technologies

Evolution of technologies and materials used in wind turbine blade manufacturing

In recent decades, there has been a number of rapid improvements in wind turbine blade manufacturing, driven by costs, cycle time and quality issues. The value propositions for new and emerging technology are enabling wind industry evolution. However, when reviewing the history of wind blade technologies, it is clear that the small evolutions may turn significantly disruptive to the industry. To keep up with the trends of the evolving industry, it is crucial to understand the past developments and identify potential new technologies arising in the next five to ten years.


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Selecting the best available material technologies, being innovative and keeping up with industry trends are critical for material suppliers to become leaders in the market. This is especially true when talking about wind energy, where the majority of the active blade manufacturers or OEMs have experienced tough financial periods during their operation. Their success is linked to their ability to permanently deliver a lower cost of energy with their current and new products. Innovation, and reacting to change, can be approached in different ways, all contributing to the success (or failure) of a product or even more crucially, a company.

Harvard Business School professor Clayton M. Christensen defined the term disruptive technology. He separates new technology into two sub-categories: sustaining and disruptive. Sustaining technology relies on incremental improvements to an already established technology. Disruptive technology lacks refinement, often has performance problems because it is new, appeals to a limited audience and may not yet have a proven practical application[1]. Disruption is also associated with about a 10-fold improvement in any aspect of the material and technology.

Nevertheless, in recent decades, a number of material and process evolutions have occurred in rotor blade manufacturing, some minor, some more significant or some even decisive for success. Three key technology developments will be outlined here, and their level of disruption will be assessed.

Epoxy resin infusion as the main manufacturing process for blades

For the early years of the industry, the 80s and early 90s, the main blade manufacturing method was wet lay-up. Resins had been supplied by local formulators, and given the niche nature of wind energy applications, they could handle the low volumes and provide the associated services to promote their use. During this time, the use of polyester was typical, but there was a quick shift to epoxy and, to a lesser extent, vinylester. The primary reason for the transition was the enhanced mechanical properties making the higher cost justifiable.

As turbine sizes and numbers increased, higher volumes became more attractive for top tier resin companies with back-integrated supply chains. In the late 90s, epoxy prepregs and polyester infusion were seen as the state of the art and these technologies led the market for a number of years until approximately 2005. However, as OEMs were driving costs down and optimising the supply chain, prepreg disappeared from most blade components, with the exception of spar caps and root inserts. Instead, epoxy infusion became dominant in Europe, America and Asia. Infusion provided an adaptable and scalable processing method with lower capital expenditure (CAPEX) and training requirements, a simpler supply chain (no need to convert into prepregs) and improved health and safety (Figure 1). In a growing wind energy industry, this created an opportunity for larger companies such as the global leader in epoxy, Olin Corportation(which took over the division from The Dow Chemical Company) to enter the market and directly supply blade manufacturers with systems. Therefore, suppressing a converting step in the supply chain (prepregs) and lowering cost significantly compared to the existing suppliers. It is believed that

(1)Clayton M. Christensen: "The Innovator's Dilemma," 1997

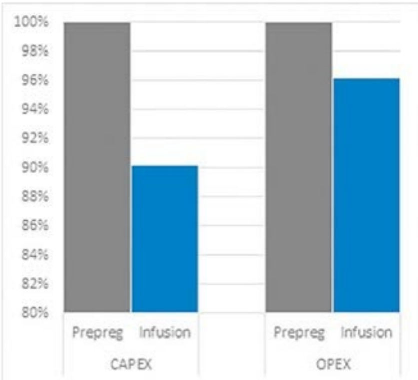

Fig. 1: CAPEX and OPEX cost difference based on STRUCTeam's 80m reference blade, STL80-6MW

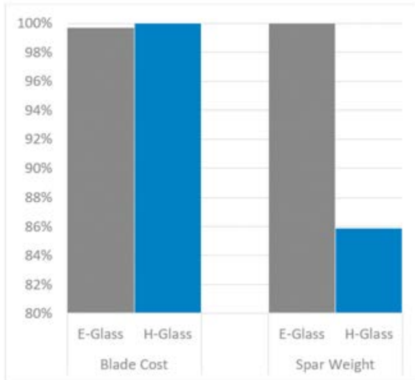

Fig. 2: Blade cost and sparcap weight differences based on STRUCTeam's 80m reference blade, STL80-6MW

the overall resin cost reduction achieved in the last 15 years is around 30%.
The adoption of epoxy was initially driven by improved fatigue performance, whereas the adoption of resin infusion for blade manufacture was accelerated by the availability of epoxy resin at the time. It is also interesting to note that the creation and the boom of the Chinese wind energy sector were essential to this transformation of the industry.

