FEATURE

Hundreds, if not thousands, of composite plies of various materials and numerous pieces of core material are required to manufacture a wind turbine blade. (Picture © zentilia. Used under license from Shutterstock.com.)

Wind blade manufacturers face balancing act

Designing wind turbine blades is about balancing aerodynamic performance and structural integrity, but design and analysis is often disconnected from the blade manufacturing process. Dr Olivier Guillermin, Director of Product and Market Strategy at VISTAGY Inc, believes the firms that implement the most efficient composites engineering processes will lead the wind energy industry, and key to this is a PLM-based engineering environment built around a hub of composites design and manufacturing software.

While wind energy is growing around the world, the three major regions are at different stages of developing their engineering processes. Europe is the most mature inland market and is spearheading the effort in the largest wind turbines for offshore use. North America is still a growing inland market which is grappling with fossil fuel competition and regulatory issues. Meanwhile, China and India are ramping up very rapidly but they have a dearth of composites and wind blade design expertise.

In this uneven landscape, some manufacturers are already using a state-of-the-art 3D CAD engineering environment (Figure 1),

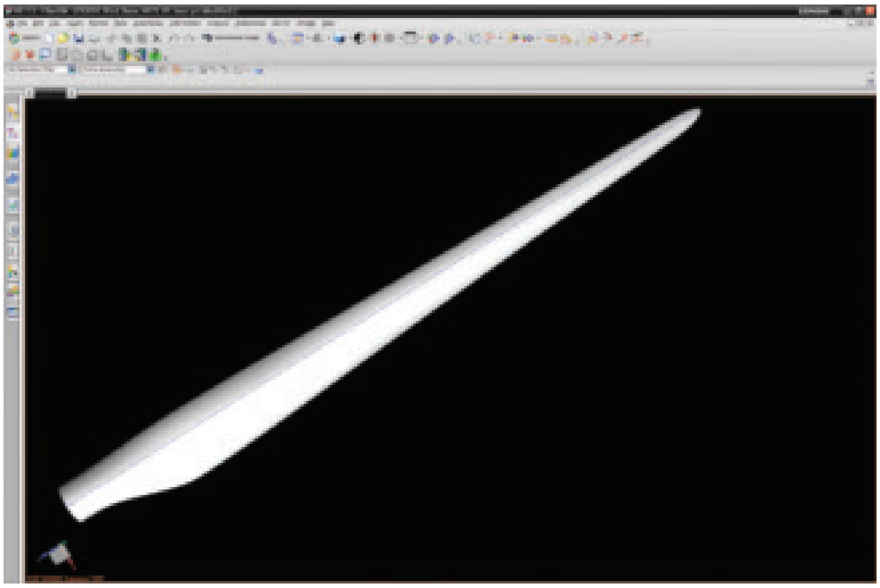

Figure 1: State of the art 3D CAD systems, such as Siemens NX pictured here, enable easy virtual definition and prototyping of complex structures such as wind turbine blades.

while others are still living in a 2D CAD or paper and pencil world. Some companies have been outsourcing their wind turbine and blade structural analysis but realise that it is time to bring that skill in-house. Some firms have adopted more advanced manufacturing techniques while others use very basic and costly touch labour – scissors and rollers – to build their blades.

As a result, there is no one solution that fits every company. Rather, each firm must determine the best combination of engineering software and manufacturing hardware given their current circumstances. That is the key to increasing productivity and quality throughout the composites design and manufacturing lifecycle and represents a critical factor in fulfilling the goal of developing bigger and lighter wind turbine blades.

Taking on the engineering challenge

Designing wind turbine blades is about balancing aerodynamic performance and structural integrity. The goal is for blades to extract as much energy from the airflow as possible over at least a 20-year lifespan with the lowest possible lifecycle costs. These blades can weigh up to 20 tons and can be required to withstand tens of millions of rotations and fatigue cycles at speeds up to 200 miles per hour at the tip of the blade. They must also withstand bird strikes, harsh sun, heavy rain, snow, ice, hail, gusty winds, and lightning strikes.

As blades increase in length, reducing weight becomes even more critical because weight increases faster than energy throughput. So the detailed design of the blade must be spot-on to avoid internal cracking and de-lamination leading to failure due to nature's forces. Mastering such a precise process typically requires advanced design and analysis using tools such as finite element software and 3D CAD composite design software (Figure 2).

