SparPreg™
UD Prepreg Spar Solution
As the design of large multi-megawatt wind turbines progresses, wind turbine blade designers are investigating the benefits of new prepreg materials. Two recently launched Gurit Sparpreg™ products are true game changers and convincing arguments for blade builders to look again at their designs and production processes in a holistic manner. This brochure explores some of the technical and commercial challenges facing WTG designers in the pursuit of longer blades and evaluates the material solutions available to them.

Gurit has been supplying materials to the wind energy market, for the manufacture of composite blades, since 1995. Gurit has been actively involved in the development of specialised blade materials, required as blade designs have increased rapidly in size and complexity. The tendency amongst large turbine manufacturers in the industry in recent years is to supply longer blades on existing turbine designs to suit light wind sites, or to install offshore turbines that are multi-megawatt machines, requiring larger blades, that can withstand higher loading.

The main load bearing structure of a wind turbine blade is the spar component, which is either integrated into a structural shell as a spar cap, or constructed in parallel production to the shell as a separate spar structure complete with shear webs.

What is common to both approaches is the utilisation of unidirectional fibre (UD), glass or carbon, to provide the required bending strength and stiffness. The fibre has to withstand compression loads, particularly in longer carbon blades, and as a consequence the fibres need to be kept straight and be consistently supported by the surrounding resin to prevent buckling.

Collimated fibre formats, like prepreg, provide a good starting point to maximise the performance of the fibres, but there are additional challenges to maintain the fibre straightness, prevent voiding during the application and cure, and maintain the lowest cost of use.

There are many variables in the complex equation of how to reduce the cost of a turbine blade and Gurit has recently launched two new products which significantly change the calculations by using prepreg technology. Prepregs have had a reputation of offering superior physical and mechanical properties, though generally at a higher price and with higher tooling and infrastructure costs. To address these issues Airstream™ coating technology, in combination with the unidirectional SparPreg™ prepregs, allows for the production of superior thick laminates at unparalleled low void contents of <1.5%, at ambient production temperatures ranging from 15-40°C, without the need for costly air temperature regulation and cold storage facilities, and utilising low temperature tooling.

Gurit has set out a clear strategy to address the historical barriers to the adoption of prepreg and enables the next generation of blades to be manufactured using advanced products with minimal investment in infrastructure. Two key technology steps in this strategy are:

- Airstream™ Coating Technology to enable very low void content laminates without debulking or the requirement for air conditioned factories
- Advanced SparPreg™ Resin Technology to enable low cost tooling, minimise cure time, eliminate the requirement for chilled storage and enable application direct to complex curvature tooling
## Glass Sparcaps

**Glass Blade Design Study**
This study explores the potential for extending the life of a blade design using glass materials by exploring alternative material options to traditionally used E-Glass infusion, including:
- E-glass prepreg
- High modulus glass prepreg

Three key design limitations are considered:
- Natural Frequency
- Tip Deflection
- Edgewise Fatigue

### Carbon Sparcaps

**Carbon Blade Design Study**
A study focussing on the benefits of using carbon fibre, including:
- Design limitations of glass
- Benefit to blade weight

**Thermal Expansion**
The use of carbon components, in otherwise glass blades, raises some important design considerations. This section discusses the fundamentals.

**Lightning Protection**
The elevated risk of lightning strikes due to higher, longer blades is widely recognised, particularly when using carbon. This section discusses potential solutions to this problem.

**Carbon Cost Study (glass vs carbon)**
The higher material cost makes choosing carbon a difficult choice when only considering the impact on blade design. This cost study uses a blade design study in conjunction with empirically derived WTG component costs to understand the fundamental contribution to cost per megawatt of using carbon and why carbon does make sense.

## 9MW, 75m Blade Design Study

This section explores the implications of a 9MW, 75m blade and the options available to maximise the potential of glass fibre and the benefits of carbon.

## 50m Sparcap Manufacturing Process Study (prepreg vs infusion)

Gurit has recently launched two new products which significantly change the calculations of building wind energy turbine blades by using prepreg technology for certain parts. These products enable the direct substitution of a prepreg in the infusion process whilst still utilising the same moulds, with the added benefits of no cold storage and no air conditioned lay-up which have been some of the key technical barriers to the adoption of prepreg within the industry.

A virtual factory manufacturing 50m sparcaps has been modelled to understand how a prepreg process compares to an infusion process from a commercial perspective.

