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A Research over Recent Trends in Material selection of Wind Turbine Rotor Blades for Optimum Functioning

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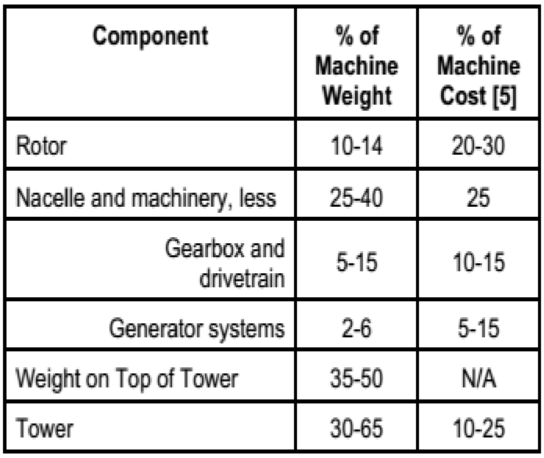
ABSTRACT:

Wind energy is renewable, pollution free and abundant in the earth and it can reduce the dependency on fossil fuel for energy requirement. Wind energy is different form of solar energy, and it will available till sun is available. Large amount of wind energy can be continuously generated from wind source, that's why large horizontal axis wind turbines are being installed to produce power, for more power extraction aerodynamic parameters associated with blade geometry and the material for blade are important, so in this paper we will discuss about the material selection for wind turbine rotor blades and the different materials available for the wind turbine blades manufacturing.

1. INTRODUCTION

The focus on Renewable Energy Resources has increased significantly in the recent years in the wake of growing environmentalpollution, rising energy demand and depleting fossil fuel resources.Different sources of renewable energy include biomass, solar,geothermal, hydroelectric, and wind. Among these resources wind has proved to be a cheaper alternative energy resource and hence extensive research efforts have been put to improve the technologyof electricity generation through wind. The world has enormouspotential of wind energy that can be utilized for electricity generation.In recent years, wind energy has drawn more attention due to the increasing prices of fossil fuels and improving economic competitiveness of wind turbines relative to conventional generation technologies. Today, wind energy has been developed into a mature, competitive, and virtually pollution-free technology. Usually a typical large, utility scale wind turbine can produce 1.5 to 4.0 million kWh annually and operates 70-85% of the time the wing shaped blades on the rotoractually harvest the energy in the windstream. The rotor converts the kineticenergy in the wind to rotational energytransmitted through the drivetrain tothe generator. Generated electricitycan be connected directly to the load orfeed to the utility gridThe weight and cost of the turbine isThe key to making wind energy competitive with other power sources, because research programs have significantly improved the efficiency of the rotor and maximized the energy capture of the machine. The real opportunity today is through better, low cost materials and though high volume production, while ensuring the reliability is maintained. The typical weight and cost of the primary turbinecomponents today are shown in Table 1.[1]



Component	% of Machine Weight	% of Machine Cost [5]
Rotor	10-14	20-30
Nacelle and machinery, less	25-40	25
Gearbox and drivetrain	5-15	10-15
Generator systems	2-6	5-15
Weight on Top of Tower	35-50	N/A
Tower	30-65	10-25

Table -1.1

There appear to be several areas wheretechnological progress and costreduction are needed. Turbinesubsystem costs are generally evenly split between rotor, nacelle, drivetrainpower systems, and the tower. There isno single component that dominatesturbine cost. The rotor is the highestcost item on most machines and mustbe the most reliable. Towers are normally the heaviest component and could benefit from weight reduction, but lightening the rotor or tower-top weight has a multiplier effect throughout the system including the foundation [2].