One could argue that current blade manufacturing technology has drawn more from boat building than other composites-intensive industries, such as aerospace. Indeed, several of the major blade manufacturers converted from marine activities. Large blades are almost all made of glass fibre reinforced polymer (GRP) because it is relatively inexpensive and provides sufficient strength and stiffness. However, as blade size increases and higher performance is required, carbon fibre reinforced polymer (CFRP) is becoming more appealing for some parts of the blades, such as spar caps and some of the blade root areas.

The layup of the glass plies and core material is manual and labour intensive, which leads to a lack of repeatability and accuracy. Assembling the various parts into the final blade typically requires

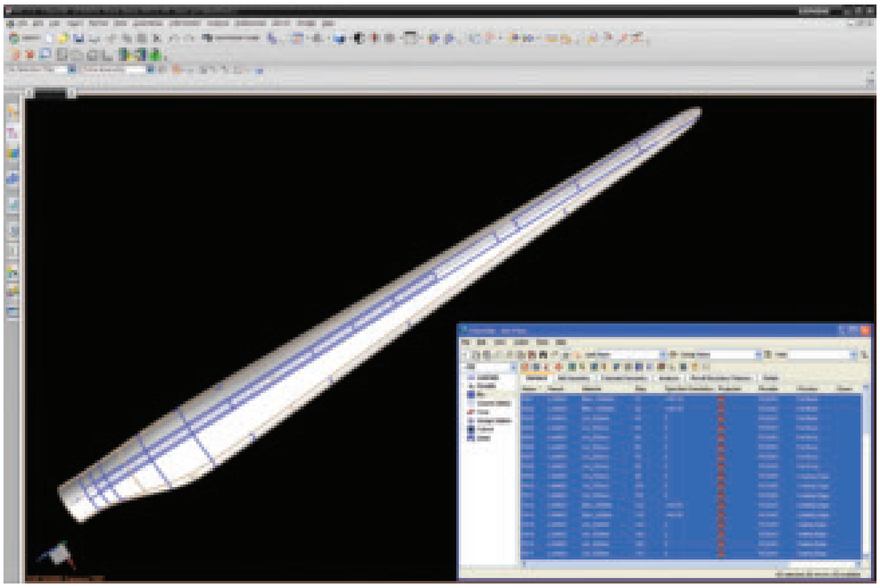

Figure 2: Software applications such as VISTAGY's FiberSIM complement the 3D CAD systems with powerful capabilities for composites design and manufacture. This image shows how such software enables complete and detailed glass layup definition prior to any prototyping and production. Design changes can be quickly and reliably included in the development process.

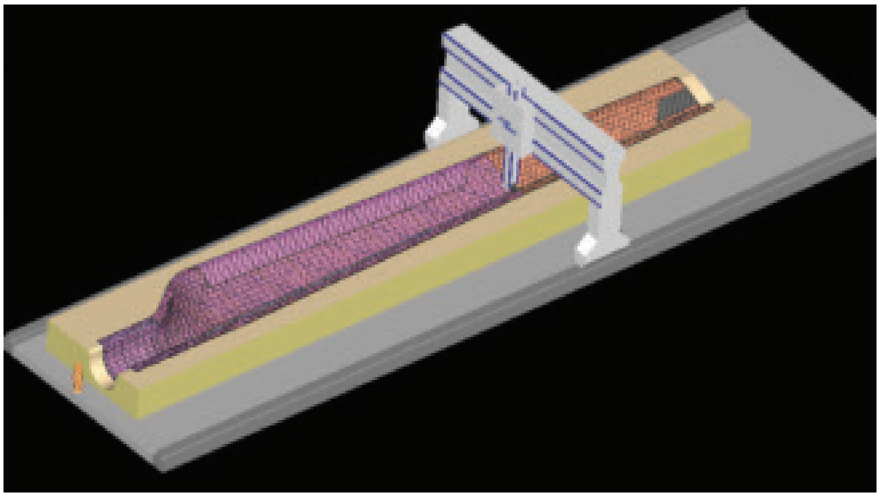

Figure 3: Large robotic and machine systems such as the concept illustrated here have been developed to automate the manufacturing of wind blades and reduce cycle time and labour costs. (Image courtesy of CG Tech.)

several hundred kilograms of adhesive paste. Most large blades are made with resin infusion techniques, including the Seeman Composite Resin Infusion Moulding Process (SCRIMP) and resin transfer moulding (RTM). Only a few companies are relying on more expensive methods, such as prepreg materials and heated mould curing. Tooling is very large and expensive, and manufacturers therefore tend to avoid making costly design changes in order to reuse the same tools as much as possible. That limits design optimisation and variants.