**SparPreg™, Technical Information, Availability, Pricing & Contacts**
SparPreg™ is an advanced UD prepreg, developed to enable the economic manufacture of unidirectional sparcaps for more demanding blade designs. Available in carbon and glass formats, SparPreg™ benefits from innovative SparPreg™ Resin and Airstream™ Coating Technology.
Glass Blade Design Study

To explore the advantages of higher modulus glass materials such as prepreg and high modulus glass fibres, it is useful to firstly model a traditional glass design and discuss the key design drivers as a function of blade length. A Gurit in-house engineering blade design model was used to calculate the amount of unidirectional glass composite required in a spar cap for a given load case and tip deflection plotted as a function of length. This is shown in the figure below for blades of length 45 to 55m.

Natural Frequency & Tip Deflection

Blade stiffness, to maintain tower clearance, and a requirement to maintain a high natural frequency to avoid resonance (caused by the pressure drop as the blade passes the tower – quantified by the tower passing frequency of each blade known as 3P) can drive the design of many large blades. However, above approximately 45-50m blade length, the design becomes dominated by tip deflection. The obvious solution to increase stiffness is to add more glass UD, but this is not ideal as the glass has to be added further and further away from the outer surface and therefore becomes less effective. Furthermore, the additional glass increases the weight of the blade thus increasing fatigue loads in the edgewise direction. The edgewise fatigue loads are created by the weight of the blade creating bending firstly in one direction, as it climbs to the highest point above the nacelle, and then reversed loading as the blade heads back towards the ground.

Thickening Blade Sections

Another approach to avoid the blade striking the tower is to design the blade with pre-bend, or to increase the angle of the hub. However, as the blades increase in size there are limitations to this solution. Another option for increasing stiffness is to increase the thickness of the blade. This enables a significant increase in length, due to the inherent stiffness increase from the geometry, but also due to the glass UD being further away from the neutral axis and therefore more effective. The problem with this approach is that increasing the blade thickness reduces the aerodynamic efficiency of the blade.

The figure above shows the spar cap mass versus blade length and the approximate blade lengths at which the design driver changes from tip deflection to edgewise fatigue loads. The lower line shows the effect of increasing the blade thickness on the spar cap mass, which enables the design of longer blades, but at the cost of aerodynamic efficiency.

Higher Modulus Materials

An alternative to compromising aerodynamic efficiency can be to simply use higher modulus materials, such as E-glass prepreg, high modulus materials such as R-glass, S-Glass or carbon fibre (see page 5 for more information on carbon fibre).

Generally, higher modulus glass fibres are 20% more expensive with a 15% benefit in modulus. This study has shown that using a prepreg with a high modulus glass (92 GPa) has enabled a 5-10% increase in blade length for the same blade mass. However, higher modulus glass also provides an alternative solution to blade designers, critical when designing the next generation of off-shore turbine, as discussed in the next section.
Carbon Blade Design Study

Even when using thicker blade sections there comes a point when designing with glass becomes increasingly difficult because of high edgewise fatigue loads caused by the rapidly increasing blade weight. The alternative is to use a high modulus fibre like carbon that has inherently more stiffness compared to glass. Although more expensive, carbon provides significant design advantages:

- 3 x Modulus
- 2 x Strength
- 30% Lower Density
- Increased Fatigue Strength

The net result is that you can design significantly lighter and longer spar caps for a given tip deflection and negate the effects of edgewise fatigue that is inherent in heavy glass blades (see page 3 for more information on glass blade design limitations).

**Carbon Weight Saving**

The figure below shows the comparison of spar cap mass as a function of blade length for carbon and glass UD laminates. The carbon spar cap is significantly lighter due to the high stiffness (therefore less material is required for a given tip deflection) and lower density of the carbon fibre. It is also noted that the main design driver for carbon blades in the range 45 to 65m is compression strength as natural frequency, tip deflection and edgewise fatigue become less significant. Relative design drivers and limitations are explored in more detail in the 75m blade design study (page 7).

**Commercial Justification for Carbon**

Carbon spar caps enable the use of more aerodynamic blade profiles (thinner sections), and therefore the possibility of generating more power for a given blade length, but the primary benefit is the large reduction in blade weight. This is because the weight saving not only impacts on the design of the rotor blades but also the hub, pitch mechanism, bearings, spinner, nose, shaft and gearbox. The next section explores the Turbine Capital Cost (TCC) of a WTG and how this is affected through the use of carbon.

