Development of composites manufacturing processes for large MW-scale wind turbine blades

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Abstract

This paper discusses the use of composite plastic materials in the manufacture of wind turbine blades. An overview of the design requirements of wind turbine blades is followed by an explanation of how composite materials can meet these requirements. Current manufacturing processes are explained, followed by recent advances and future developments in a number of areas. Advances in materials are discussed, followed by design and manufacture developments. The use of composite materials to deal with maintenance and reliability issues is discussed. Finally, developments in multi-section and modular blades is discussed. A number of approaches from different manufactures are discussed and a number of patents are looked at. Developments in each of these areas are required to meet this demand, but there is no consensus from manufacturers on the best way forward

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1. Introduction

Wind energy is a booming industry with more and more farms being developed each year. The three bladed horizontal axis wind turbine has become the industry standard design, and there are many competing companies developing wind machines and components.

Wind machines have gradually grown in size. 3MW machines are very common onshore, and 5MW - 8MW machines are becoming common in offshore projects. Companies are developing 10MW and larger turbines.

These machines generate more power by using longer blades - power generated by a wind turbine is proportional to the square of the diameter of the rotor, so an increase in blade length can significantly increase the power generated by a turbine. A 3MW Vestas V90 uses 44m long blades [1]. The Enercon E-126 is a 7.5MW machine with a rotor diameter of 127m [2], giving it an approximate blade length of 63m.

As the size of the blade increases, the blades must be made stronger and stiffer, while keeping the weight to a minimum.

Wind turbine blades have the following requirements:

Complex Shape: Wind turbine blades have a complex shape and curve in many directions along their length. Both the angle of attack and camber of the blade change along the length. The chord of the blade also reduces from root to tip. Some blades are also pre bent in an arcuate curve along their length from root to tip.

Lightweight: Wind turbine blades need to be as lightweight as possible. Higher weight increases the wind turbine's moment of inertia. If the blades can be kept as light as possible, particularly towards the tips, the moment of inertia can minimised. Less wind energy is then required to rotate the rotor and more energy can be extracted to generate electricity. Weight is also an issue when transporting blades.

Strength: High wind speeds produce high loads on wind turbine components. Blades must be strong enough to withstand these forces, both when in use and when not operating in storm conditions. Turbine blades must withstand many thousands of cycles of loading and unloading.

Stiffness: The blades must also be incredibly stiff to prevent them from hitting the turbine tower and to prevent vibrations in the blade.

Corrosion Resistance: Turbine components need to be resistant to the harsh environment where they are used. Wind farms are increasingly being sited offshore so blades must be resistant to corrosion from salt and airborne dust and sand particles. Any material used must also be UV stable to prevent it degrading over the lifetime of the turbine.

A number of other factors also need to be taken into account to reduce the overall cost of energy:

Ease of manufacture: With more and more turbine deployments each year, the number of blades required is increasing. Manufacturing methods must be improved to enable cheaper, quicker construction, while keeping quality high.

Transportability: Blades must be transported to hard to reach areas. Most blades are currently generally built in one long section. These long loads can be difficult and costly to transport.

2. Composite Materials

In this context, the term composite materials or composites refers to reinforced plastic materials. The composites consist of two different materials, a strong fiber material and a matrix material. Mixing the two materials results in a new material that shares the characteristics of both.

The fiber material typically comes in a mat or thread of fibers. Glass, carbon, aramid or natural fibers can be used.

The matrix material is a usually a thermoset epoxy or poylester resin in liquid form. Some composites use a thermoplastic matrix. These materials will be discussed later in this paper.

Stiffness can be added to the material by sandwiching a layer of lightweight foam or balsa wood between layers of fiber reinforced plastic [3].

Building with composites is an additive process - rather than cutting the required shape from a block of material, the material is added in layers to form the required shape. This makes composites suitable for the complex curved shapes needed in wind turbine blades.

Composite materials can be engineered to have superior strength and stiffness to other materials. Parts can be manufactured to have different properties in different locations by “strategically placing material and orienting fiber direction” [4].

Composite materials have been used in the marine industry for years. Unlike metals, they do not oxidise. Composite materials do degrade after prolonged exposure to UV in sunlight. Protective gel coats and other treatments have been developed to reduce UV degradation.

3. Current Manufacturing Methods

3.1. Open Moulding

In this process, a negative mould of each face of the turbine blade is built. The mould is first covered with a mould release agent, followed by a gel coat layer of polyester or epoxy resin. Next, a layer or laminate of glass fiber mat is applied. The glass fiber is fully wetted out with resin resin. Another layer of glass fiber is added, with the fibers running at 90°to the previous layer. This layer also wetted out. The next layer is laid at 45°to the last. The material is gradually built up in this manner.

Stiffeners and struts can be added where required. Most blade designs have a spar running along their length.

The resin sets and the half blade is removed from the mould. The two faces of the blade can then be joined together. Moulds are reused for each blade, ensuring that the blades are identical.

Open moulding or hand-layup is the simplest composite manufacturing method. It has been used for many years in many different industries and is ideal for short production runs as it does not require complicated tooling and a large investment like other methods.

