design

VAP® infusion-moulded carbon fibre spar caps

To meet the increasing demand for longer wind rotor blades (up to 107 metres), Saertex uses many new material and process developments in the area of the spar cap in addition to well-established unidirectional E-glass fabrics.

Dipl.-Ing. Uwe Tiltmann,
Managing Director
Composyst GmbH
Dr. Helge Haberkern,
Technical Sales & Marketing Asia
Saertex

Polyacrylonitrile (PAN) -based carbon fibres with a high carbonization degree (>99%) and the corresponding industrial production process were first developed in the 1960s. The high mechanical performance (tensile E-modulus and strength) of this new material offered new opportunities for composite applications, but it was also highly priced accordingly for decades. This limited its use to industries that either could sell their products at a high price, had no other technical alternatives or could afford it, e.g. the aerospace industry.

This situation changed around the 2000s. New suppliers emerged and made available "industrial-grade", high-tow-count carbon fibres (~240GPa / 4000 MPa, 50K) at lower prices, enabling other industries to use high volumes for their applications.

Carbon fibre spar caps

Wind energy is one of the industries that adopted carbon fibres extensively around the 2010s. As the power generated by a wind turbine is directly proportional to the area overswept by the rotor, blades tend to get longer and have now crossed the 100 m mark (e.g. GE Haliade-X, 12MW / 107m). However, a longer blade also means higher mechanical loads during operation and a higher blade weight.

A technical solution to these two problems is to produce the spar cap – which runs from the root to the tip of the blade and takes up the compressive and tensile loads – with carbon fibres (Figure 1).

Compared with glass fibres, the lower density of carbon fibres (approximately 1.8 g/cm³) and their higher mechanical properties (E-modulus about 240 GPa, tensile strength about 3,800 MPa) dramatically reduce the weight of both the spar cap and the entire blade. Additionally, a carbon fibre spar cap takes up less space than a technically equivalent glass fibre version. This

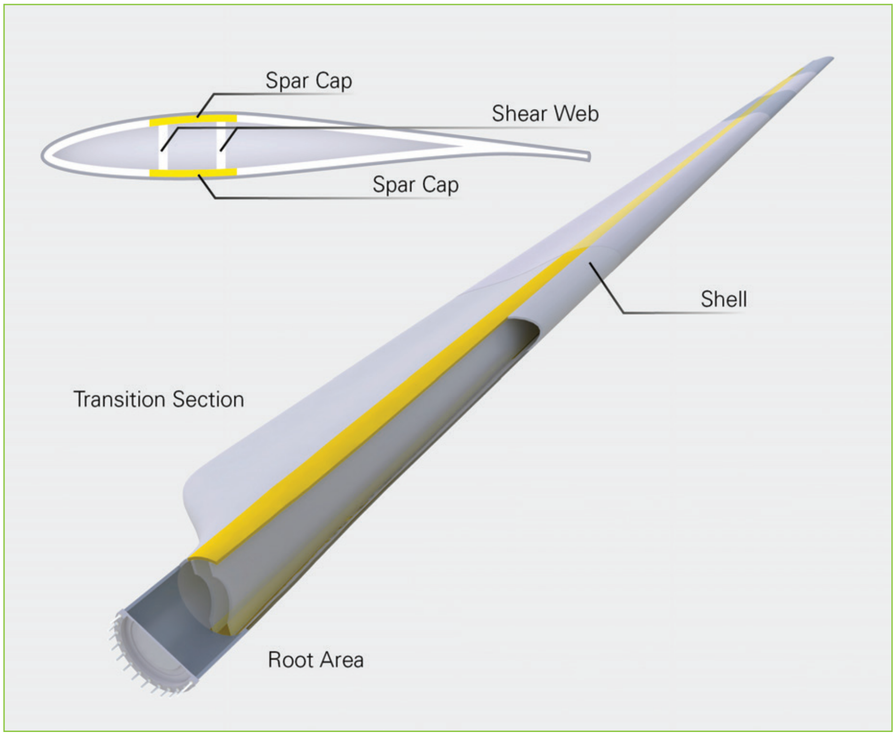


Fig.1: Parts of a wind turbine rotor blade, carbon fibre spar cap made with Saertex®

allows the design of longer and stiffer blades.
Now that the availability of affordable carbon fibre more or less solved the commercial issue of its high-volume use, a question that still needs to be answered is which carbon fibre-based material and process should be used to manufacture the spar cap. There are currently 3 "main" options on the market to choose from: prepregs, pultrusion and infusion.

