Hybrid wheel: New key factor for fuel economy in automotive”
Development and Manufacturing of Thermoplastic Carbon Wheels

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car weight vs. fuel consumption and emissions

You cannot think at our society without transportation. Private transportation is a source of immense freedom but also of side-effects, whose consequences are gradually noticeable: air pollution and continuously growing consumption of fossil fuels, for example.
Fuel consumption and emission are closely related to the car weight: the heavier the car, the more energy it requires. During the last decades the trend in the automotive industry was definitely towards heavier cars: on one hand because of safety systems (active and passive safety elements for passenger and pedestrians), on the other hand in order to increase the ride comfort. Nevertheless, since 2007-2008 a change of direction can be observed, with all the OEM trying to reduce the weight of their cars, in order to comply with the always more stringent environmental regulations and with the zeitgeist of the customers. Most blatant example are the i-cars of BMW, built around a carbon chassis.

The weight of VW Golf basic version steadily increased during the years.

Fuel consumption and emission can be reduced by means of several measures:

- improvement of the drivetrain efficiency
- reduction of the aerodynamic drag
- reduction of the rolling friction
- reduction of the weight

By reducing the weight of a car by 100 kg improvements are expected in the reduction of CO_2 emissions in the order of 4-10 g/km. The 4 g figure is the expected direct result of weight reduction, while the 10 g figure takes into account a snow-ball effect such as a the reduction of weight of directly linked components, made possible by the weight reduction of the first component.
A weight reduction has not only for the fuel consumption and the emissions positive effects: the performance will also dramatically improve, like proven in the motorsport.

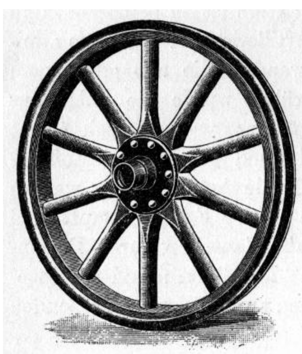
The car components promising the most important impact when reducing their weight are indisputably the wheels. A wheel is an unsprung, rotating mass: according to a rule-of-thumb from the physics, a rotating mass counts twice, because it has to be accelerated both translatory and rotatory. The tyre industry uses a factor of 1.8x for rim and and tyre weight.

Reducing the wheel weight by 50% causes a reduction of the carbon dioxide emission between 2.5 and 6 g/km, thus reducing also the due CO_2 penalty payment. Furthermore, reduction of unsprung mass significantly enhance the riding comfort.

On the other hand, the automotive industry suffers under a strong competition and pricing pressure: new products have to find a trade-off between performance and costs.

wheels' state of the art

The invention of the wheel has been the most astonishing technical achievement of mankind. Not only it allows to cover big distances without effort and is the basis for many machines, but it is an invention that has not been copied from the nature.
The wheel hardly changed its shape, function and construction in the last centuries. Only after the car's invention the wheel requirements suddenly increased. The original chariots wheel made of wood evolved in the thirties into metallic wheels – punched blanks or wire wheels – and in the sixties they changed their shape into a bowl-shape, which still represents the state of the art.
Not only the shape, but also the materials experienced a transformation: the traditional material wood was replaced by steel. Nowadays, approx. 60% of the car wheels are made of steel. Its supremacy nevertheless is strongly endangered by aluminium, accounting for more than 40% of the car wheels.



(left) wooden wheel from the early 20th century and (right) the Georg Fischer Simplex wheel made of cast steel of 1927.

Light alloy wheels are becoming a commodity product, whereby their design has priority. Nevertheless in the last year a new trend arose, namely the sporty driver and the OEM are more and more attentive to the wheels' weight and to its influence on performance.
Alloy wheels can be cast or forged: cast wheels are heavier and more brittle, on the other hand cheaper in the production, while forged wheels show lower weight and better mechanical properties but also higher production costs.