Disadvantages to this method include [5]:

Lower quality laminates: The quality of the laminates depends on the percentage of voids (not wetted out areas) in the material. Open moulding is generally done by hand so the quality will depend on the individual operator.

Heavier components: Manually wetting out areas results in laminates with a high resin content. This means the components are heavier and more expensive than they need to be.

Environment, Health and Safety: Polyester and epoxy resins release volatile organic compounds (VOC's) that are dangerous to human health and harm the environment. As wetting out is a manual process, the operators may be exposed to a high level of VOC's.

3.2. Vacuum Moulding

The issues with open moulding and requirement of long production runs of turbine blades have resulted in manufactures moving to closed vacuum moulding techniques [5].

In this process, the fiber layers are laid out in a mould which is then closed and sealed. Air is removed from the mould. The resin is sucked into the mould by a vacuum, impregnating the fibers.

This process has a number of advantages including:

Safer for operators and environment: As the system is closed, the resin does not give off VOC's as it is curing. Operator contact to the resin is minimised.

Fewer voids: The vacuum sucks all the air from the mould, meaning the resin can better impregnate the fibers. Fewer voids result in a higher quality laminate with more predictable qualities.

Lighter: Resin quantities can be carefully controlled, preventing excess use. This results in a light, well balanced blade.

LM Wind Power has been using vacuum assisted resin transfer moulding (VARTM) since 1997 [6]. They highlight the flexibility and improved control of the process, fast throughput and safe working environments as advantages of VARTM over other technologies.

3.3. Pre-Impregnated Materials

Prepreg materials differ in that the fibers and matrix are combined before moulding. The matrix is applied to the fibers and it cures to a gel consistency. The material is kept at a low temperature to prevent it from curing. The material in this state is know as B-stage prepreg.

Prepregs are typically manufactured in sheets of material. During manufacture, the material is laid into a mould in the required number of laminates and shape. The material is then compressed and heated. The matrix cures solid and the component is formed.

Prepreg materials also come in tape form. The tape is wound around a mandrill (male mould) by an automated machine. This automated method is ideal for making cylindrical components. Patents exist that cover the manufacture of full blades in this way [7], but it is not commonly used to manufacture industrial scale blades.

Prepreg materials have a number of advantages including:

Ease of use: The material is already combined, eliminating a major stage of the manufacturing process.

Low void percentage: The impregnation of the fibers can be controlled carefully and voids can be eliminated.

Clean: The moulding process does not involve liquid matrix material, eliminating the messiest and most environmentally damaging aspect.

Consistency: The amount of resin in a prepreg material can be carefully controlled.

Automation: Use of prepreg materials can simplify automation of construction methods.

Disadvantages of prepreg materials include:

Cost: Prepreg materials are more expensive.

Lower shelf life: B-stage prepreg materials have a limited shelf life. Some materials need to be stored at lower temperatures.

Heat cure: Prepregs require higher temperatures to cure. Manufactures need to use autoclaves or heated moulds to cure prepreg components.

A number of prepreg manufactures are working with blade manufactures to supply suitable materials. Hexcel supply Vestas and have opened factories close to Vestas manufacturing sites in Colorado, USA and Tianjin, China [8].

4. Material Advances

4.1. Carbon fiber

Glass fiber (GF) is currently the most widely used fiber material. Carbon fiber based composites are lighter and stiffer than GF. These properties would make it ideal for construction of longer blades if it wasn't for the higher price of carbon fiber. Current manufacturing methods for carbon fibers are slow and energy intensive [9].

Carbon fiber is widely used in the aerospace industry. New planes from Boeing and Airbus use a lot of carbon fiber and there were concerns that manufacturing supply would not be able to meet demands. The aerospace companies can afford the higher prices [10], but some blade manufacturers believe it is not economically viable to extensively use carbon fiber in wind turbine blades. When LM Wind Power designed a 61.5m blade in 2007, one of the design requirements was to avoid using carbon fiber [10]. They managed to build the then longest blades in the world without this advanced material. Other manufactures such as Vestas and Gamesa currently use carbon fiber reinforcement spars in their blades [11]. Gamesa interleave layers of carbon and glass fiber in some areas.

As production of carbon fiber is scaled up, the price is likely to fall, making carbon fiber a more economically viable option.

4.2. Thermoplastics

A number of blade manufactures have researched the use of thermoplastic composites. These composites use a thermoplastic polymer as the matrix rather than the usual thermoset resin. Thermoplastic polymers melt and become viscous at high temperatures. The viscosity of thermoplastic polymers is less than thermoset polymers, meaning manufacturing techniques such as open moulding and vacuum moulding are not appropriate.

Thermopreg™is a trademarked glassfiber and polypropylene thermoplastic composite. Thermopreg™is made of commingled glass and polypropylene filaments [12]. It is supplied as a roll of material and can be formed by heating above the polypropylene melting point of 180°C - 230°C.

Advantages of these materials include:

Recyclable: Thermoplastic polymers are generally recyclable.

Durability: Thermoplastic composites are more durable and resistant to impact than thermoset composites.

Automation: Thermoplastic composite are suitable for a wider range of automated manufacture methods.