In all, hundreds, if not thousands, of composite plies of various materials and numerous pieces of core materials are required to be put in a complex arrangement and run through a sophisticated curing process to make a wind turbine blade.

Leveraging design knowledge

European wind blade companies, especially in the northern part of Western Europe, have been designing large blades for several decades. The most advanced of these companies have sought a competitive advantage by developing their own wind blade design software to preserve their intellectual property and distinguish their blade characteristics from the competition. And a couple of software companies offer specialised commercial software for wind turbine and wind blade design and are making progress with their installed base. Such solutions typically address the preliminary design and structural analysis stages. There the blade structure is idealised and considered as a relatively simplified box beam or clamshell structure. These solutions provide a preliminary representation of the blade suitable for optimisation of the blade mass distribution, damping, and stiffness characteristics, but are unsuitable for detailed manufacturing engineering.

The same is true in North America though on a smaller scale. A few companies, dominated by giant GE, are designing blades mostly using home grown preliminary design software. Several companies rely on European-based blade design offices and speciality firms. Recently, however, more European companies have begun establishing design and R&D offices in North America to cater to local needs.

In Asia in general, and China in particular, few companies have tackled the design of wind blades. They typically rely on available commercial software. Many more are in the process of learning about blade design and analysis so they can start to develop their own end-to-end engineering process. Companies that do not create their own design outsource this function to engineering services companies specialising in blade design, most of which are located in Europe.

In general, however, the design and analysis developments remain quite disconnected from the blade manufacturing process. The transfer of information from design to manufacturing is still very much a manual, time-consuming step. As a consequence, iterations and exchange of information unfortunately remains limited. Typically, the manufacturing engineers find themselves in charge of detailing the blade composite design and making sure it can go into production. They often rely on traditional methodologies, such as paper drawings and work instruction folders. They have to rely on previous designs for lack of a reliable and rapid innovation and update loop between design and manufacturing.

Diverse manufacturing methodologies

Manufacturing skills are more evenly distributed across the world than design skills because this function has been outsourced to lower cost regions for a while. However, Europe continues to spearhead the manufacturing of ever larger blades and wind turbines. Some companies are aiming to manufacture wind turbines that can produce 5 MW or more of electricity for highly touted offshore applications. As such, they stand at the forefront of new technologies for large blade manufacturing because traditional methods can't scale up on the basis of feasibility, cost, performance, or quality.

There is no real convergence yet toward a single manufacturing process. European and American companies have developed diverse proprietary manufacturing techniques, some around resin injection, and some around the use of prepregs, either for box beam or for shear web designs that may include some automation for spar cap layup or for other parts of the wind blade. However, true full scale automated production is absent from current blade manufacturing practices. In fact, the manufacturing being performed in Asia and China is largely based on manual and touch labour.

Hence, the immediate needs are somewhat different from one region to the next.

In Europe, production is readily moving toward much more complete automation in an attempt to drastically reduce time-to-market and labour costs. Many blade manufacturers are seriously looking into large automated systems that will drastically reduce or eliminate touch labour in some of the key time-consuming manufacturing operations, such as the glass layup (Figure 3). This is a giant step considering that a very large portion of the blades made in Europe are still produced only with scissors and rollers.

In North America, ramping up production is mostly based on the introduction of manufacturing aids, such as cutting machines and laser projection. These production methodologies are under consideration or have already been implemented at some production facilities.

From a manufacturing standpoint, Asia (particularly China) is more concerned with enhancing quality while keeping costs low with their current manual processes.

The need for a PLM approach

Manufacturing automation is only as reliable as the data that is fed to the machine. In order to generate effective manufacturing, the process needs to include the following characteristics:

- the data must accurately and completely represent what the manufacturer needs to produce;
- the data must be easy to update because changes are inevitable; and
- the manufacturing data must be exchangeable because it is likely that, at some point, the manufacturing will be outsourced.