**Summary**

Designing longer blades using glass sparcaps requires more and more trailing edge and/or shell laminate to deal with increasing edgewise fatigue loads. This results in increased weight, a loss of aerofoil efficiency and increased edgewise loading. This design circle makes the blade design increasingly more and more difficult. Solutions to break the cycle:

- Use a thicker blade section: structurally efficient but aerodynamically inefficient → a longer blade is required
- Reduce Rotor speed: however, this reduces efficiency as the blade moves away from its optimum tip speed ratio
- Use higher modulus material: High Modulus Glass or Carbon Fibre
Thermal Expansion

The economic advantages of carbon fibre in the spar cap do not generally transfer to other parts of the wind turbine blade, because they are driven by strength rather than stiffness, and the weight penalty of glass becomes less significant. This means that carbon spar caps need to be interfaced structurally with glass laminate, potentially leading to thermally-induced stresses caused by the difference in coefficient of thermal expansion (CTE) of the two fibre materials.

Generally speaking, blades built using the same material (glass for example) for all the components (spar, webs, shell) will see much smaller thermal stresses than those built with glass shell and webs but a carbon spar cap. Whether or not structural blade designers should consider thermally induced stresses as an additional load case is often the key aspect to consider when designing with carbon.

The aim of this study is to understand the magnitude of these stresses and how they can affect the strength of the materials and the material interfaces. Some typical values for coefficients of thermal expansion are shown in the table (for the fibre direction in unidirectional and multi-axial materials).

The most noticeable effect is shown when materials with a big difference in CTE are combined; for example at the interface between the glass biaxial shear web and the carbon unidirectional spar cap whereby the CTE is one order of magnitude different.

Thermally induced strains can be easily calculated as: \[ \Delta \varepsilon_{\text{THERMAL}} = \Delta \text{CTE} \times \Delta T \] and the allowable strain reduction as \[ \frac{\Delta \varepsilon_{\text{THERMAL}}}{\Delta \varepsilon_{\text{FAILURE}}} \]

Wind energy guidelines account for thermally induced stresses with a material partial factor:

- Det Norske Veritas (DNV): \( \gamma_m = 1.1 \)
- Germanischer Lloyd (GL) \( C_{2a} = 1.1 \)

Note: \( \gamma_m \) should be taken as 1.2 for polyester and vinylester laminates. This means that the characteristic strength values are conservatively knocked down by 10%, well above what thermal stresses in normal operating temperature can induce.
Lightning protection of wind turbine blades and generations is a major concern within the industry for a number of reasons: safety of personal during tower maintenance, significant number of insurance claims, costly on-site repairs and costly disruptions to power supply. Furthermore, lightning protection of wind turbine blades becomes more challenging with the increasing size, particularly offshore, where the uppermost blade tip may be 150m above sea level.

The main aim of lightning protection is to avoid a lightning arc inside the blade itself, which can overheat the structural laminate, causing permanent damage. Glass fibre blades are typically fitted with metal lightning receptors near the tip and at intervals along the blade, connected by a heavy gauge copper or aluminium cable. Earth connection is provided through the hub, nacelle and the steel tower to the foundation.

As carbon fibre is a conductor of electricity, the traditional protection systems developed for glass-fibre blades need some refinement to protect carbon spar caps. Cured carbon laminates have a conductivity about 1000 times lower than aluminium, therefore given its large cross-sectional area the carbon spar cap can become a preferential route for the lightning current. The conductivity of the carbon is also dependent on the orientation of the fibres, consequently, a lightning arc can be formed within the laminate itself. Diverting the lightning current from the attachment point along the surface to the blade root, using metallic conductors either fixed to the blade surface or inside the blade, is therefore recommended.

Traditional aluminium conductors for the lightning current are not compatible with carbon composites, since galvanic corrosion can occur, where carbon is the cathode (Passive end) and the aluminium the anode (Reactive end) when in the presence of an electrolyte (air moisture). However, there are a series of alternatives, for instance copper based solutions, since the latter is a metal on the passive end of the spectrum avoiding ionic flow between carbon, currently being used both in modern aircraft and wind energy industries.