Éirecomposites Teoranta have researched these materials extensively, and currently produce a small turbine blade from Twintex™.

LM Wind Power also researched the use of these materials for their “Blade King” development program, but found that no thermoplastic composite is ready for production of large wind turbine blades [13].

Blade Dynamics have developed durable film made from a thermoplastic composite to protect the leading edge of their wind turbine blades [14].

Research into these composites continues and they may have a more significant role to play in the future.

5. Design and Manufacture

5.1. Computer Aided Design

Computer aided design tools such as computational fluid dynamics (CFD) and finite element methods (FEM) are used extensively to model blade designs, stresses and aerodynamic loads. The detailed analysis can give a clear picture of the composite properties required.

LM Wind Power also use software to simulate resin transfer and infusion in it's vacuum moulds [6]. This reveals areas where voids or dry spots are likely to appear and helps them optimize resin transfer.

5.2. Heated Moulding

Some composite manufacturing methods require high temperatures to cure the resin. Traditionally this is done by placing the part in an autoclave. This is not feasible for components as large as wind turbine blades. Some manufacturers have instead developed a method of heating and cooling moulds.

Éirecomposites Teoranta have patented a process to produce moulds containing heating elements [15]. The heating elements are embedded in a ceramic material, which is spread on a polymer composite. The ceramic material is heated past it's curing point and it sets to form a solid ceramic body. The polymer is then cured, bonding it to the ceramic. This results in a strong, durable, temperature stable mould with an operating temperature up to 230°C. They use these moulds to build 13m blades for the Vestas V27 [16].

Interestingly, LM Wind Power have moved from heated moulds to unheated moulds to save on capital and energy costs[10].

6. Maintenance and Reliability

Wind turbine blades are designed to move at high speeds for long periods of time. They are susceptible to damage from fatigue, erosion or foreign object strike. Repairing or replacing a blade is an expensive process, requiring machine downtime. In an offshore environment, gaining access to the machine is an issue, meaning a turbine could be shut down for long periods. The development of structural health monitoring technology could help predict and prevent catastrophic failures in blades. A number of new and emerging composite manufacturing technologies can help to reduce damage, reducing the overall cost of energy of wind power.

6.1. Self Healing Composites

Blades that can repair themselves after damage would offer a huge advantage to wind farm operators. A number of different groups are researching self healing composites. These materials are inspired by biological systems. Research from the the Wichita State University has produced a material containing microcapsules of polymerizable healing agent [17]. When a section of the composite is damaged, the healing agent cures and prevents crack propagation.

6.2. Leading Edge Blade Coating

The leading edge of the blades is most susceptible to impact damage and erosion. Many blade manufacturers are now offering leading edge protection as an optional add on. Blade Dynamics are proposing to use a durable thermoplastic film to protect the leading edge of their wind turbine blades [14]. This patented process is being marketed as Bladeskyn.

6.3. Lightning Protection

Wind turbine blades are susceptible to lightning strikes which can cause severe damage to the blade. A number of manufacturers have patented lightning protection systems. The LM Wind Power system consists of a lightning conductor running along the blade, with electrically conductive receptors embedded in the composite skin of the turbine blade [18].

7. Multi-Section Blades

Transportation of long wind turbine blades from the factory to the wind farm presents a unique challenge. Specialist haulage contractors with specialist equipment and careful route planning is required. The difficult logistics add expense to any wind farm project and increase the cost of energy. As wind turbine blades increase in size, this will be more and more of an issue.

Manufacturing companies are opening manufacturing facilities close to major markets to reduce transportation costs. Many companies are also researching multi-piece blades. These blades would be easier to transport and would be assembled on site.

General Electric [19], Blade Dynamics [20] and Vestas [21] are among the manufacturers that have patented methods to connect sections of blades together.

Blade Dynamics have developed a modular blade system [22]. The blade is assembled from a number of components, and each component can fit inside a 40ft or 80ft shipping container. Blade Dynamics have a number of patents on their technology. The main patent [20] describes a method of joining two sections of blade with a third, small connection piece. The method uses scarf joints and adhesives to form a strong bond.

Apart from better transportability, Blade Dynamics believe the modular system has many advantages including:

Quality Control: Manufacture of smaller parts can be more easily automated, helping to keep quality high. If a defect in a part is found, that part can be swapped out, rather than replacing the full blade.

Standardised Components: Components can be used in many different designs. Production of the standardised components can be more easily scaled up.

Blade Dynamics are currently testing a 78m blade built to their modular designs [23].

8. Conclusion

The industrial scale wind energy industry could not exist without composite materials. Composites can be engineered to have the required properties for wind turbine blades - high strength, high stiffness and light weight - at reasonable cost.

The requirement for larger blades is expected to continue. Advances in design, manufacturing techniques and materials are needed to meet the requirements of tomorrow's wind turbine blades. Manufacturers differ on the best route to achieve these larger blades. While Blade Dynamics are developing a modular system based on new technologies, Vestas are introducing more carbon fiber and LM Wind Power are concentrating on minor improvements to existing, well understood technologies. Each approach is a valid engineering solution and it remains to be seen which approach will be most successful.

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