

## Carbon Composites in Light Weight Design of Next Generation, Benefits of Mechanical Fastening and Ways to Increased Economy

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### Introduction

Composite materials are used since years in special areas of light weight design like aviation or space exploration. Especially carbon fiber reinforced plastics (CFRP) provide a really high strength to weight ratio compared to other light materials like metals, but up to now they need a specific design, specific manufacturing technology, specific equipment for production and test evaluation, advanced engineering knowledge for any particular application (type of fiber- and matrix materials, number and orientation of layers, fiber volume content, load introduction geometry, load-deformation-behavior, failure sensitivity, a.s.o.).

### Light Weight Design of Next Generation

Based on increasing demands for energy saving advanced light weight design is of basic importance to all moved components in Mechanical Engineering – applications are using even more CFRP for replacement of light metals, also in Mechanical Engineering like automotive or automation equipment. Future aircraft designs use CFRP for app. 50 weight-% (Airbus A 350, Boeing 787). Another field of the future for light weight design is growing by large mechanical components which have to be handled or transported with significant efforts like components of Wind Energy Power Plants.

All over the world on one hand the production capacities for fibers are increased, and the use of such materials is of great interest. On the other hand the optimization for economic large scale production is still a challenging task.

### Component related aspects

The large scale availability has to be done along with reducing the high material cost and also the extreme high production cost. One technically critical point of CFRP is its sudden heavy-impact- or crash behavior, because it shows often almost no ductility after linear stress-strain-relation to rupture.

Due to this three basic aspects of optimization are necessary: 1. achieving advanced weight reduction, 2. realizing save (over)load-deformation-behavior, 3. providing increased economy.

The minimum weight for a mechanically loaded structure is achieved, if as much as possible is made of a material with highest strength to weight ratio and if a high material utilization is

realized within the entire component; this normally leads to unacceptable high cost. Considering that the structure has to provide a acceptable price, a combination of different materials leads to the optimum in practice (Fig. 1, column 'hybrid').

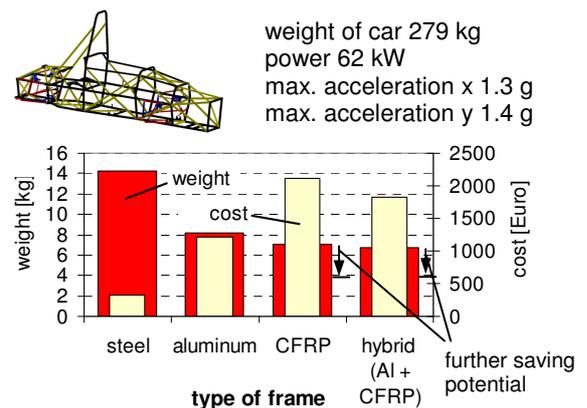


Fig. 1: weight and cost of frame structure made of different materials defining a body of race car

### Benefits of Mechanical Fastening

Any material mix needs fastening and joining of components made of different materials - which is challenging for high loading capacity over time and load profile. From the viewpoint of composites adhesives should be used, but if a structure has to be produced in high volume series production and has to be repaired after failure in field, then advanced mechanical fastening is much more suitable (assembly process time, control parameters for quality management during manufacturing and repair, replacement of broken components). Another point is that adhesives need a large contact area to transmit forces with low local stresses – often components have to be small without such contact area. Fig. 2 shows an example from a prototype of a high duty mechanical connector for fastening a composite fiber pipe to a mechanical structure.

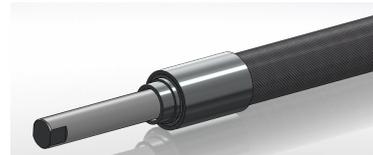


Fig. 2: prototype of mechanical axial CFRP-connector for fastening composites to metal structure; outside diameter of CFRP pipe 21 mm, wall thickness 1.5 mm

A significant advantage is that the behavior of failure when overloading can be designed by

the mechanical axial CFRP connector which determines the limit load and the ultimate load. In case of sudden failure (design a) in Fig. 3) the limit load is almost the ultimate load – especially this is a design problem for general users who do not know the specific loading behavior and use load profiles with high deviation. If a load peak exceeds the limit load, it needs extreme high loading capacity (ultimate load) which reduces the light weight design potential. A ductile overload behavior (designs b) and c) in Fig. 3) is also important for defects in materials with reasonable price for high series production. In Fig. 3 joining with adhesives (design a)) shows only very low ultimate force which by far is not enough to utilize the loading capacity of the CFRP pipe.