Sparcap reinforcements: high-modulus glass fibre for primary load-carrying members

As the resin infusion process developed, there was a transition from E-glass to high-modulus glass in sparcaps. The main value proposition for high-modulus glass is the sparcap weight reduction, around 20%, for a neutral cost compared with E-glass sparcaps (Figure 2). Higher modulus fibre was developed in the early 2000s and was first introduced into blades in 2005. This was driven by the market leaders Owens Corning and 3B (Saint-Gobain at the time), quickly followed by CPIC. Nowadays, all new sparcaps tend to be made of high-modulus glass and currently represent 80-90% of the market. The value proposition of high-modulus glass has several sides. The improved static and fatigue performance brought more robustness in a growing industry that, since 2005, has doubled the average rotor diameter. The supply of this higher performing fibre could be based around the existing assets (furnaces), therefore making it easy to ramp up in production volumes. An additional factor for the adoption of this innovation was the ability for the blade manufacturer to rely on industry leaders all working in this direction, therefore avoiding single sourcing.

PET foam as the core material in the shell sandwich structure

In the 90s, various core materials were used for blade manufacture including honeycombs, balsa and PVC foam. Honeycombs were rapidly discarded because of their disadvantageous volume-to-cost ratio and replaced with balsa and structural foams, such as PVC, PET and, to a lesser extent, SAN. Balsa and PVC have been the primary choice for blade manufacture and have dominated the market for a significant amount of time. In 2005, 3A Composites launched the first generation of PET foam for the wind market, which was successful due to its higher temperature resistance compared to PVC. As the industry developed manufacturing methods with higher peak exotherm temperatures, to increase curing speed and improve cure cycle time, the nature of the PVC foam has been a limiting factor in many cases. PET, on the other hand, has the necessary temperature resistance. It also has the advantage of being fully recyclable, which is increasingly important as sustainability is nowadays a key factor for both material and blade manufacturers. Specifically for the case of foam cores, it is linked with significant savings since 10-15% of the foam produced ends up in dust through its transformation processes (slicing, trimming, kitting) before it can be fitted in a mould.
As opposed to PVC being manufactured in a batch process, PET is manufactured in a continuous process. This has been a key factor in lowering the foam core cost, reducing lead time and addressing a need for a growing demand from the wind energy industry. The automation of the production process can also lead to new supply formats where foam core production lines could be, in theory, installed nearby or within the blade manufacturing operations.
Where the value proposition of PET has an interesting feature in comparison to the two previous examples is that the mechanical properties are often being considered "lower". This is true for strength properties although, for example, 3A's second generation PET – Airex T10 – shows significant improvements. More importantly, the intrinsic properties of PET make it a relatively stiff material, therefore contributing to the buckling resistance of wind turbine shells. Looking at the practical example of the STL80-6MW blade, we see that with the second generation PET there is a marginal blade weight increase with a noticeable reduction in blade cost when compared to the PVC/balsa reference blade (Figure 3).

Sacrificing part of the mechanical properties for a major improvement in costs and processability illustrates what has driven manufacturers to PET at a substantial rate. PET's mechanical performance relative to cost ratio (i.e. MPa/€) has always been better and this advantage is ever increasing. The adoption of PET is well under way, with today a rapid adoption pattern where ten years after its introduction, this technology has captured 50% of the market share previously held by other foam core types. However, it is yet to reach its full potential. More evolution of this technology can be expected in the next few years.