2. PARTS OF A TYPICAL WIND TURBINE

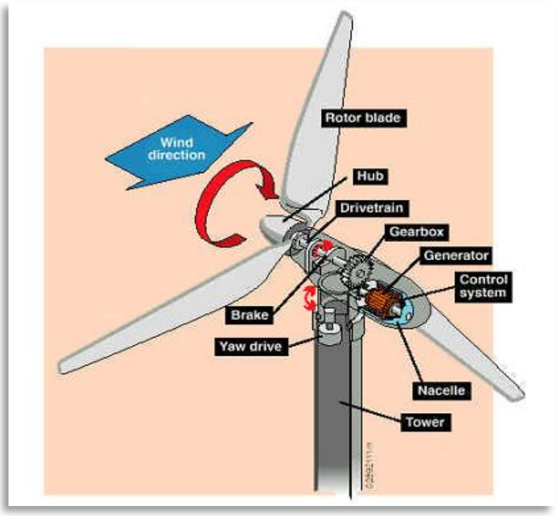


Fig. 1

1.1. Rotor

The rotor is the most important component in a wind turbine, designed to capture wind energy and convert it into rotating mechanical energy. The rotor should be strong enough to stand steady, periodicand randomly changing loads . The rotor assembly consists of several blades joined to a common hub, a cone nose and fasteners. The blades are critical components of the rotor, and consist of the airfoils which interact with the wind and convert the power in the wind to mechanical power. The geometry and dimensions of the blades are determined by the performance requirements of the wind turbine. Two fundamental issues must be considered simultaneously in blade design process: aerodynamic performance and structural design aerodynamically advantageous features such as sharp trailing edges are often so difficult to build that compromises must be made so that the blade design can be manufactured. The choice of materials and manufacturing methods for the blades should also be considered during structural design and strength analysis [2]

2.2 Generator

In all electricity generating wind turbines, a generator converts the mechanical power from the rotating wind blades to electrical power. Induction generators and synchronous generators are among the most common generators in large wind turbines . Most small wind turbines use direct drive generators, which are actually special synchronous generators with enough poles to enable generator work well at the same speed of wind turbine rotor . Because there is no gearbox required with these generators, the reliability of the system is generally better than when a gearbox is included. The Bergey XL 1.0 used in this study employs a direct drive permanent magnet alternator. Permanent magnets mounted on the interior surface of the rotating hub pass close to stationary coils mounted to the main frame. The changing magnetic field at the coils induces three-phase alternating current that is rectified to direct current by a rectifier in the nacelle (Bergey, 2012).

2.3 Nacelle

The turbine nacelle houses all the principal components of the wind turbine except the rotor.Within the nacelle, a main frame provides the backbone of the wind turbine; the bearings supporting the hub, generator, tail assembly and yaw bearings are all connected to it. A nacelle coverprotects these components from sunlight, rain, ice and snow.

2.4 Tail assembly

Most small wind turbines are pointed into the wind using a tail assembly. A tail assembly usually consists of tail fin and tail boom, which are the primary components of the yaw system, keeping the turbine pointed into the wind. Larger turbines generally dispense with a tail because as the turbine size increases, the weight and loads associated with a tail become excessive. Instead, most large turbines use an active yaw system in which geared motors point the turbine into the wind based on the readings of wind direction sensors mounted on the nacelle.In many small wind turbines, the tail assembly includes an auto-furling system. Furling is the most popular mechanism in small turbines to limit rotor speed, power output and wind loads in extreme winds. Furling is also used in the products of Bergey and Southwest Wind power. IN the turbines from these companies, the rotor is installed eccentrically with respect to the yaw axis (or vertical axis). The rotor thrust produces a moment about the yaw axis. Furling occurs if the thrust becomes too great: the rotor pivots relative to the tail fin, which is hinged where it joins the main frame, with the effect of turning the rotor to face away from the prevailing wind direction). When wind speed is below the rated critical point, the rotor is kept oriented to the wind; otherwise, furling will work to protect the rotor and generator [1].

2.5 Controller

Controller technology for wind turbines ranges widely from dynamic control systems to supervisory control systems and computer, which vary on different wind turbine systems. Small wind turbines can utilize a controller to covert the variable, noisy power from the generator into a steady direct current at an appropriate voltage for charging batteries.