Available technologies according to IEC 61400-24 [10] are:
- Lightning air termination systems on the blade surface or embedded in the surface
- Adhesive metallic tapes and segmented diverter strips
- Internal down conductor systems (used in aircraft and most common on rotor blades up to 50m, i.e. in leading and trailing edges)
- Conducting surface materials (aircraft and new generation rotor blades use metal meshes or surface treatments)

The latest systems are placed on the blade surface to make the surface itself conducting. In the aircraft industry, lightning protection of glass and carbon fibre composite materials for wings and surfaces exposed to lightning, is achieved by adding conducting material to the outer layers, thereby reducing damage to a small area at the attachment point. The conducting material may be metal sprayed onto the surface, metal coated fibres in the outer layers of the composite material, metal wire woven into the outer layers of the composite material, or meshes of metal placed just beneath the surface. Lightning protection of carbon wind turbine blades has similarly been made with metal mesh placed along the sides of the blades outside the spar caps.
The uptake of carbon fibre in the design of wind turbine blades has been restricted due to the high cost of carbon fibre and the difficulties in using it in blade manufacturing processes. The point at which carbon becomes a viable alternative to glass is the subject of much debate due to the many factors that need to be considered.

The first benefit is the capability to design with small blade thicknesses increasing the aerodynamic efficiency. This has been illustrated by estimating the effect of blade aerodynamic geometry on energy capture for 3.6 MW turbine with 60m blades.

The figures to the right show the effect of wind speed on power for two blade geometries. Although the differences appear small the effect over 20 years is significant and it is estimated that the additional cost of the carbon fibre is recovered by the aerodynamic advantage alone within 5 years of operation.

With a reduced blade mass, it is also possible to save costs on other elements of the turbine. In particular, the low speed shaft, bearings and hub cost are likely to be reduced. Tower top mass is also reduced facilitating cost savings on the tower and foundations. In order to give an illustration of the potential cost savings for a WTG when using lighter carbon blades, Gurit in-house engineering blade design models have been used in conjunction with an NREL technical report ‘Wind Turbine Design Cost and Scaling Model’. The NREL report uses empirically derived formulae to estimate the cost of key WTG components based on blade length, mass, and power rating.

The blade mass was first evaluated for a 50m blade intended for a 2.5 MW Class II WTG using E-glass infusion and carbon prepreg spar caps. The resultant blade mass was then used in the NREL model to estimate the mass and subsequently the costs of the other major components in the WTG. The Figure above shows that the reduction in blade mass of 8 tonnes has a secondary effect of reducing pitch mechanism, bearing and hub weight by a further 4 tonnes. This weight saving can then be translated into a cost saving which significantly reduces the impact of the higher BOM cost when using carbon. The saving then increases with blade length, as demonstrated in the 75m cost study (page 8). This model does not consider the thinner, more aerodynamically efficient rotor blade designs that are possible when using carbon.

### WTG Component Costs

<table>
<thead>
<tr>
<th>W TG Component</th>
<th>50m E-Glass Infused Spar Cap</th>
<th>50m Carbon Prepreg Spar Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade Materials Only</td>
<td>$165,983</td>
<td>$191,722</td>
</tr>
<tr>
<td>Blade Manufacture Cost</td>
<td>$204,138</td>
<td>$204,138</td>
</tr>
<tr>
<td>Hub</td>
<td>$67,103</td>
<td>$55,957</td>
</tr>
<tr>
<td>Pitch mechanism &amp; bearings</td>
<td>$99,310</td>
<td>$99,310</td>
</tr>
<tr>
<td>Spinner, Nose &amp; Cone</td>
<td>$7,405</td>
<td>$7,405</td>
</tr>
<tr>
<td>Drive train, nacelle</td>
<td>$1,033,622</td>
<td>$1,033,622</td>
</tr>
<tr>
<td>Control, Safety System, etc</td>
<td>$35,000</td>
<td>$35,000</td>
</tr>
<tr>
<td>Tower</td>
<td>$288,310</td>
<td>$288,310</td>
</tr>
<tr>
<td>Foundation / Support Structure</td>
<td>$69,689</td>
<td>$69,689</td>
</tr>
<tr>
<td>Transportation, Assembly, Installation, etc</td>
<td>$600,095</td>
<td>$600,095</td>
</tr>
<tr>
<td>Turbine Capital Cost (TCC)</td>
<td>$2,570,655</td>
<td>$2,585,248</td>
</tr>
<tr>
<td>Per MW Turbine Capital Cost (TCC)</td>
<td>$1,028,262</td>
<td>$1,034,099</td>
</tr>
</tbody>
</table>
9MW, 75m Blade Design Study

The next generation of WTG require blades in the region of 75m in length raising new design and processing challenges. Whilst higher modulus materials can greatly help designers, the use of a new material, requiring different processing techniques can in itself prove to be too great a challenge. This section explores the implications of a 75m blade and the options available to maximise the potential of glass fibre.