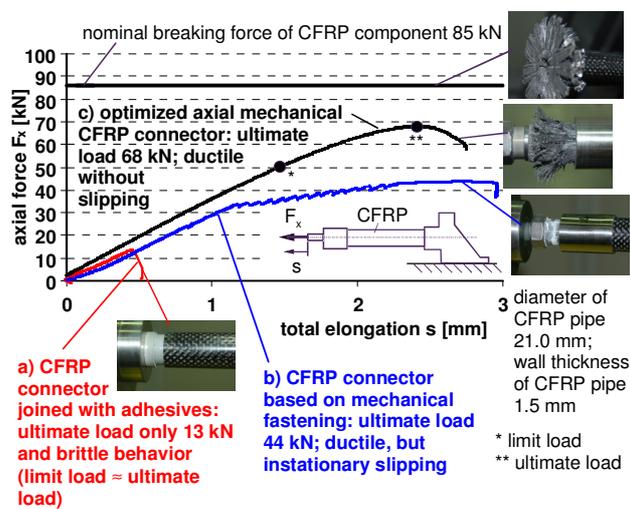


Fig. 3: overload behavior of axial CFRP connector in experiment – force-elongation diagram for three designs a) joining with adhesives, b) mechanical fastening without optimization and c) fastening mechanically with integrated elastic-plastic reserves

**Ways to increased economy**

Increasing the economy of components with CFRP needs to lower the material cost and also production cost - both can be provided with semi-finished CFRP parts of standardized geometry (rods, bars, pipes, plates, shells, a.s.o.). They already utilize the benefits of large-scale production (e.g. pultrusion) and allow reducing cost in Light Weight Design significantly. In principle, all needed component geometries can be realized with these semi-finished parts.

Frame-structures can provide a more homogeneous material utilization when loaded. Therefore they will be focused in future for high duty light weight structures. Besides this, when using semi-finished CFRP parts engineers do not have to be familiar with the CFRP-specific design approach because of given limit load and ultimate load

So, overall, the use of semi-finished CFRP-components with optimized mechanical fastening is one important way for increased economy and market penetration of CFRP in Mechanical Engineering. Fig. 4 shows with a flow chart the comparison between individual engineered CFRP components and semi-finished CFRP parts.

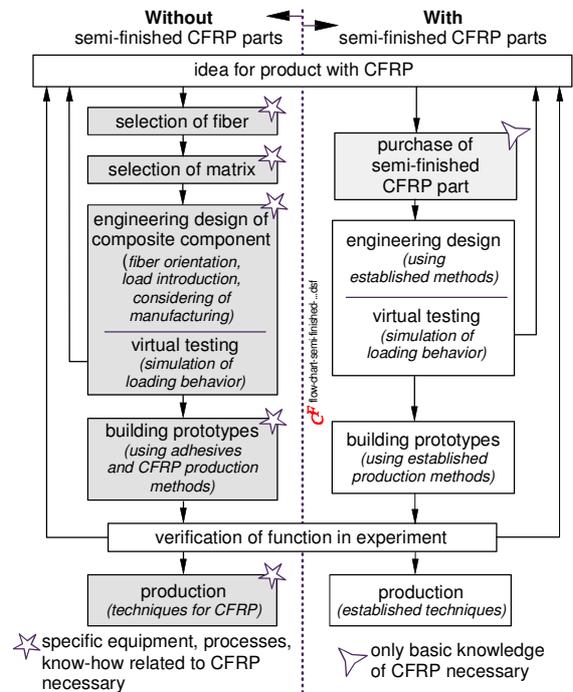


Fig. 4: flow chart for design process with and without semi-finished CFRP parts

**Conclusions**

Economic CFRP components for high series production need semi-finished parts and optimized mechanical fastening techniques. One significant advantage of an axial mechanical CFRP connector is the potential for design of limit load and ultimate load which means save overload behavior. Other aspects which are not covered in this short paper are nonlinear numeric analysis with FEA, influences from tolerances as well as impact- and long time behavior.

**Literature**

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