Implementing a reliable product lifecycle management (PLM) system is the best way to allay these concerns. PLM embeds design, analysis, manufacturing, data and process management and provides a framework that covers the entire engineering process, from conceptual design to production and aftermarket.

Composites engineering is handled within the PLM environment by industry-specific

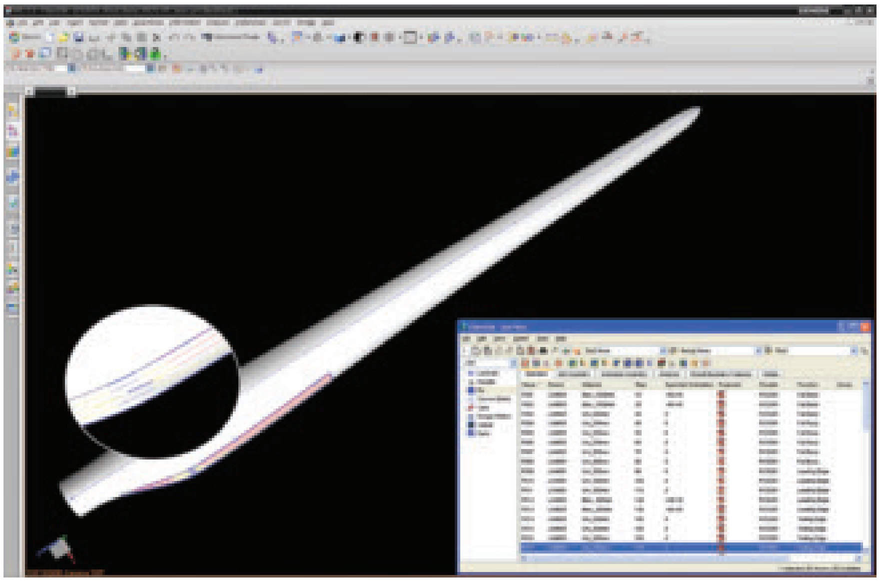

Figure 4: FiberSIM provides the ability to simulate the ply layup and indicates possible manufacturing issues, such as wrinkling, bridging, and fibre buckling (circular image shows simulation detail for trailing edge ply). Accurate simulation of the manufacturing layup process shortens the development cycle by providing a design that can be manufactured and does not require rework and design changes late in the process. It also enables the production of optimised lighter and stronger blades.

Moving toward automated layout deposition

The automation of the blade manufacturing process happens in stages and involves using different methods and hardware systems, including the following.

Cutting machines – The first change companies usually make is deploying cutting machines to replace scissors to enable faster cutting and kitting of the glass layup plies. This type of manufacturing aid is widespread in aerospace composites and other industries. It originated in the textile and garment industries. It results in more repeatable and accurate flat patterns. It most often includes using nesting software to nest the flat pattern automatically in the roll of material, which reduces waste.

Laser projection – Typically, the next step is the implementation of laser projection systems that can replace rulers and notches engraved in the tools. Laser beams are used to shine the position of the plies on the tool surface sequentially so that the operator knows where to lay down each ply. This technique is widely used in the aerospace industry to enable repeatability of a manual deposition process and some even feature automated verification of ply material, orientation, and foreign object detection for quality control of the laminates.

Robotic deposition – Many wind blade manufacturers (mostly in Europe) are devoting resources to finding more automated ways to make blades. Most of these advanced projects are highly confidential but information is filtering out from the machine system vendors that have started to demonstrate some of their technology at wind power exhibitions. These new systems are often expensive and will have to prove their return on investment to make inroads in an industry that so far has been largely guided by the principle of suppressing costs. Lessons can be learned from the aerospace sector where fibre placement and tape laying have become mainstream practices. However, there are great differences between the industries because a large wind blade and an aircraft wing have a very different shape, size and thickness, and require different materials and levels of quality. Both industries also have very different cost structures.

