WHITEPAPER

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YOUR OPTION TO OUTPERFORM METAL

Six reasons to start using high performance alternative for metal and thermoset composites:

CFR Thermoplastic material

As an engineer in today's world, you're dealing with many challenges, from environmental legislation to internal rules of your company. Yet your drive is to create a product, to materialize an idea. A design that is better, smarter, and more sustainable than before.

To design or improve a product, your start is the set of the requirements or specifications followed by creating a 'bigger' picture than just the bullet point list you have received. That way you can start to work on your design and think 'outside the box'. And you certainly don't want to get trapped in the same circle of solutions and assumptions applied during a previous design cycle.

So how to find the opportunities of an improved design: Which areas of improvement can be focused on, and which are relevant for your specific product and its requirements. That list is subject to the product and the requirements and can differ from case to case. However, in today's global themes, there are several area's that will likely to be part of your list and I will list them here.

Areas of improvement for product design

In random order, the improvement areas discussed in this whitepaper are listed here:

- Environmental impact (or CO2 reduction) during lifetime
- Product performance
- Comfort and stability
- Safety
- Raw material consumption
- Product design complexity

Let's go through the list one by one and define some specific improvement opportunities for each area.

Environmental impact (or CO2 reduction) during lifetime

For any product applied in the mobility sector, it is obvious that weight has direct relation with energy consumption and in case the energy is generated through fossil fuels, the CO2 emissions are high. Today transport is responsible for more than 20% of the global CO2 emissions and for the passenger car segment, each 100 kg weight saving reduces the CO2 emissions with 6 grams for each kilometer driven. In other words, weight saving is crucial to reduce energy consumption and therefore also CO2 emissions (even in case we all use electric vehicles/EV's with renewable energy, the advantage of weight saving supports the lower need for energy).

Weight saving can be achieved by applying a material with lower density yet maintaining the strength and stiffness capability (mechanical properties). Where metal has the tradition to be applied, composite materials (FRP or fiber reinforced plastics) have surpassed metal already in the aviation industry since a long time. And where common plastic materials have taken over from metal in the interior of the car for long, the exterior materials are being substituted by the FRP materials. And the next stage is starting: parts of the drive train and construction are currently being developed from FRP materials. And this is necessary if we want to reduce the overall weight in EV's, as the heavy battery will move the car weight in the wrong direction.

Weight saving is often related to mobility but its effect on the accuracy of (non-moving) equipment is equally important. For instance, to achieve accuracy on a scale of nanometers requires tight control of inertia, which is easier to control and consumes less energy if you apply low weight / high performance materials!

CFR (Continuous Fibre Reinforced) Thermoplastic material has the ideal combination of high mechanical properties and low density. The combination of these two characteristics reinforces the weight saving opportunity because the high mechanical properties allow you to use less material, with a low density: multiplying the advantage.

Lower weight means lower CO2 emissions. In this white paper it is not doable to discuss the CO2 impact of all fibers/ thermoplastic combinations, so we will focus on the downstream processes. **CFR Thermoplastic material** is processed with a thermal source and does not require curing. A one step process that has no harmful emissions and only uses (renewable) energy.

Together with the recyclability of thermoplastics, all these mentioned points give **CFR thermoplastic material** a head start on both metal and thermoset composite materials.

Note: It is important to mention that the CO2 emissions for the full supply chain of CFR Thermoplastics can vary significant. The production of CFR Thermoplastic material is highly dependent of the type of fibers and thermoplastics used. For instance carbon fibers are very energy intensive to produce compared to glass fibers. For that reason the scope is limited to the comparison of the downstream processes.

