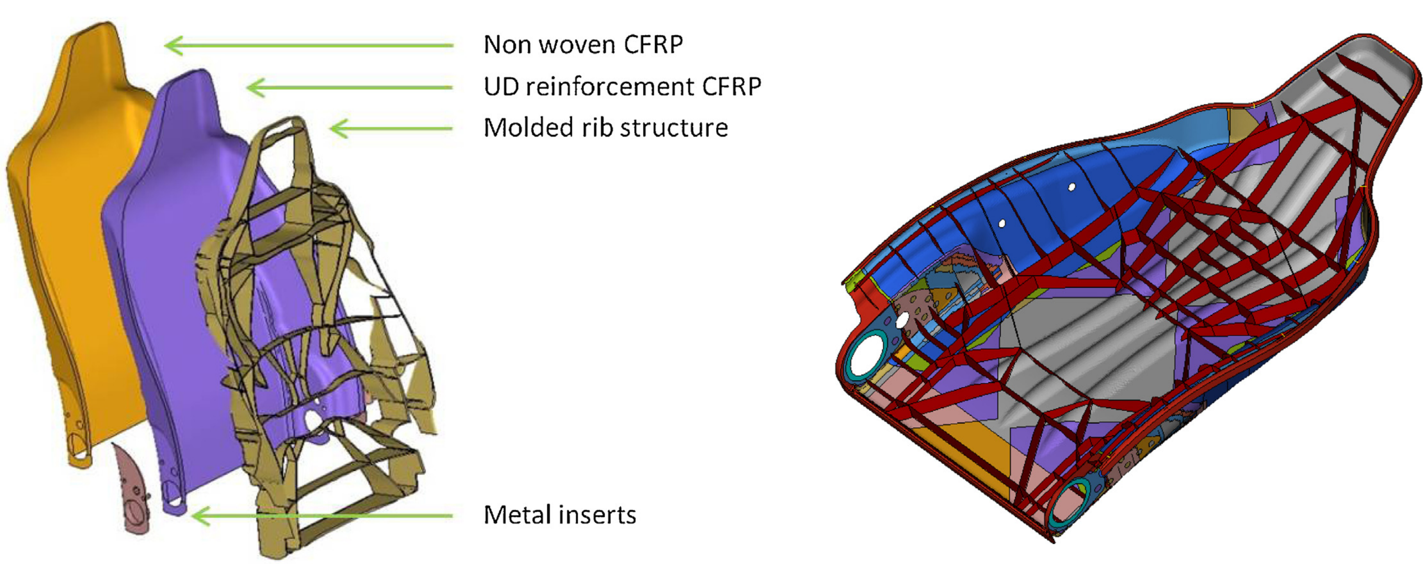

FIGURE 2

3 shell model, non woven (orange) UD tape (purple) PA12 GF (brown), final model. Courtesy of Evonik: A Köver, Johnson Control 'Simulation and Manufacturing of an Automotive Part for Mass Production', ITHEC 2014.