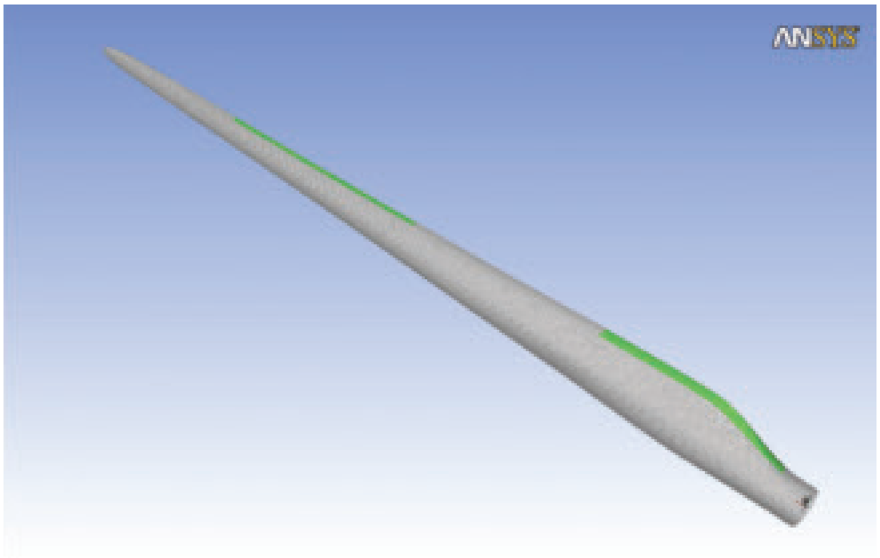

Figure 5: The integration of composite design and analysis has been a major advancement in recent years. Pictured here is a finite element model of a wind blade built with composites ply data from FiberSIM. Such data integration enables more accurate analysis and much faster and better optimisation of the blade's structural performance. (Image courtesy of ANSYS.)

software and services. Solutions such as VISTAGY's FiberSIM® composites engineering software are used by all the major aerospace companies and in many other industries, including automotive, jet engines, marine, and for manufacturing large wind turbine blades.

PLM-integrated software, such as FiberSIM, supports the entire blade design and manufacturing process. A single complete and detailed master model of the blade is defined, including all pertinent information on laminates, layup plies, core materials, fibre orientations, and thicknesses. This master model evolves from a preliminary and idealised definition used for early optimisation and trade off analysis, to a fully producible definition compatible with the manufacturing process. This kind of design environment acts as a window to the shop floor, allowing engineers to simulate the process of laying up the plies in the mould and visualising any potential manufacturing effects, including wrinkles, bridging areas and fibre buckling (Figure 4). Significant time is saved by using this virtual prototyping approach instead of the traditional build-and-break or rework methods.

Once the master model is fully completed and deemed producible, all the data required for production are seamlessly and readily exported to the machines and the technical documentation is automatically generated.

Integrating design and analysis

One challenging aspect of composite blade engineering is the iteration process between composite design and structural analysis. The stress analysts typically work with a simplified and idealised representation of the actual blade to suit their goal of assessing the behaviour of the blade with respect to loads, vibrations, failure, acoustics, and more. It is neither possible nor desirable at this stage to fully model all the details of the actual blade. On the other hand, the composite designer must incorporate into his or her detailed design model everything that pertains to assessing whether the blade can be manufactured, including individual plies, core, drop-offs, staggers, darts, and splices. The goal of the designer is to generate a composite blade definition that can be taken to the shop floor and be manufactured as designed without any late changes or rework.

Then it should not be surprising that trying to synchronise design with analysis remains a challenge. This issue was recognised more than a decade ago in the aerospace industry and has been elevated to a major issue in the composites engineering process. Much improvement has been made in recent years with specialised composites CAD applications, such as FiberSIM, being integrated with FEA software, including MSC Patran, ANSYS, and Siemens NX CAE (Figure 5).

Today, bi-directional composites data exchange is available and becoming a more common part of the advanced composite engineering process for wind blades.

Who will lead the way?

While the wind industry is growing, the three regions of the world are at different stages and are faced with varied challenges. Wind firms in the more mature European market are actively searching for more manufacturing automation and advanced composite design tools, while players in newer markets, such as China and India, are seeking more education. North America is focusing on cutting costs, improving quality, and ramping up production in the short term.

Even though these wind companies are starting from different places, the key for each is to move in a thoughtful and expeditious manner toward a true PLM-based engineering environment built around a hub of composites design and manufacturing software.

To accomplish that, wind firms will need to engage with companies that have a long record of accomplishment in the composites industry and can understand and fulfil the varied needs of manufacturers. Ultimately, the firms that can implement the most efficient composites engineering processes will lead the way in the wind energy industry. ■

Further information

VISTAGY Inc; www.vistagy.com