3. MATERIALS FOR SMALL WIND TURBINE BLADE

The blades in a normally operating wind turbine rotor are continuously exposed to cyclical loads from wind and gravity. The expected lifetime for a blade is usually 20 years for large wind turbines, and less than 20 years for small wind turbines (Clausen and Wood, 2000). Based on these conditions, Brøndsted et al. (2005) summarized that the primary requirements for blade materials are high stiffness to ensure aerodynamic performance, low density to minimize massand long-fatigue cycles. In the wind turbine industry, many materials have been used for blades, including metals, plastics, wood and composites

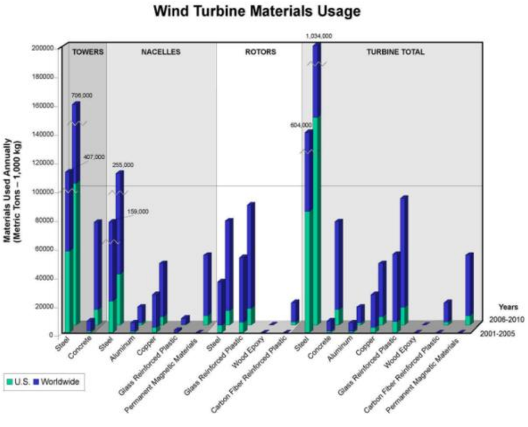


Fig 2

3.1 Metal

Steel is a common, relatively inexpensive material used extensively in industry, however, it is difficult to manufacture into a complex twisted shape, and the fatigue life of steel is very poor compared to fiberglass composites (Burton et al., 2001). While steel was used for wind turbines blades before the 1950s, it is essentially no longer used (Man well et al., 2002). Another metal that has been considered for wind turbine blades is wieldable aluminum. However, its fatigue strength at 10^7 cycles is only 17 MPa compared with fiberglass 140 MPa and carbon fibre 350 MPa (Burton et al., 2001). Aluminum was sometimes used for small wind turbine blades, usually to produce non-twisted blades by protrusion (Manwell et al., 2002). However, like steel, aluminum is little used in practice.

3.2 Glass and carbon Fiber Composites

While various materials have been applied successfully in wind turbine blades, fiberglass based composites predominate (Veers et al., 2003). This is mostly because fiberglass is a low-cost andhigh tensile strength material. It is also easily knitted and woven into desired textiles to meet different engineering requirements (Manwell et al., 2002). Usually the fibreglass is embedded within a plastic matrix to form a composite known as glass reinforced plastic (GRP). Carbon fiber is also becoming more popular because it has higher modulus, lower density and higher tensile strength than fiberglass and it is less sensitive to fatigue. However, carbon fibre is more expensive than fiberglass and it is difficult to align the fibres to maintain good fatigue performance (Veers et al., 2003; Manwell et al., 2002). Recently, there is increased use of hybrids combining glass and carbon together to achieve moderate mechanical performance with moderate cost (Veers et al., 2003; Brøndsted et al., 2005). Also fiberglass and carbon/wood hybrids are currently promising materials options for blades (Veers et al., 2003). In composite structures, matrix, also called binder, is the resin used to hold fibres in position and make the blade strong. The most common thermoset matrices are unsaturated polyesters, vinyl esters and epoxies (Veers et al., 2003; Brondsted et al., 2005). Thermoplastics were alsodeveloped in the past, however, the performance of these materials, such as PBT and PET, are lower than thermosets (Veers et al., 2003). At present, no commercial examples of thermoplastics being used for this engineering application has been found.

3.3 Wood and bamboo

Minimally processed natural biocomposites such as wood and bamboo are particularly appealingto make the blades environmental friendly. Wood had been used to make wind turbine blades for a long time because wood has good strength for its mass, as long as the direction of wood structure is placed right (Manwell et al., 2002). Also wood is widely applied in making wood epoxy laminates for large wind turbines, and reportedly none has failed in fatigue (Burton et al., 2001). Peterson and Clausen (2004) conducted fatigue testing on a 1 m blade for a wind turbine with rated power 600 W using two types of wood commonly available in Australia. The results illustrated that both radiate and hoop pine could meet the operational requirements, though there was difference in strength between the two woods. In addition, they predicted that wood should be suitable for blades for small turbines up to 5 kW capacity with 2.5 m blades. However, the manufacturing and selection of wood would be great problems, and it is very difficult to find wood with homogeneous quality free of knots (Peterson and Clausen, 2004; Wood, 2004). Bamboo is well known to have good mechanical performance: it has greater fracture toughness, greater specific strength and modulus than woods such as birch (Holmes et al., 2009). In addition, the processing cost is not high and bamboo grows quickly. Holmes et al. (2009) concluded that bamboo would be a good material for blade building. However, bamboo has to be incorporated into composites for wind turbine blade applications because single bamboo stalks are not big enough for a blade. In addition, the properties in different layers of bamboo may vary greatly, and there is a need for more tests to determine specific data [3].

