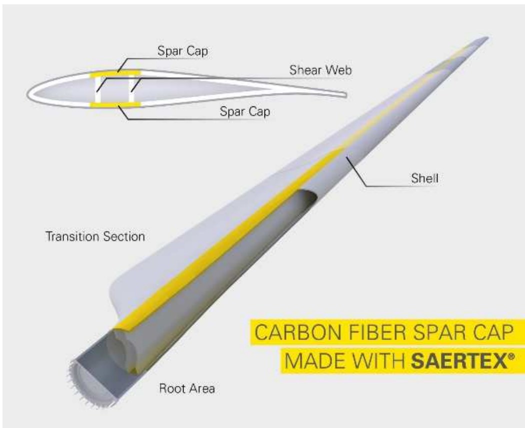
DIPL.-ING. UWE TILTMANN,
MANAGING DIRECTOR
COMPOSYST GMBH
DR. HELGE HABERKERN,
TECHNICAL SALES ß MARKETING ASIA
SAERTEX

VAP® infusion-moulded carbon fibre spar caps

PAN-based carbon fibres with a high carbonization degree (>99%) and their 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 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 like 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 and enabled other industries to use high volumes for their applications.

One of the industries who adopted carbon fibres extensively around the 2010s is the wind energy: As the power generated by a wind turbine is directly proportional to the area over-swept by the rotor. Blades tend to get longer and have now already crossed the 100 m mark (e.g. GE Haliade-X, 12MW / 107m). However, an increased blade length also means higher mechanical loads during operation and a higher blade weight.
A technical solution for 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 of the blade, with carbon fibres.



[Parts of a wind turbine rotor blade]

The lower density of carbon fibres (approx. 1.8 g/ccm) and their better mechanical properties (here: E-modulus approx. 240 GPa, tensile strength approx. 3.800 MPa) compared with glass fibres reduces weight of the part itself and with that the entire blade weight dramatically. Additionally, the carbon fibre spar cap takes up less space than a technically equivalent glass fibre version. These allows the design of longer and stiffer blades.

Now that the availability of affordable carbon CF more or less solved the commercial issue of the high-volume use of this material, a question which 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:
Carbon fibre prepregs have been around for more than 50 years and are still used widely. As the fibre comes with the resin already, 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 down-sides: During the lay-up, air is trapped between the individual layers. This is inherent to the material and technology and cannot be avoided. This leads to an increased porosity of the spar cap (usually a 1-digit % value), reducing the built quality accordingly.

[Air inclusions in a pre-preg laminate]

Additionally, the stiffness of the materials 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.

The latest trend which has been attracting a lot of attention recently is pultruded rods: carbon fibres are pulled through a die, impregnated either with a VE- or an EP-resin system and then cured immediately. The obtained standard rods vary in widths from 100 mm to 300 mm and thicknesses from 3 mm to 5 mm and are wound up on coils before they are sent to the manufacturers. Technical advantages are that the rods are already cured, their well-defined FVF and good fibre alignment, leading to high mechanical properties.
There are, however, also some disadvantages: The rods need to be un-wound, cut and chamfered. Expensive machinery is necessary to perform these tasks. 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 prebuild. Also, usually, a glass fibre fabric layer is introduced between the rod layers put over each other. This reduces the mechanical properties of the spar cap compared with the values of the pure pultruded rod obtained from the test in the lab. Last but not least, the stiffness of the rods, which accounts for the 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.

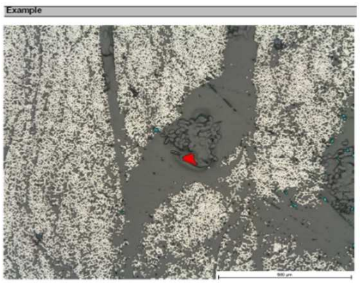
The 3rd option is to produce carbon fibre spar caps by infusing dry carbon fibre UD fabrics with fibres running in the 0° direction.
Infused laminates made of CF UD fabrics and EP resin systems reveal lower mechanical properties in lab tests than prepregs and pultruded rods. This definitely needs to 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 the 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 shape of the mould a lot easier than the other material options, which is important for spar caps with a pre-bend, twist or both. It is also exactly this drapability which allows the designer to move the spar cap (or spar caps) position which is best for the blade structure. That way it offers more freedom for the spar cap concept design, including the use of CF UD tapes for trailing edges.