Conclusions from previous technology developments

We have reviewed briefly the key suc-

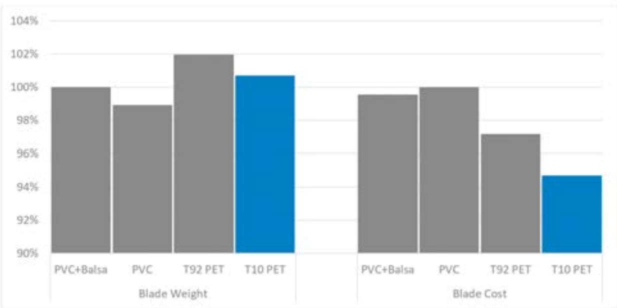

Fig. 3: Blade weight and blade cost differences based on STRUCTeam's 80m reference blade, STL80-6MW

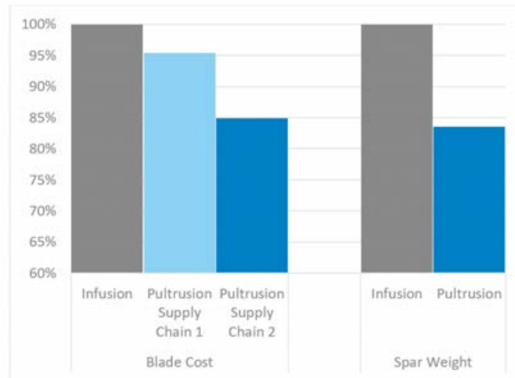

Fig. 4: Blade cost and sparcap weight differences based on STRUCTeam's 80m reference blade, STL80-6MW

cess factors for three different material technologies. The common element is essentially linked with lowering cost for any successful evolution. While taking a closer look, it is clear that the wind energy sector is extremely supply chain focused. Any gain within the supply chain demonstrates a major attribute for any innovation. Finally, technical performance improvement linked with easier series builds is primary when compared against improved intrinsic individual material performance. In addition, the adoption of the technologies seems to have an initial five-year cycle during the innovation introduction period, followed by a five-year adoption period where it displaces the previous technology.

What is next?

Wind energy generation in itself is very disruptive. It is one of those industries where disruption enables development and it has a major influence on the everyday life of humanity and many other sectors as well. Let us just think of transitions like animal force vs. steam vs. internal combustion vs. electric, or coal vs. nuclear vs. renewables in energy generation.

There are a few candidates for the next big disruption in material technologies.

The most obvious candidate is carbon fibre. Although it seems straightforward in principle, with its great performance attribute and its good track record in the sector, the adoption of carbon fibre has stalled for various reasons. The lack of standards and the small volume of fibre available (compared to glass fibre availability) have proven to be hurdles preventing its broader adoption. From a technical standpoint, achieving consistent quality has always been a challenge that was further aggravated by the mismatch in process of choice for carbon and glass fibre. Glass fibre is essentially processed with a resin infusion process while carbon fibre is more suited to prepreg and pultrusion. The opportunity for carbon fibre adoption lies in its ability to be processed in a similar way to glass fibre, therefore enabling hybrid blades using both glass and carbon fibre in their spars. In this case, the fibre volumes available could be leveraged in a lower cost of energy, therefore ensuring the supply chain is a managed risk for the blade manufacturer or OEM.

The next technology candidate, the manufacture of sparcaps using pultrusion, embeds many of the features seen in the three examples. To this end, STRUCTeam has formed the Pullwind consortium to develop and enable its adoption addressing the supply chain, the material performance, the design and manufacturing challenges associated with the use of pultrusion for wind turbine blades. The Pullwind consortium members are Olin (resins), CPIC (glass fibre) and other key suppliers. Advanced negotiations are taking place to complete the partnership with the final addition of a carbon manufacturer. Pultrusion enables a cost reduction of blade manufacture through its supply chain that can be tailored to the OEM requirements for either local content or low-cost production (Figure 4). Additionally, improved mechanical performance leads to less material being used and associated, lowering CAPEX for the blade manufacturer and also allowing for glass and carbon fibre to be processed using a common process. The selection of this technology by an industry leader for a number of years also demonstrates its potential to grow as an innovation and displace the current methods for manufacturing sparcaps.

Finally, further evolutions for resins are expected. Epoxy suppliers are continuously working to improve their current systems with a core focus on cycle time and cure improvement. Polyurethane is also being explored, essentially due to the potential in cycle time reduction, but yet to remain proven in a series application and on the scale required to supply the delivery of 50GW+ each year. One possible disruption is the use of thermoplastic resins in blades, however they have been more suited to smaller parts traditionally.

Conclusion

In such a cost and performance driven industry, small gains can have a significant impact. As shown, the speed of technology adaption in the wind sector is immense and within a decade, evolutions have set a different standard. The technologies discussed might not be deemed disruptive on their own rights when looking for the ten-fold benefit gain discussed, however these evolutions combined together could be considered disruptive. ▫

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