3.4 Bio composites

The other method to utilize biomaterials is to develop bio composites. There are two main areas of research related to the use of bio composites in wind turbine blades. The first is to develop natural fibers that can partially or fully replace fibre glass. Thygesen et al. (2006) extracted natural hemp fibre whose stiffness is close to that of fibre glass, but the tensile strength is much lower. Brøndsted et al. (2005) thought that cellulose fibre would be the most promising material for future blades; the stiffness of cellulose fibre (80 GPa) is a little higher than fibre glass (72 GPa) whereas its tensile strength (1000 MPa) is much lower than fibre glass (3500 MPa) though the specific kind of cellulose fibre examined was not detailed (Brøndsted, et al., 2005). Nottingham Innovative Manufacturing Research Centre (NIMRC, 2011) also separated four natural fibresfrom flax, jute, hemp and sisal to test, however the final report on their study is not yet published. Frohnapfel et al. (2010) tested three types of nature fibres forcomposite of wind turbine blades [4].

4. ROTOR BLADE MATERIAL

A rotor blade is built up of the following elements:

• External panels - form the aerodynamic shape and carry a part of the bending load

• Internal longitudinal spars/webs – carry shear load and a part of the bending load, restrain the cross section against deformation and the panels against buckling.

• Inserts like bushings - transfer the loads from the panels and spars into the steel hub.

- lightning protection – carries a lightning hitting the blade tip to the root

• Aerodynamic brake – for some types of turbines with fixed pitch an aerodynamic brake is part of the protection system. The aerodynamic brake is typically the tip turning on a shaft.

Rotor blades are usually made of a matrix of fiberglass mats, which are impregnated with a material such as polyester, hence the term glassfiber reinforced polyester, GRP. The polyester is hardened after it has impregnated the fibre-glass. Epoxy is sometimes used instead of polyester. Likewise, the basic matrix is sometimes made wholly or partly of carbon fibers, which form a lighter, but more expensive material with a high strength. Wood-epoxy laminates are sometimes used in large rotor blades.

The design of the outer contour of a wind turbine rotor blade is based on aerodynamic considerations. The cross-section of the blade has a streamlined asymmetrical shape, with the flattest side facing the wind. Once the aerodynamic outer contour is given, the blade is to be designed to be sufficiently strong and stiff. The blade profile is a hollow profile usually formed by two shell structures glued together, one upper shell on the suction side, and one lower shell on the pressure side. To make the blade sufficiently strong and stiff, so-called webs are glued onto the shells in the interior of the blade, thus forming a boxlike structure and cross-section, see Figure 3 From a structural point of view, this web will act like a beam, and simple beam theory can be applied to model the blade for structural analysis in order to determine the overall strength of the blade.

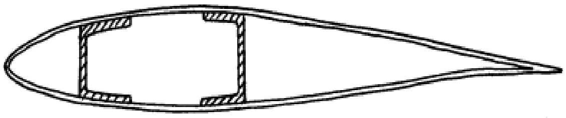


Fig. 3

It is important that the blade sections near the hub are able to resist forces and stresses from the rest of the blade. Therefore, the blade profile near the root is both thick and wide. Further, along the blade, the blade profile becomes thinner so as to obtain acceptable aerodynamic properties. As the blade speed increases towards the tip, also the lift force will increase towards the tip. Decreasing the chord width towards the tip will contribute to counteract this effect. In other words, the blade tapers from a point somewhere near the roottowards the tip as seen in Figure 4. In general, the blade profile constitutes a compromise between the desire for strength and the desire for good aerodynamic properties. At the root, the blade profile is usually narrower and tubular to fit the hub [5].