A quantitative comparison of structural designs of three 75m, 9MW blades using e-glass epoxy infused, e-glass epoxy prepreg and r-glass epoxy prepreg spar cap laminates for a wind site defined as IEC Class II (1) using representative extreme and characteristic flap-wise and edgewise loading. The designs are optimised to use the minimum practical thickness to chord ratio consistent with the practical limits of the e-glass infused material. Designs are performed in accordance with Germanischer Lloyd guidelines (2). In all cases, shell laminates were assumed to consist of e-glass epoxy infused triaxial laminates and SAN/PVC foam.

Ultimate flapwise and edgewise cases were analysed together with a characteristic maximum tip deflection case and the material safety factors from GL2010 used. The maximum static tip clearance was taken to be 9m. As per GL2010 (Germanischer Lloyd, 2010), up to 70% of this tip clearance may be used, leading to an allowable tip deflection of 6.3m.

Aerodynamic Design

A baseline aerodynamic design was produced and the blades designed using a typical wind energy aerofoil family (NACA 63-4XX), as these sections offer a high maximum lift:drag ratio, low noise properties and insensitivity to surface roughness. The chord of the blade outboard was optimised according to Schmitz and the twist was optimised for maximum lift:drag ratio at tip speed ratio 7. The turbine performance assuming 5% variable losses, pitch control and fixed rotational speed of 9rpm.

Tip Deflection

The tip deflection for the glass spar cap blades was the design driver and was optimised to 6.3m leading to near identical deformations for the blades. The carbon spar cap blade, however, was driven by the ultimate compressive strength of the carbon laminate. This is because the relative increase in material stiffness is greater than the increase in material strength.

Natural Frequency

The table below shows the blade natural frequencies. Due to the large thickness to chord ratios used for the blade (required to maintain tower clearance), it was possible to keep natural frequency above 3p tower passing frequency in all cases, but difficult to maintain sufficient margin. Maintaining this margin or increasing it would require further careful optimisation of the laminates, along with very strict controls on mass in production. Alternatively, the blade mass distribution could be altered to allow the natural frequency to fall below tower passing frequency. This would mean that the blade would pass through resonance on start-up. The carbon spar cap blade, however, was found to easily have sufficient margin over 3p tower passing.

<table>
<thead>
<tr>
<th>Fibre Material</th>
<th>1st Natural Frequency (Hz)</th>
<th>Margin over 3p tower passing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-Glass Infused Spar Cap</td>
<td>0.490</td>
<td>8.8%</td>
</tr>
<tr>
<td>E-Glass Prepreg Spar Cap</td>
<td>0.494</td>
<td>9.7%</td>
</tr>
<tr>
<td>R-Glass Prepreg Spar Cap</td>
<td>0.504</td>
<td>12.0%</td>
</tr>
<tr>
<td>Carbon Prepreg Spar Cap</td>
<td>0.579</td>
<td>28.6%</td>
</tr>
</tbody>
</table>

The glass spar cap blades were modelled with a 1m wide spar cap, tapering at the tip as shown in Figure 4 and the carbon spar cap blade had a 0.7m spar cap as shown in Figure 5. This is because, with less material required, the carbon spar cap may be more concentrated in the region of the aerofoil with the largest section depth and a less wide spar cap is less prone to buckling.
Flapwise Bending

For the glass spar cap blades, due to the tip deflection requirements, it was found that all axial strains due to flapwise bending were significantly below allowable values meaning that the blade flapwise bending strength was not driving the design in this case.

For the carbon spar cap blade, however, it was required to make slight reductions in the spar cap strain in order to meet the ultimate strength requirements. The increase in stiffness of the spar cap material is more than the increase in strength meaning that the carbon spar cap has a lower allowable strain.

Edgewise Bending

Under edgewise bending, it was found that large shell thicknesses and a large amount of infused e-glass unidirectional trailing edge tapes were required to maintain trailing edge axial strains at acceptable levels at the blade sections with the largest chord.