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 is reduces the resin flow accordingly. To achieve full wet-out for thick components like spar caps, 3 points are important:

The CF UD used needs to have a good z-permeability (i.e. through-plane) to allow the resin to travel through all fabric layers from the bottom to the top of the entire stack without any dry spots. SAERTEX has developed such a CF UD fabric made of 50K fibre which allows the infusion for 120 layers, resulting in a laminate thickness of approx. 73 mm. The enhanced z-permeability 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 system, 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 which avoids problems during curing.

The third essential role plays the VAP® technology. The applied VAP® membrane is positioned between the stack to be infused and the vacuum bag. The semi-permeable VAP® 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 the VAP® process offers 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.



Specimen No.: **B232/13-L546 (B461/12-L546)**

Specimen			
Measured area	26,393 mm²	Void area based on measured area	0,458 mm²
No. of measured field	19	Void fraction of measured area	1,737 %
Void number	40		

Statistic:			
Number	40	Average value	88,1933 µm
Minimum	20,1534 µm	Standard deviation	82,54 µm
Maximum	337,9640 µm	Absolut deviation	317,8106 µm

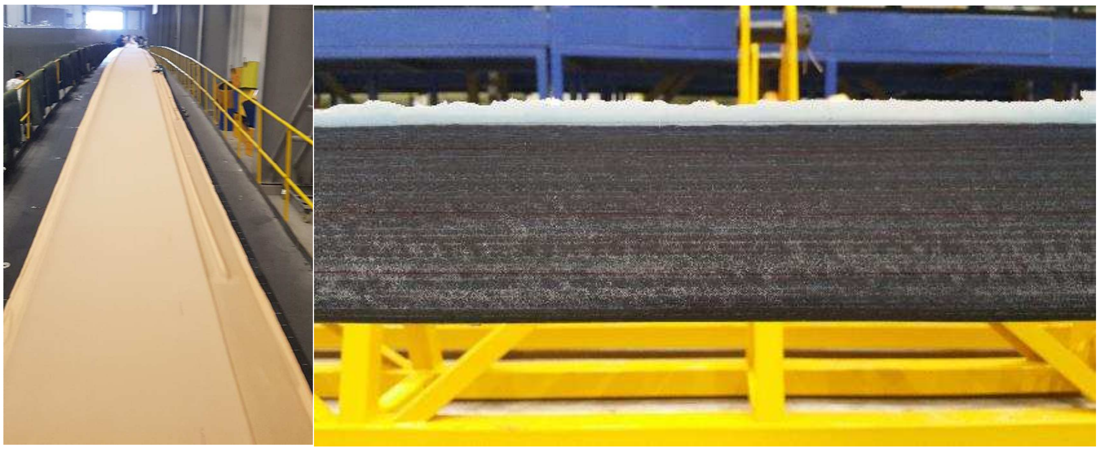
Microscope analyse			
Device:	Neophot 32	Evaluation:	manually
Discription:	**Whold area = 300 mm²**		
	Void area = 0.458 mm²		
	Void fraction = 0.15%		

[Porosity analysis of a laminate infused in VAP technology, cut through a laminate]

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

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

Dry CF UD fabrics infused with the VAP® membrane do not show the best, but sufficiently high mechanical properties to produce a CF spar cap. The 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 drape of the soft CF UD fabrics, this option offers the highest freedom for designers to realise different spar cap concepts.



[An 87m long spar cap infused with VAP ; side view of the thickest section (120 layers)]

What's next? Currently, the infusion of dry CF UD fabrics with a latent resin system in VAP® technology is the solution which provides the highest design freedom and generates least overall costs. Further development of materials and process technology is under way so manufacturers will be able to infuse spar caps thicker than 100mm in the future under standard production conditions in serial production. This will make it possible to infuse CF spar caps for blades longer than 100m.

More information: www.saertex.com