Prepregs

Carbon fibre prepregs have been around for more than 50 years and are still widely used. As the fibre is already pre-impregnated with the resin, the user does not need to worry about how to impregnate the material or how to adjust the desired fibre-volume fraction (FVF). Additionally, the fibres are well aligned, leading to good results in mechanical tests – at least in the lab. But there are also a few downsides. During the lay-up process, air is trapped between the individual layers, resulting in an increased porosity of the spar cap (usually a single-digit percentage value), reducing the built quality accordingly. This is inherent to the material and technology and cannot be avoided (Figure 2).

Fig.2: Air inclusions in a prepreg laminate

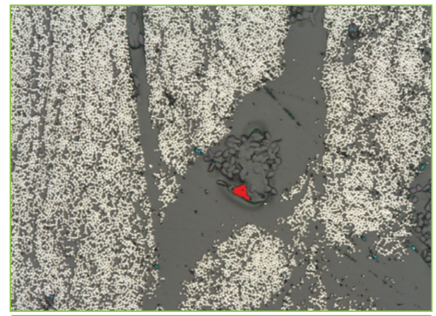
Additionally, the material's stiffness makes it more difficult – or sometimes even impossible – to manufacture spar caps with a twist, pre-bend or both. The limited shelf life of prepregs is another inconvenience.

Pultrusion

The latest trend, which has been attracting a lot of attention recently, is pultruded rods, namely carbon fibres pulled through a die, impregnated with a vinyl ester or epoxy resin system and then cured immediately. The resulting standard rods vary from 100 mm to 300 mm in width and from 3 mm to 5 mm in thickness and are wound up on coils before they are sent to the manufacturers. The technical advantages are that the rods are already cured, offer a well-defined FVF and good fibre alignment, leading to high mechanical properties.
However, there are also some disadvantages. The rods need to be unwound, cut and chamfered with expensive machinery. The usually square cross-section of the rods can lead to resin-rich zones in the part, especially when the spar cap is not flat but twisted prebuilt. Also, a glass fibre fabric layer is usually introduced between the overlapping rod layers. This reduces the spar cap's mechanical properties compared with the pure pultruded rods obtained during the lab test. Last but not least, the stiffness of the rods, which accounts for their good mechanical properties, can also lead to problems. It is more difficult to lay up the material in a mould with a noticeable pre-bend and make sure it does not shift when vacuum is drawn. Therefore, the possibility to position the spar cap freely within the blade is limited.

Infusion

The third option is to produce carbon fibre spar caps by infusing dry carbon unidirectional fabrics with fibres running in the 0° direction.
Infused laminates made of CF UD fabrics and epoxy resin systems reveal lower mechanical properties in lab tests than prepregs and pultruded rods. This definitely needs to be taken into account when designing the blade. However, what you see is what you get: The lab values reflect the mechanical performance that can be expected from the real spar cap. To achieve a good built quality with these mechanical properties, a good fibre alignment in the mould is crucial. As UD fabrics are softer than prepregs and pultruded rods, the lay-up process has to be performed carefully with the material coming from a cart running above the mould.
The softness, or so-called drapability, of the UD fabric tapes does not only cause problems though. It allows the fabric to adapt to the mould shape more easily than the other material options, which is important for spar caps with a pre-bend, twist or both. It is also exactly this drapability that allows the designer to move the spar cap in the position that is best for the blade structure. This offers more design freedom for the spar cap concept, including the use of CF UD tapes for trailing edges.



Specimen No.:	B232/13-L546 (B461/12-L546)		
Specimen			
Measured area	26,393mm²	Void area based on measured area	0,458 mm²
No. of measured field	19	Void area fraction of measured area	1,737%
Void number	40		
Statistic			
Number	40	Average value	88,1933 um
Minimum	20,1534 um	Standard deviation	82,54 um
Maximum	337,9640 um	Absolut deviation	317,8106 um
Microscope analyse			
Device	Neophot 32	Evaluation	Manually
Description	whold area = 300 mm²		
	Void area = 0,458 mm²		
	Void fraction = 0,15 %		

Fig. 3: Void analysis on a thick carbon fibre laminate infused in VAP® technology (IMA)