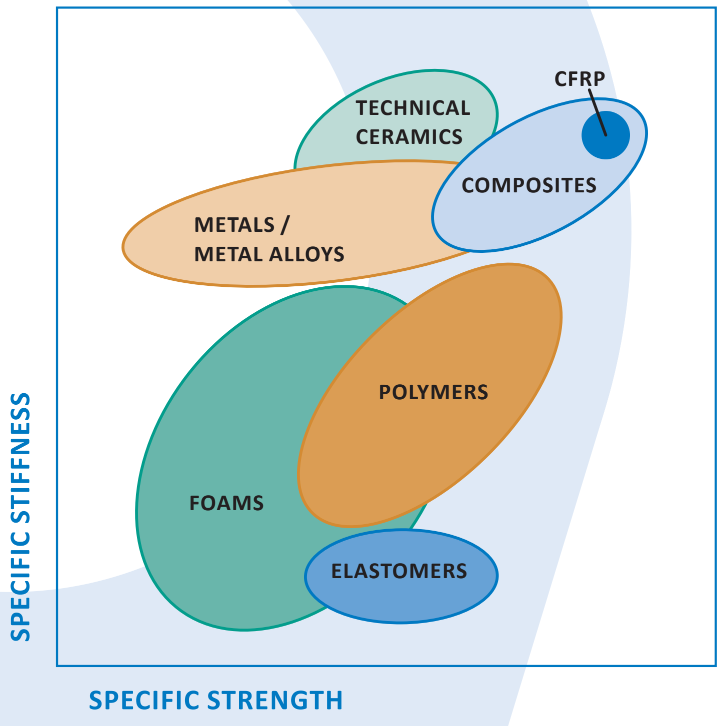
Product performance

When looking for the optimum design of your product, you will search for the limits, the best combination of properties and features to be combined in your product. As mentioned before metal and composite materials compete on the field of mechanical properties like tensile strength and E-modulus values.

In the graph, you will find a general comparison of materials, showing the position of metals and composites. This shows that for high load applications, composites have the ideal combination of specific strength and specific stiffness. What is equally important when selecting a material for your product is the additional requirements to maintain high performance over a long period (preferably the whole lifetime) with minimum costs. It is often in the challenging conditions that provide the complete view on the required performance over the lifetime of a product being designed. Temperature, corrosive and/or chemical impact, mechanical wear are all factors that will seriously influence the performance (and costs) of your product. The influences are often resisted by additional treatments like coating, hardening, heat treatment etc. but the effect is not always for the duration of the expected lifetime and need sometimes to be maintained/repeated.

Obviously, there are many properties contributing to the performance of your product, where strength and stiffness are often seen as leading. For instance, the vibration damping, and shock/energy absorption can also be part of the performance of a product. I have taken the liberty to use specific areas of improvement to cover these topics separately.

The highlights and features of CFR Thermoplastic material:
- Lightweight (4 times lower than steel)
- High strength-stiffness ratio
- Corrosion and chemical resistant
- Excellent impact energy absorption and vibration damping
- High fatigue resistance



***Graph 1**: Comparison of materials (source: Composites Part B: Engineering)*

Comfort and stability

During the design process, comfort and stability is often difficult to consider. Especially the effect of vibration on the product performance and lifetime is not easy to predict. It is however an area of improvement that can give your product a unique selling point in a competitive market. Either situation of static application or for a moving product, the comfort/stability is of importance. It is also a topic that can be complex and require insight depending the situation (structure, materials used, natural frequency etc.), which by the way I experienced during the work on my thesis at the Eindhoven University of Technology (Dynamic behavior of feed pumps). Choosing another material can completely change the dynamic behavior and improve the comfortability/stability of your product.

Any structure will most likely have to deal with the vibration from for instance contact with the surface, external factors like wind or from the internal drive system and should not hinder the proper functioning nor the user experience. A nice example is the bicycle frame where the evolution from steel to aluminum and more and more composite materials have reduced the vibration damping and improved the user experience. And realize that even a small element like the saddle pin of a bicycle has an important impact on the dynamic behavior of the whole bicycle.

CFR Thermoplastic material has excellent vibration damping characteristics in comparison to thermoset composites and to metal. In general fibre reinforced -polymers have a better vibrational damping mechanism due to the viscoelasticity of the material and thermoplastic resins perform even better than thermoset resins. That is also a reason why car manufacturers are replacing more parts like aluminium sun roof guiding rails with a CFR thermoplastic version.