Bill of Materials

For the glass spar cap blades, a strong correlation was seen between the longitudinal modulus and mass of the unidirectional plies due to the stiffness critical nature of these blades. This mass saving, however, only constituted a small percentage of the total bill of materials for the blades.

The mass saving for the carbon spar cap blade, however, was significant and constituted a 17% saving in total blade mass over the glass infused spar cap blade. Despite the fact that the design of the carbon spar cap blade was driven by ultimate strength and therefore flapwise bending strains and deflections were slightly lower for the carbon blade, the mass of the spar cap was reduced by more than the ratio of the longitudinal modulus due to the more efficient use of material further from the blade section neutral axis.

75m Blade Design Summary

Four 75m (9MW) blade designs were produced using E-glass epoxy infused, E-glass epoxy prepreg and R-glass epoxy prepreg and 48k carbon prepreg spar cap laminates. It was found that:

- Large thickness to chord ratios were required for the glass spar cap blades to make the blade structurally feasible.
- For the glass spar cap blades, the blade design was driven by tip deflection and natural frequency. The carbon spar cap blade, however, was driven by the ultimate compressive strength of the carbon laminate which was slightly more critical than tip deflection.
- The first flapwise natural frequency of the glass spar cap blades was close to the 3p tower passing frequency, but sufficient margin was easily achieved with the carbon spar cap blade.
- The use of E-glass and R-Glass prepreg spar cap laminates resulted in some weight savings compared to the e-glass infused laminate but this saving was small compared to the total bill of materials. However, the use of R-glass prepreg spar caps may be of use to designers when struggling with natural frequency margins.
- The mass saving for the carbon spar cap blade was significant and constituted a 17% saving in total blade mass over the glass infused spar cap blade. The mass of the spar cap was reduced by more than the ratio of the longitudinal modulus due to the more efficient use of material further from the neutral axis.
Evaluating the commercial impact of longer, heavier blades on the overall WTG cost is a highly complex calculation dependent on too many factors to be able to generalise. The figure (right) shows just such a conservative estimate using the same approach as for the 50m carbon cost study (page 6) with the weight saving of key WTG components through using carbon spar caps as being up to 35 tonnes for a 75m blade.

There are also other important factors to consider such as the fact that carbon spar caps enable lighter, slimmer and therefore more efficient blades leading to more energy capture and a lower total cost of energy compared to an equivalent glass spar cap of the same length.

Weight Saving

Whilst it remains true that saving blade weight can only help to lower the cost of other WTG components such as the hub etc, trying to predict such savings based on empirically derived models for current turbines becomes very difficult to validate and verify. A more interesting approach may be to understand how the WTG blade components contribute to overall blade weight.

A key conclusion from the blade design study was that large shell thicknesses and a large amount of infused e-glass unidirectional trailing edge tapes were required to maintain trailing edge axial strains at acceptable levels at the blade sections with the largest chord. When considering the proportional influence each component of the blade might have on the final blade weight, it can be seen that this additional reinforcement of the shell sees a sharp drop in the spar to blade weight ratio at around 70-80m (below).

This may help to identify the next area of WTG blade design that could benefit from higher performance materials – the structural blade shell. Typically driven by strength and not stiffness it might be that carbon, coupled with prepreg technology to improve fibre placement, control resin content and improve laminate quality in thick sections, may become commercially viable in blade shells as well as spar caps.

75m WTG Cost Summary

The potential weight saving in WTG components by using carbon spar caps in 75m blades could be as much as three times the saving for a 50m blade. The spar to blade weight ratio drops significantly at around 70-80m:

- At 75m, the blade shell becomes much thicker due to the large amount of trailing edge UD tapes required to control edgewise fatigue loads
- The blade shell effectively becomes structural and, driven by material strength, could be the next area of WTG blade design to benefit from higher performance materials
Gurit has recently launched new products which greatly change the calculations of building wind energy turbine blades by using prepreg technology for certain parts. These products enable the direct substitution of a prepreg in place of infusion materials using the same moulds, no cold storage and no air conditioned lay-up which have been some of the technical key barriers to the adoption of prepreg within the industry.

### Manufacture Process

In order to fully appreciate how this is possible, and the implications of using prepreg in place of infusion, the two processes have been mapped out side by side for a 50m spar cap in the table below. The product used in this comparison is SparPreg™ with low exotherm and long-shelf-life resin coupled with Airstream™ Coating Technology.

