On the cost and performance of CFRP in the passenger car industry

Being one of the premium German car brands, Audi has a long-standing “Leichtbau” tradition. Living up to the company motto “Vorsprung durch Technik”, Audi is currently working on implementing CFRP in cars such as the S7, A8 and R8. In a combined internship and thesis project in Neckarsulm, Germany, I assessed the performance and cost of Automated Fiber Placed composites, a new technology, opening up possibilities for cost effective manufacturing of highly efficient structures.

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The average weight of passenger car vehicles has increased over the last decades as a result of improving passenger comfort levels and the rise of ever-strict crash safety regulations. Rising fuel prices, environmental awareness and governmental regulations on the other hand require a decrease in the structural weight of a car, instead of an increase.

One way to reduce the vehicle weight without sacrificing safety or comfort is the use of lightweight materials. Hence, the interest in Carbon Fiber Reinforced Composites (CFRP) technology was borne. The current use of structural composites in the automotive sector is confined to ultra-high performance, small series supercars such as the Ferrari F430 Scuderia, Lexus LFA and Lamborghini Murcielago where cost is not an issue. The Lexus LFA for instance has been designed with a carbon fiber cabin that weighs 100 kg less than a comparable aluminum one whilst retaining the same rigidity (Reinforced Plastics, 2010). In a way, this sector can be compared to the space industry, where a one kg weight saving can lead to a €7,500-15,000 fuel cost reduction depending on the mission. For the passenger aircraft industry, this number lies somewhere between 800-1,200€/kg. Passenger cars are more sensitive to the manufacturing costs with a 7.5€/kg weight to cost ratio. Profit margins are generally small and a difference in cost of a few cents per part can make or break a design. This means, that if CFRP is to be implemented successfully on a large scale in passenger cars, it must not only be lighter, it must also be cost competitive with traditional metal designs.

CURRENT SITUATION
The most common example of the use of structural composites in passenger car vehicles today is the all-electric BMW i3. Other cars, such as the current Audi R8 and BMW M3, employ carbon accessories such as roofs or spoilers, but the primary reason for these CFRP components is the cosmetic appearance and not the weight. The majority of supercars today are manufactured using epoxy prepreg hand lay-up and autoclave curing. Originating from the field of Aerospace engineering, this is a low volume, expensive production process which yields excellent strength and stiffness characteristics. More cost sensitive cars such as the i3 are manufactured using Resin Transfer Moulding (RTM) where dry fabrics are preformed and afterwards impregnated with resin under high pressure using a two-sided mould. This semi- to fully automated process is used for medium volume series. Current problem areas are speed, material scrap, performance consistency and formability. In essence, the automotive industry uses aerospace technology, leader in the field of lightweight construction and the use of CFRPs, and strives to apply this in a cost-effective manner. It can be said that lightweight car construction is all about bringing aerospace technology down to earth by making it more cost-effective.

AUTOMATED FIBER PLACEMENT PROCESS
The need for automation, low scrap rates and affordable prices led to the develop-
ment of the AFP process, currently used to manufacture large sections of the Boeing 787 Dreamliner as well as the Airbus A350 XWB. The AFP process (Figure 1) builds up a laminate by placing bands of multiple narrow tow, which are compacted on the substrate whilst controlling fiber directionality and steering. This means that the conventional approach of building up a laminate, by stacking prefabricated angled plies by hand can be replaced by a fully automated process. Being able to cut and restart each of these tows, the process allows for a high degree of control, precision, and minimum material waste. The individual pay-out of the small tows enables in-plane steering of the fibers leading to curved fiber paths. The amount of in-plane fiber steering that is allowable is limited by the material and processing conditions as excessive curvature leads to manufacturing defects such as waviness, tow buckling and deviation of tow-paths.

The majority of advanced composite structures that are manufactured today are built using thermostet epoxy prepreg tows. Both industry and scientists are currently working hard to make the AFP process suitable for processing dry fiber and thermoplastic material as well. The main reason for this is the potential to use cheaper materials and reduce cycle times and investment costs. Thermoplastic binder material inside dry fiber tows is activated by the application of heat just prior to the placement to provide tack, making it possible to build up a preform for the RTM process using AFP. The use of AFP in combination with RTM processing has the potential to reduce process cycle times to minutes rather than hours when compared to autoclave curing. This has brought Dry Fiber Placement (DFP) to the attention of the automotive sector.

OPTIMISATION

The in-plane steering capabilities of AFP make it possible to vary the lay-up or stacking sequence over the planar direction of the composite component. This results in a non-uniform stiffness distribution, hence the name variable stiffness (VS) or steered fiber composites. This allows the designer to utilize the anisotropic nature of the composite material to its full potential by tailoring the stacking sequence to the internal loading state at each point in the laminate. Research at the AS&CM group has shown that fiber steering can be applied successfully to improve the stiffness, buckling and fundamental eigen frequency of composite structures. Figure 2 provides an example of the use of fiber steering on a curved panel with a hole loaded in compression and shear, in order to improve the buckling characteristics by moving the load away from the unsupported hole region of the panel to the supported edges. Fiber steering can thus be used as a means to design more efficient structures that make for lighter cars.

THESIS PROJECT

Audi, my supervisor dr. Christos Kassapoglou and me together formulated a project to investigate the potential of automated steered fiber placement. Due to the confidential nature of the project only a rough outline is given here. The first goal of the project was to find the maximum potential of steered fiber composite structure by means of mechanical testing. For the optimization, various software packages such as MATLAB and MSC Nastran were used in combination with user-defined codes and routines. Manufacturing took place in France and Germany, whilst the mechanical testing was conducted in the DASML lab at the Aerospace faculty.

The second part of the project focused on generating insight in the cost of manufacturing of straight- and steered fiber reinforced structures for the dry-, thermoplastic- and thermostet fiber placement processes by performing a manufacturing cost analysis in order to see if the improved performance is worth the cost. This information, together with the data on achievable performance gains, was used to evaluate the feasibility of steered fiber placement being applied on the next generation of Audi cars.

EVALUATION AND OUTLOOK

Finishing up my thesis, I can look back at a challenging but very worthwhile period in my life. Working at one of the largest car manufacturing companies in Germany on a hands-on project and being able to manufacture and test my own designs has been a great experience. In retrospect, the practical experience I gained from joining the Formula Student team Delft in 2010 and 2011 has been very valuable and is highly recommended for people looking for a job or internship position in the German automotive sector. The next two decades will tell if and when the automotive sector will shift to composites as a means of "enlightening" the car. If so, the AFP process is likely to play a vital role.

References