The weight of a wheel – a rotating unsprung mass – has often been neglected, even if it plays an important role for performance, driving dynamics, fuel consumption and emissions. Among all car components, the wheel is the part with the most important potential for weight reduction and the strongest effect.
Alloy wheels attain more and more their limits: a relevant weight reduction without compromising the safety can only be achieved by a new generation of wheels exploiting the advantages of fibre reinforcement, like other products in several application fields already demonstrated.

The first fibre reinforced wheels were developed in the seventies and sporadically till nowadays. Most of those wheels were made of glass fibres embedded in a thermoset matrix. In the following a couple of examples: the Michelin glass fibre wheel "RR" (short glass fibres /

thermoset resin) for the Citroën-Maserati SM (1971), the Fiberide Wheel of Motor Wheel Corp. (glass fibre / vinylesther resin) for the Dodge Shelby CSX (1989) and the “plastic wheel” of BTE Felgentechnik (glass fibres / polyesther resin) (1999).
Nowadays there are several companies working on carbon wheels, either hybrid or full carbon. Most of them are based on continuous oriented carbon fibres impregnated with a thermoset matrix (epoxy), usually in a liquid composites moulding process such as RTM or similar. Some manufacturers did produce wheels with thermoplastic matrix in an injection moulding process. kringlan is until now the only producer of continuous, oriented carbon fibre reinforced wheels with thermoplastic matrix.

(from left to right): Fiberide wheel (1987), AZEV carbon wheel (2003), BTE-Felgentechnik (1999), Dymag wheel (2005).

state of the art of continuous fibre reinforced thermoplastics

Standard composite materials are made of reinforcing fibres and a thermoset resin embedding them. A thermoset (may it be epoxy, vinyl or polyester resin) matrix shows low fracture toughness and long processing times, thus making it unsuitable for a cost-effective production of composite parts in high-volume.
The ideal matrix material is a representative of the class of thermoplasts, which show high fracture toughness and can be processed very quick. Furthermore, thermoplastics are recyclable as materials, making them very interesting for the automotive industry, with regard to the “end of life” policy prescribing that cars have to be recycled to at least 85% (since 1st of January 2015).

Injection moulding and GMT (glass mats thermoplasts) technologies do not ensure sufficient mechanical properties to be better than metallic competitors, therefore the use of continuous, oriented carbon fibres is necessary. The presence of continuous fibres strongly reduces the formability of the material, so that new technologies are required. On one hand, the rim has to be manufactured, so that every required fibre orientation can be manufactured. On the other hand, the spider has to fulfil both mechanical and design requirements. All these requirements cannot be fulfilled with only one manufacturing process.
kringlan’s approach is to separately manufacture rim, and spider and to join them together in a further step. kringlan has the chance to optimise every single component, so that both optical and mechanical requirements are fulfilled. On the other hand kringlan has a modular system that will have positive influence on the cost-effectiveness of the whole process.

The most important point is the production of the rim. The rim is not allowed to have seams (weak points) and the fibre orientation of the laminate should be free to chose. Furthermore, the process must ensure a short cycle time.

Standard processes for thermoset composites (hand lay-up, resin transfer moulding) cannot be used for thermoplasts (except for some exotic formulations). Filament winding and tape laying processes reduces the freedom to chose the laminate orientation and do not allow for manufacturing of the required geometry. Autoclave technology would be a possibility, but it requires long cycle-time and very expensive consumable materials.

kringlan wheel technologies

kringlan processing technology has been developed specific for the automated production of carbon fibre reinforced thermoplastics wheels

preforming

In order to make composite processing cost-effective, an automated preforming approach is required. kringlan developed several concepts and machines for different applications. Our expertise encompasses flat preforms, near net-shape 3d preforms as well as round preforms for our round press technology.

Flat and near net-shape 3d preforms.

round press technology

kringlan developed a proprietary technology to press closed circular parts with complex geometries such as a car rim. Our technology enables us to produce parts with every required fibre orientation in order to optimally exploit the fibres' properties, and with varying cross-sections and thicknesses along the part. Cycle times of 10 minutes per part or less are possible for industrial manufacturing, depending on material and geometry.

conventional press technology

For the full carbon wheel, the spokes are manufactured in a conventional press process.