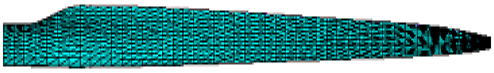


Fig. 4

5. PREPREG TECHNOLOGY

Prepreg is an abbreviation for “pre impregnation” where a fiber layer or fabric is impregnated with a resin to form a homogenous precursor that is subsequently used to manufacture composite components. The resins used to manufacture prepregshave inherently high viscosities and are therefore semi-solid at room temperature allowing easy handling, cutting, and lay-up into the mould without any transfer or contamination from the resin. Once in the mouldprepregs are then cured under vacuum at elevated temperatures, typically between 80 and 20 °C for industrial applications.

Prepregs are often supplied in roll format and provide the benefits of highly controlled resin content, higher performance resins than with infusion or wet systems, controlled fiber alignment in unidirectional products, and fast deposition rates and automation capability. However, as a consequence of the inclusion of higher performance resins, the requirement for chilled storage and shipping, and the additional processing step of “prepregging”, prepregs are more expensive per kg than the equivalent resin and reinforcement in an infusion process. Furthermore, the increased processing temperatures required for prepregs can also increase tooling costs.

5.1 PREPREG CHARACTERISTICS

When defining the properties and characteristics of an infusion resin the main focus is around the viscosity and reactivity of the product as a function of temperature. Thermal and mechanical data is also provided on some standard fabrics at a range of cure temperatures to enable comparison to other resin systems. With prepregsthe viscosity and reactivity during processing are also key characteristics, and mechanical and thermal properties can be easily defined for the specific prepreg, but there are also some additional handlingparameters to consider.DrapeThe process of combining a high viscosity resin with the fiber/fabric makes a significantdifference to the ability of the fabric/fiber to conform to amould surface geometry. The ability of a prepreg to conform to a mould surface is known as drape and is dependent on the fabric/fiber architecture (fiber types, orientation, stitching pattern etc) and the resin chemistry. If there is insufficient drape in a prepreg problems can arise during lay-up as the prepreg plies will form bridges over details trapping large volumes of air in the laminate reducing the final part quality. Unlike the infusion process, these large voids won’t be filled in with additional resin as the volume of resin is predetermined in a prepreg laminate. Drape is also strongly dependent on temperature and therefore the minimum working temperature of a workshop needs to be considered when specifying the characteristics of the resin system.

5.2 TACK

Although the resin used in prepregs is generally semi-solid at room temperature, the surface of the prepreg will have some level of “stickiness”. The level of tack is somewhat subjective when measured by hand, but at the extremes a low tack prepregwould exhibit no stickiness even when applying considerable pressure, and a high tack prepreg would transfer resin to the finger on contact without significant pressure. The tack will vary considerably from one prepreg to another due to the resin content, the fibre and fabric type, to variations in resin formulation, and to variations in workshop temperature. In order to obtain a consistent tack level and subsequently a stable lay-upprocess, it is usual to air condition the production area where the prepreg will be laid into the moulds and consolidated under vacuum.In general tack is beneficial to enable the prepreg to adhere to the mould surface and to subsequent plies during the lay-up process. If the mould has vertical surfaces a higher level of tack will be required to ensure the prepreg remains adhered to the mould. Excessive tack can lead to problems with removal of the protective PE/PP backers and repositioning of plies.

Flow

During the cure of the component the resin in the prepreg reduces in viscosity as the temperature increases. This enables the resin to flow creating seamless bonds between adjacentprepreg plies but also allows some air to be displaced from the laminate into the vacuum system. Resin flow is also essential to form good adhesive bonds with other materials such as gelcoats at the mould surface and the large volumes of core material insandwich structures. Flow is primarily a function of viscosity and therefore the viscosity profile of a resin system is a key material characteristic of a prepreg. A typical viscosity profile as a function of temperature is shown in the Figure below.