<table>
<thead>
<tr>
<th>Process Time</th>
<th>Infusion</th>
<th>Sparpreg™ Airstream™</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacture Process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>-</td>
<td>Same storage and transport – SparPreg™ Airstream™ does not require refrigerated storage - 35°C transport and storage for 6 months.</td>
<td>-</td>
</tr>
<tr>
<td>Mould tool</td>
<td>-</td>
<td>Same mould tool technology - 100°C heating capability and 120°C exotherm tolerance.</td>
<td>-</td>
</tr>
<tr>
<td>Lay-up temperature</td>
<td>-</td>
<td>SparPreg Airstream™ tolerant from 15°C to 35°C factory temperature - no air conditioning required.</td>
<td>-</td>
</tr>
<tr>
<td>Lay-up</td>
<td>6.8</td>
<td>Lay-up of fabric using deposition cart. Control of fibre straightness critical to achieving the maximum carbon prepreg properties is not possible.</td>
<td>The high flexibility of SparPreg™ Airstream resin allows draping to complex curvature tool without wrinkling. Gurit is able to provide a deposition cart. Fibre straightness achieved during prepreg manufacture - 25% less carbon required due to higher achieved properties. 60 minute consolidation time recommended.</td>
</tr>
<tr>
<td>Vacuum &amp; air removal</td>
<td>3.1</td>
<td>High vacuum level required to ensure low void content. Use of specialised fabrics required to achieve good carbon infusion</td>
<td>Lower vacuum level required as bag leaks are less critical. SparPreg Airstream™ coating provides an air path for the removal of all inter-ply voiding.</td>
</tr>
<tr>
<td>Infusion</td>
<td>2.5</td>
<td>Additional step required in infusion process</td>
<td>No infusion.</td>
</tr>
<tr>
<td>Cure</td>
<td>8.5</td>
<td>7 hours.</td>
<td>Low reactivity of SparPreg™ Airstream reduces the potential to exotherm allowing short cure cycles - 5 hours.</td>
</tr>
<tr>
<td>Quality Inspection</td>
<td>2</td>
<td>Easier UT inspection with SparPreg™ Airstream™ due to lower void content and more controlled resin content Reduced scrap and re-work due to removal of infusion step.</td>
<td>2</td>
</tr>
<tr>
<td>Result</td>
<td>22.9</td>
<td>Standard quality glass sparcap Difficult process with carbon infusion</td>
<td>SparPreg™ part produced with infusion processing conditions Higher mechanical property sparcap.</td>
</tr>
</tbody>
</table>
Manufacture Process

A virtual factory manufacturing 50m spar caps has been modelled in order to understand how a prepreg process compares to an infusion process from a commercial and capacity perspective. This model focuses purely on the processing costs and ignores the actual material cost comparison of glass/carbon and infusion/prepreg. This is discussed in detail in the carbon cost study (page 7) and the 75m blade design cost study (page 8).

The basic cost model metrics are summarised in the table below, with a target volume of 1000 WTG blades or 2000 individual spar caps per annum.

<table>
<thead>
<tr>
<th>Model Metric</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working days per year</td>
<td>240 days</td>
</tr>
<tr>
<td>Working hours per day</td>
<td>24 hours</td>
</tr>
<tr>
<td>Mould size</td>
<td>88m²</td>
</tr>
<tr>
<td>Hourly rate</td>
<td>$25</td>
</tr>
<tr>
<td>Cost of energy</td>
<td>$0.51</td>
</tr>
</tbody>
</table>

Direct Costs & Consumables

The direct costs such as labour, lifting equipment & tooling energy consumption have been calculated based on the approximate process times shown opposite. This has also allowed for the number of moulds required to be calculated based on the mould utilisation time. The costs of parallel processes such as QC inspection, finishing, repair and packaging have also been evaluated.

A further advantage to using prepreg processing techniques is the significantly lower consumable costs through the elimination of infusion mesh, pipes, spiral hoses and waste or excess infusion resin.

Indirect Costs & CAPEX Contribution

The model considered targets of a fixed volume of 1000 spar cap sets per annum and so is most sensitive to the number of moulds, which is one of the largest CAPEX items and directly affects the size of factory required. The unique properties of SparPreg™ Airstream™ mean that the same infusion grade tooling may be used, no additional air conditioning is required (for ambient conditions up to 35°C) and no chilled or frozen storage is needed.