Wheel centre made of carbon fibre reinforced thermoplastics.

joining

It is not new that thermoplastic composites can be welded, for example our full carbon wheels. Critical parameters like temperature, welding pressure and time need to be well controlled. We developed strong competencies in welding of high-performance thermoplastics by means of different welding methods: vibration, hot-plate, infrared, hot-gas welding technologies have all been tested and used by kringlan. We are also able to perform 3-dimensional welding on complex composites and injection moulded parts.

In case of the hybrid wheels, the mismatch in the coefficient of thermal expansion of the aluminium wheel centre and the carbon rim is so high, that over the service temperature range a diameter difference of more than 0.5 mm can be observed. State-of-the-art products try to protect the carbon rim by decoupling the joining from the deformation. Our approach is the opposite, namely we use the thermal expansion of the aluminium centre to ensure an optimal joining of the parts. This effect can be achieved with a dedicated geometry of the joint and a bespoke fibre layout in the same region.

kringlan wheels

We developed two kind of automotive wheels, hybrid and full carbon.
The hybrid wheel is made by a carbon rim coupled with a metallic wheel centre. This solution is more conservative and reduces the overall costs and risks, retaining a metal part, while reducing the weight there, where it is the most important, namely in the outermost part of the wheel (rim). Hybrid wheels are cheaper and easier to manufacture than full carbon wheels, but they are slightly heavier, assuming a comparable styling.

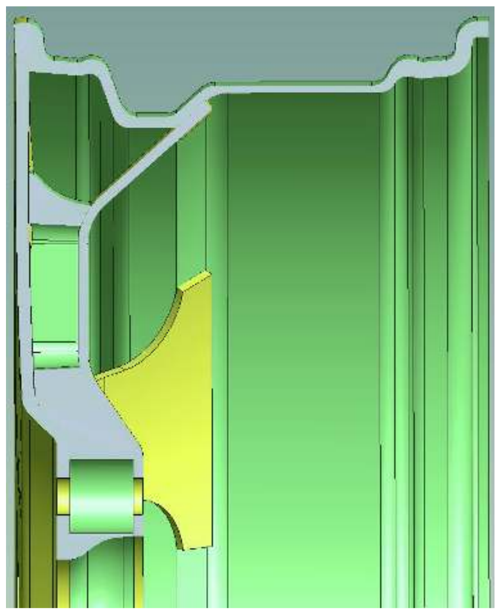
Full carbon wheels are the final goal and are a quantum leap in processing technologies and offer the biggest weight reduction potential. The development of our full carbon wheel is finalised and the wheel is ready for application, but the main drawback is the acceptance from side of the automotive industry. Full carbon wheels, made of thermoplastics, are “too new” and before they get widely accepted a couple of years of experience with hybrid wheels will be required.

The following table gives a comparison of the weight of kringlan's wheels against the state of the art, based on the design and requirements of the full carbon wheel.

cast aluminium wheel	13-14 kg
forged aluminium wheel	11 kg
hybrid carbon wheel	7.6 kg (very filigree styling)
full carbon wheel	8.3 kg (potential: 6.5 kg)

design of a full carbon wheel

kringlan Mk2 full carbon wheel has 4 different parts: rim, inner spokes, outer spokes and a core. All the components except for the core are made of continuous, oriented carbon fibre reinforced polyetherimide (PEI). The core is made by the same material combination as the other parts, but with short fibre. The base material is actually the scrap from the processing of the other components, so that we have approximately 100% usage of the prepreg.



Cross section of the Mk2 full carbon wheel.

This approach allows for the combination of different parts, such as the same wheel centres with rims of different width, allowing for an increase of wheel variety with no additional tooling costs.

summary

Carbon wheels, either hybrid or full carbon, allows for improved performance and reduced consumption and emissions compared to light alloy wheels.

Thermoplastic carbon wheels add the advantages of a high fracture toughness, materialwise recyclabilty and suitability for high-volume production.

While the wheels are ready to be installed on cars, the automotive industry is yet ready to apply them on a broad scale, so that additional work is required, in order to reduce the perceived risks.