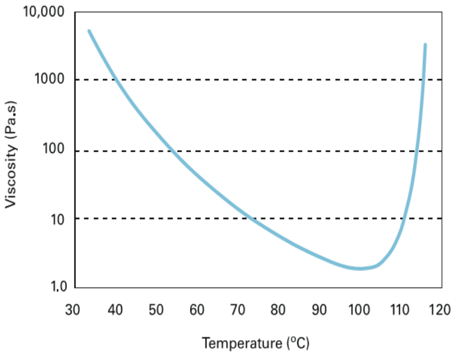


Fig 5

5.3PREPREG PROCESSING

Prepreg is designed for the manufacture of monolithic (prepreg only) and sandwich (prepreg and core) composite structures and is generally processed using either atmospheric vacuum bag technology or by autoclave. The autoclave (pressured oven running at 6 atmospheres) approach is used extensively in the aerospace industry but is expensive due to the capital intensity of the autoclave equipment. Autoclaves also become prohibitively expensive for very large components. In recent years there has been significant progress in achieving very high quality laminates in large structures without the use of autoclaves and this has been primarily due to advances in prepregtechnology such as SPRINTand SparPregTM. For most industrial applications prepregis processed using standard vacuum bag techniques and atmosphere of pressure to enable rapid cycle times on relativelylow cost moulds.Prepreg Lay-upPrepregs are transported and stored at low temperatures to preserve their outlife. Therefore, before application the prepreg rolls have to be conditioned or ‘tempered’ to return the whole roll to room temperature. This has to be done with the protective packaging in place as condensation can contaminate the material. The prepreg is then cut to shape, with its protective backers intact. The prepreg is then transferred to the mould and the first backer removed before being tacked against the mould surface. The ply can be moved if required as the tack is designed to allow replacement and small adjustments. The second backer on the first ply is only removed when the second ply is ready for application to prevent contamination. Special attention is required to ensure that each ply of material goes down as flat as possible without any bumps or creases, and that there are no bridges formed around details like core edges. For sandwich structures core kits are tacked onto the first layers of prepreg before additional prepreg plies are applied over the top of the core to create the second skin. The Vacuum StackOn completion of the lay-up of the prepreg (and core for sandwich structures) a nylon peel ply is immediately placed across the entire surface of the laminate to prevent any contamination of the prepreg. The peel ply is used to remove the vacuum stack from the laminate after cure and also provides a suitable laminate surface for subsequent bonding operations.The peel ply is followed by a perforated release film that is used to control the flow of the resin during the early stages of the component cure. The size and frequency of the holes in the film are selected to match the flow characteristics of the resin system. A degree of flow is required to create a high quality laminate and ensure secondary elements such as core and surface gelcoats are well bonded to the prepreg. However, excessive flow can be detrimental to the quality of the component as too much resin is removed from the laminate creating dry areas [6].

6. SPRINT TECHNOLOGY

6.1 INTRODUCTION

SPRINTis a prepreg product group that was developed specifically for large structures. Aslaminate thickness began to increase withincreasing component size, the problem of removing entrapped air between prepregplies became significant. The figure below shows how the inter-ply voiding can increase in a simple UD laminate constructed of individual plies of 600g UD glass prepreg.

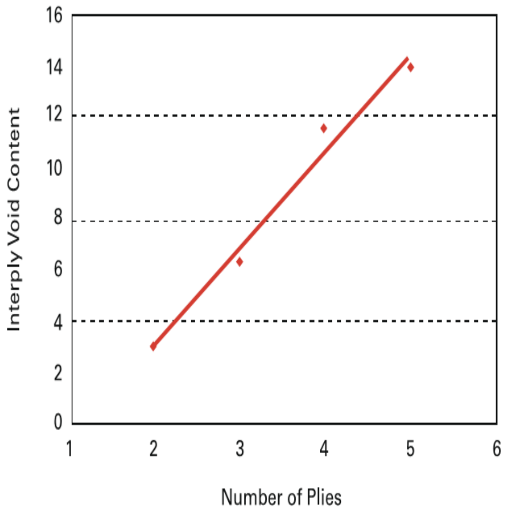


Fig 6

This could be overcome by debulking the laminate after the application of every 3-4 plies, i.e. applying a vacuum bag and increasing the temperature to around 40 °C. However, this approach is prohibitively expensive and time consuming for a component that is manufactured in high volumes and at minimal cost. Therefore, to overcome the issue of removing inter-ply air between adjacent layers of prepreg, SPRINTmaterials were enveloped.SPRINTdiffers from conventional prepreg in the way the fibers and resin are combined. In a conventional prepreg the fiber is fully impregnated by the resin, but SPRINTkeeps thefibers as dry as possible especially the outer surfaces. SPRINTcan come in a number of formats but the mostcommon are the “double sided” (two dry fabrics on either side of a resin film), and the “single-sided” (one dry fabric joined to a resin film)