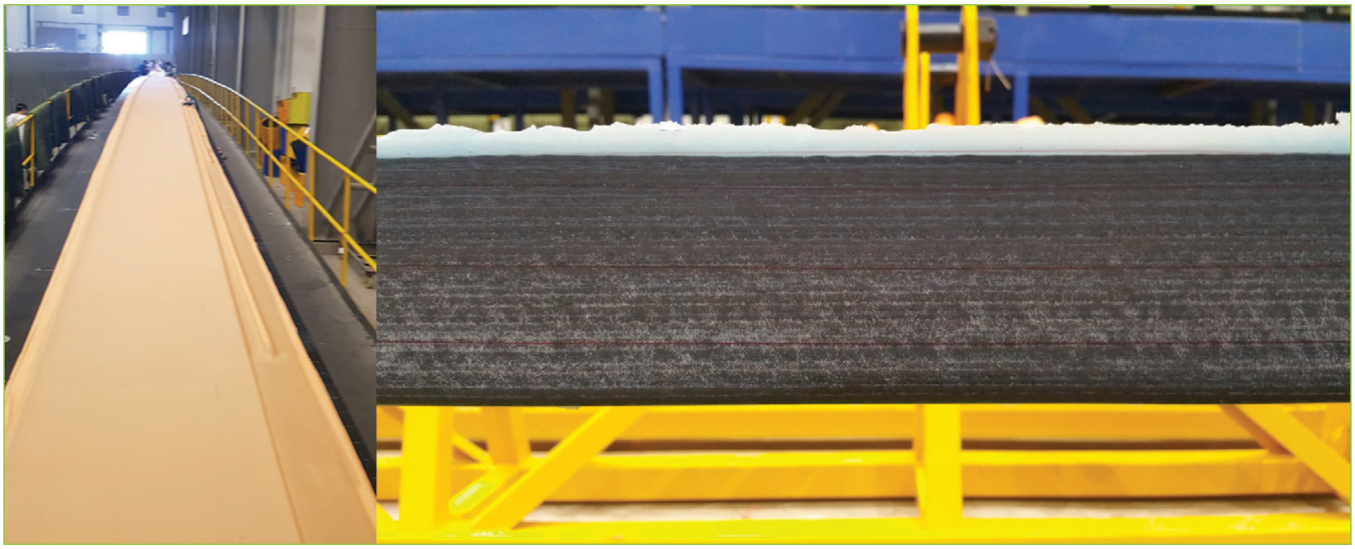


Fig.4: (Left) An 87m long VAP-infused spar cap; (right) side view of the thickest section (120 layers)

Another important matter to consider is the infusion process itself. CF fabrics are harder to infuse than GF fabrics because their filaments are much thinner. The smaller space between the filaments reduces the resin flow accordingly. To achieve full wet-out for thick components such as spar caps, three points are important: good z-permeability, using a latent resin system and using VAP® technology (Figure 3).

The CF UD used needs to have a good z-permeability (i.e. through-plane) so that the resin can travel through all fabric layers from the bottom to the top of the entire stack without any dry spots. SAERTEX developed such a CF UD fabric made of 50K fibre that enables the infusion of up to 120 layers, resulting in a laminate thickness of approximately 73 mm (Figure 4). The enhanced z-permeability is achieved through a specially developed, proprietary stitching technology.

Additionally, it is important to use a latent resin system. These resin systems have a low viscosity and a long pot-life as long as they are kept at the proper temperature, so the resin has enough time to permeate the entire fabric stack. As with any other infusion and resin systems, it is important to respect the recommended temperatures for the mould, the fabric stack and the mixed resin system. Some latent resin systems also have a mild exothermicity that avoids problems during curing.

The third essential point is the use of VAP® technology. The VAP® membrane is positioned between the stack to be infused and the vacuum bag. This semi-permeable membrane traps the resin inside the material stack while air and gas can go through it. Additionally, it helps the resin permeate the entire material and ensures an even resin distribution over the entire part dimension. The main advantages of the VAP® process are control of the resin content by infusing the previously calculated amount of resin needed for the desired FVF and a reduction of porosity in the part well below 1% due to the degassing function during the running infusion process. The overall process safety and reliability avoid very expensive scrap parts.

Prepregs used to be the first choice for CF spar caps when there was no working alternative. However, because of their lack of drapability, their limited shelf life and a relatively high porosity in the part, their use is progressively decreasing.

Pultruded CF rods show high mechanical properties. If the manufacturer is willing to spend the money for the necessary machinery, they are an interesting alternative. However, their stiffness restricts the designer in terms of position and shape of the spar cap, i.e. blade designs have to be adapted to this particular material (and not the other way around). A few process issues need to be solved such as handling of the long planks, the positioning and integration in the blade.

Dry CF UD fabrics infused with a VAP® membrane do not show the best, but sufficiently high mechanical properties to produce a CF spar cap. VAP® infusion is very similar to a standard infusion process, meaning that the transition is quite easy for the manufacturers, merely the lay-up and the process conditions are slightly different. Due to the drapability of the soft CF UD fabrics, this option offers the highest freedom for designers to produce different spar cap concepts.

What's next?

Currently, the infusion of dry CF UD fabrics with a latent resin system using VAP® technology is the solution that provides the highest design freedom and generates the lowest overall costs. Further development of materials and process technology is underway so that, in the future, manufacturers will be able to infuse spar caps thicker than 100 mm under standard serial production conditions. This will make it possible to infuse CF spar caps for blades longer than 100 metres. ◻

More information:
www.saertex.com