The same fixed indirect labour cost has been included for infusion & prepreg manufacturing processes covering factory management & office staff.

Manufacturing Cost Comparison

Comparing the key manufacturing cost components shows that a significant cost saving is possible using SparPreg™ Airstream™. Alternatively this can also be viewed as a substantial capacity benefit without needing to invest in additional tooling.

Manufacturing Process Study Summary

- The faster deposition rate and cycle time using Airstream™ in place of infusion, results in lower direct labour costs, fewer moulds and the size of factory required. This also reduces the CAPEX depreciation contribution.
- The unique properties of SparPreg™ Airstream™ mean that the same infusion grade tooling may be used, no additional air conditioning is required (for ambient conditions up to 35°C) and no chilled or frozen storage is needed.
- A cost model is unique to the WTG design and production facility, however the clear benefits of SparPreg™ Airstream™ over traditional prepregs, mean that traditional perceptions and cost implications of prepreg technology do not apply.
SparPreg™

SparPreg™ is an advanced UD prepreg, developed to enable the economic manufacture of unidirectional spar caps for more demanding blade designs, ideal for use in conjunction with other Gurit products. Available with carbon and glass fibres, SparPreg™ benefits from:

- SparPreg™ Resin Innovation
- Airstream™ Coating Technology

**SparPreg™ Resin**

SparPreg™ Resin has been supplied by Gurit for spar component manufacture for over 10 years, and has benefitted from continual development and innovation to ensure the best possible performance for out of autoclave processing. The latest iteration of this well-known system provides two new key characteristics:

**Reduced Exotherm**

The enthalpy of an industry standard 120°C curing prepreg resin has traditionally been around 200 – 300 J/g. Innovative curing technology has enabled Sparpreg™ to reduce the enthalpy to just 150 J/g without altering the chemistry or cure mechanism. Such a technology steps opens the door for standard prepreg materials to be cured using infusion grade, water heated tooling without the risk of excessive exotherm or lengthy curing cycles for thick section laminates.

**Extended Shelf-Life**

Another key barrier to prepreg adoption has been the requirement for chilled storage and transportation. Sparpreg™ resin will soon benefit from new latent curing materials that provide a much longer shelf-life at 21°C and as much as 4 months at 35°C.

**Airstream™ Coating Technology**

Airstream™ is Gurit’s answer to efficiently manufacture high quality thick laminates with unparalleled low void contents at ambient production hall temperatures of up to 35°C. In combination with Gurit’s unidirectional Sparpreg materials, the Airstream™ coating technology overcomes the generally conflicting material characteristics of low tack (to aid inter-ply breathing) and high drape (conformance to tooling geometry without formation of wrinkles) avoiding any detriment to mechanical performance of the final laminate. The result is a very cost effective user friendly material that eliminates the use of air-conditioned halls using multiple de-bulking steps and/or the use of high pressure autoclaves.

The first important feature of this technology is the increased air permeability between the plies provided by the coating. This is an extremely effective way of removing inter-ply porosity when the vacuum is applied. The resulting laminate has very low void contents (<1.5%) even when production hall temperatures are in excess of 35°C on sunny summer days. The second feature of the product is the excellent handling characteristics provided by the low tack and high drape it exhibits over a wide temperature range.

**Product Formats, Availability, Pricing**

SparPreg™ is available with E-glass, R-glass and carbon, typical product formats and laminate properties are shown on the following page. For more information regarding product samples, datasheets or pricing please go to www.gurit.com. Alternatively contact details are provided on the back of this brochure.
## Available Product Formats & Cured Laminate Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Unit</th>
<th>Infusion</th>
<th>Gurit SparPreg™</th>
<th>Test Standard</th>
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<tbody>
<tr>
<td>Fibre Type</td>
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<td>E-Glass</td>
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<tr>
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<tr>
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<td>1200</td>
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<td></td>
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<td>1025</td>
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<td>GL Char</td>
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<td>1.8%</td>
<td>1.5%</td>
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</tbody>
</table>

* Note that fibre dominated properties have been normalised to 56% fibre volume fraction

** Average Modulus = \( \frac{\text{Average 0° Tensile Modulus} + \text{Average 0° Compressive Modulus}}{2} \)

*** Allowable Compressive Strain = \( \frac{\text{Characteristic 0° Compressive Strength}}{\text{Average Modulus}} \)