Improving the Performance of Glass Fiber Laminates

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Abstract. The renewable energy sector and wind turbine industry in particular have improved their cost of energy to competitive levels [1]. For the materials used to produce wind turbine blades this means to look for ways to improve mechanical performance vs cost while keeping reliability, light weight and durability. For all this, knowing the limits of a material’s reliable performance is key. In the past years more and more so called heavy fabrics are proposed. Heavy fabrics are understood as those fabrics with an area weight above commonly used 1200g/m2. Another point which has been of concern in the market in recent years is the evolution of mechanical properties during extended terms of storage and during transportation. This paper will address these 2 aspects.

1. Heavy fabrics

Heavy fabrics reduce the number of layers to be placed and allow a reduction in processing time and cost. Main applications are spar cap and the root joint area. Resin infusion properties have to be controlled and – if possible – improved. A possible solution is shown in figure 1.
While the infusion (flow) speed is critical for the processing time, the variation of fiber volume fraction is critical for the variation of stiffness. In a series of infusion tests, an example is shown in figure 2, this variation can be shown and its impact further studied.

Figure 1: Infusion permeability tests carried out

Figure 2: Effects of number of layers/plies on Fiber Volume Fraction (FVF)
As it can be observed, FVF values increase from values below 55% rapidly to 56% when +10 layers of UD fabrics are reached. Within this laminate thickness however further increase does not exceed another 1%. This means that within current process technology, use of membranes for example and proper permeability of the UD fabrics, the increase of FVF can be well managed below +2%.

![Scatterplot of Tension Peak (Mpa) WS3000 UD Fabrics R=-1](image)

**Figure 3:** Fatigue results, R=-1, UDFA method, UD laminates vs FVF

In figure 3 fatigue curves for an identical fabric resin combination at different fiber volume ratios are shown. The 50% likelihood curves are indicated as well as a hypothetical fatigue limit considered for a blade design. The green curve at 59.9% FVF will most likely produce values which are below the design limit values considering usual spread of observations in the cycle range of $10^6$ upwards, while the red curve at 58.9% is still uncritical over the whole shown frequency range.

The recommendation for this given requirement – performance combination is hence not to increase in laminate FVF values beyond 58.90%. Taking into account the before mentioned process tolerance of +/-1% for the fiber volume fraction, the target value of FVF in this laminate would be rounded 58%.

At this value the fatigue properties can be reached.
With the information of several tensile modulus tests a statistical correlation allows to predict at this FVF of 58% a modulus of 49.6 GPa for a given group of fabrics with identical fiber modulus and cross fiber amount. Important here is to stress that this is the solution for a given fatigue requirement. If fatigue requirement can be reduced, at 59% FVF for example a modulus of 50.5 GPa can be obtained.

With the information that lower FVF values are found at lower number of layers, or mainly in areas close to the blade tip, the reduced modulus will not affect strongly blade tip deflection for geometrical reasons.

Other applications of heavy fabrics are in root joint laminates where quickly thick laminate structures are build. High modulus glasses have shown their advantages in these applications. By selectively increasing the blade root stiffness better flanging designs can be build.

2. Long term storage effects on laminate properties

Storage can affect negatively the performance of commonly used composite materials. While this is widely accepted in the area of reactive resin systems, a possible reduction of glass fiber properties has not been considered for many applications.

Thee reduction of properties can be accounted for in different ways as shown in figure 5 and 6.
In figure 5 a reduction of properties over time and under measurable conditions occurs. When the initial lower confidence limit is higher than the observed upper confidence limit after storage, the property of interest has sufficiently reduced to state at that moment the material has significantly lower properties than initially, so its storage lifetime under the indicated parameter has been reached. This value can be computed independently from customer requirements, by applying standard alpha and beta coefficients of a normal distribution for example. A good example here is the so called 5%/95% rule.

Another possibility is to use the observed distribution and compare this against a set criteria of minimum performance. This method is shown in figure 6. A possible variation of the average property is not required. The likelihood of an observation below a limit performance can be computed. A risk level according to the application can be established.

Owens Corning stores industrially produced material, glass fiber roving and fabrics, for several years now at different own warehouse to evaluate the impact of storage and to establish at regular time intervals the mechanical laminate properties.
Figure 7: Storage and climate areas chosen by Owens Corning

As shown in figure 7 selected warehouses are used as “natural ageing” sites, but we test unpacked material as well and undergo specific ageing cycles in climate conditioned rooms. Chemical analysis is done on these materials too.

Figure 8: Findings on natural aged material, transversal tensile strength (wound, infused and cured roving panels)

Basis for these tests are roving and fabrics stored the indicated time under the local climate conditions. Temperature and humidity levels have been checked. The rovings as indicated in figure 8 have been wound into laminate panels, infused with a standard epoxy resin system, post cured, cut, and measured.

From these results both methods shown in slide 5 and 6 can be applied. The average degradation can be computed, or the likelihood to observe values below a certain limit value can be computed.
An average property degradation can be “seen” argued according to the regression lines, but a “significantly reduced performance” versus initial performance cannot be found yet after 40 months of test time.

Similar observations can be made on fabrics, stored under similar conditions and tested.

![Figure 9: Key test results of stored fabrics after up to 42 months](image)

References

[1] Make Consult (Wood Mackenzie), Aarhus, Denmark, Market Research Presentation “Global Wind Industry Trends – DWIA 2018”, published 5 April 2018