Safety

This topic is important and certainly not only dependent on the material but on the complete design of your product. From material point of view there are a few aspects to be taken into consideration. Starting with the unplanned occasion that an element of your product fails and breaks into parts. The question is how it breaks and what are the risks after the failure occurred. Does the fracture cause high risk of damage to other parts or the people in the vicinity?

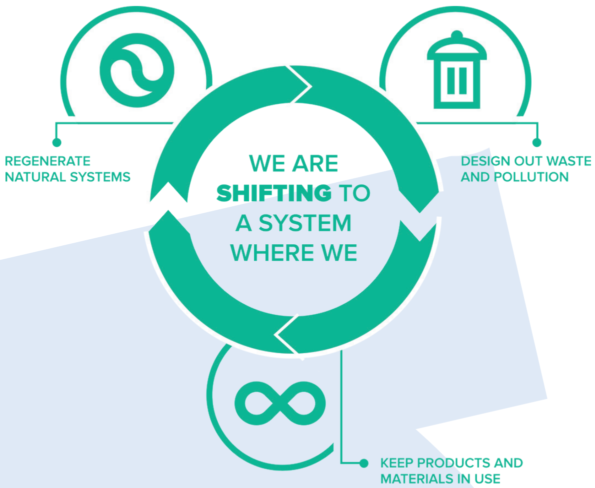
If your product can reach high speeds with high impact, you will likely want to minimize the effects to people and elements in the vicinity (if not already obliged by legalization). In case of a crash situation, it is likely and desirable to absorb as much energy from the impact and not pass the energy to vital and vulnerable elements in the product/machine or in the vicinity. This behavior is dependent on the (reinforcement) structure of the material and the way it is build-up.

The material characteristics regarding safety performance for **CFR Thermoplastic material** are impressive. During an eventual fracture, the material causes no risk due to particles and the energy absorption capability is very high, higher than aluminium and thermoset composites.

The fact is that **CFR Thermoplastic material** produced from UD-tape in layers, increases the energy absorption effect due to high energy required for delamination at the time of impact.

Raw material consumption

We are putting an enormous pressure on the earth with the extraction of raw materials and the linear economy model that we have been applying more and more intensively so far. The answer is to convert to the circular economy model and keep materials in the loop, prevent waste and pollution and to produce with natural resources, that can be regenerated. The focus at the current stage is to adhere to the 3R model: Reduce, Reuse and Recycle. That means that the area of improvement for design is first to reduce the material consumption and create longevity, then see if material is available to be reused in the design and that the materials can be recycled at end of life (EOL).



The durability and recyclability of **CFR Thermoplastic material** as well as the processes involved in the processing of UD-tape, are fitting in the circular economy model. Products made with the additive manufacturing process of laser winding, reduce the amount of material required. The products made from UD-tape are durable and can be reused and recycled. Also the development of biopolymers and natural fibres will further improve its circularity over the full supply chain. Today more and more biopolymers are developed and available for use.

Product design complexity

When you work on a design, there many different aspects to cover: functionality (should be no. 1), quality of the product design, easiness to assemble and disassemble, maintainability, durability, end of life opportunities (recyclability) and last but certainly not least: costs.

All the mentioned aspects are impacted by the product complexity. Usually, the longer your bill of material (BOM) the more complex it becomes to manufacture, maintain, and recycle the product. The most famous approach is known as KISS (Keep It Stupid Simple). In other words, if you can find opportunities to reduce the complexity, it will improve the overall design in an exponential way. Replacing a ‘bolt with nut’ solution to connect two parts, with a ‘push-in’ connection is such an example. Or materials that can be (re)shaped by thermoforming to fit to other parts is another example. Instead of machining to fit for use, the process of thermoforming to fit for use is supporting the strategy to reduce complexity. The potential of reshaping by thermoforming is not yet fully recognized by designers but gives the opportunity to reshape a given product to add functionality for instance for a connection to other parts in the product.

CFR Thermoplastic material has a thermoplastic matrix with the capability to become soft and a given temperature depending the material type. This feature is applied when welding the UD-tape to form layers which provide the full strength and protection to the manufactured product. The same feature can also be applied to reshape the product and add functionality. By simply heating (a part of) the product beyond the glass temperature allows to reshape the product.