6.2 THE SPRINT CONCEPT

SPRINTis a product group that combines the advantages of both infusion and prepregtechnology. The infusion process is capable of producing very thick, high quality laminates (air free), in a single operation. However, the process variability can become a major problem for large structures as the resin has to be moved over considerable distances. The prepreg process utilizes higher performance resin systems, allows accurate fibrealignment, provides accurate resin content in the final component, but is limited by its ability to remove the air in thick laminates. SPRINTis an acronym for SP Resin InfusionTechnology as it uses advanced prepreg resin technology to infuse laminates structures.

As the resin is supplied within the reinforcing material the infusion process occurs primarily in the z-coordinate direction (perpendicular to the mould surface), enabling large structures to be infused almost instantaneously. The infusion is facilitated by the application of a vacuum which is connected directly to the laminate. The vacuum evacuates the air from within the reinforcing fabric, and care is taken to ensure all SPRINTplies are properly interconnected. With the vast majority of the air removed from the laminate stack, the temperature is then increased to enable the resin to flow and infuse the reinforcing fibres.Single-sided SPRINT®

6.3 SPRINT MANUFACTURE

The manufacture of SPRINTuses the same building blocks as conventional prepreg; high performance resins with latent catalysis, reinforced fabrics, paper carriers, and polyethylene protective films. The fundamental difference between the manufacture of conventional prepregs and SPRINTis that the SPRINTproduct does not undergo the impregnation process. The resin film and fabrics are joined together using a small amount of contact pressure ensuring that wet-out of the fabric is minimized. SPRINT CharacteristicsMany of the characteristicsof SPRINT materials are comparable to those of prepregas they use the same fundamental building blocks. However, as the fibres are notimpregnated there aresomesignificant differences in the storage and handling of these materials.

6.4 DRAPE

The SPRINTformat provides a significant increase in the drape capability compared to itsprepreg counterpart (drape definition is provided in Prepreg Characteristics section). This is because the resin and fibre interactions are limited to the interface between the resin and the fabrics. The increased drape allows for improved conformance to the mould surface and reduces laminate defects like bridging.

6.5 TACK

In principal SPRINTproducts have no tack as the resin is concealed at the centre of a 3 layer sandwich? However, for some lower areal weight fabrics there will be gaps through which the resin can pass to provide some small amount of tack. However, this does not affect the performance or functionality of the SPRINTas the fabrics are still dry enabling air connections and subsequent air evacuation during processing. For some SPRINTapplications, some level of tack is desirable and in this instance a light weight tack film is applied to the surface of the SPRINT.In the case of single-sided SPRINTproducts (one fabric layer, one film layer) the resin layer is exposed and therefore the tack must be carefully formulated to enable easy handling and lay-up.

6.6 FLOW

Flow is a very important characteristic of a SPRINT material as its air breathing functionality is directly affected by the flow characteristics of the resin, especially at room temperature [7]. The relevance of flow at room temperature is defined in a separate SPRINTLife" characteristic below. Once the SPRINT material has been infused, typically at temperatures from 30-50 °C, the flow characteristics of the resin are very similar to those of a prepreg.SPRINT lifeThe functionality of the SPRINT product is provided by the dry fibers in the fabric. Therefore it is essential that the fabrics are maintained in the dry state prior to processing to provide the desired high quality laminates. Standard prepreg resins are not designed to resist small amounts of flow at room temperature and therefore SPRINTresins are modified to ensure that fiber wet-out does not occur. However, even at room temperature the SPRINTmaterials will begin to wet-out due to the pressure exerted on each layer of SPRINTwithin a roll. Therefore, for long term storage of SPRINT materials, chilled transport and storage is required as the SPRINT-life at ambient can be expected vary between 5 and 28 days depending on ambient conditions and product format [7]

6.7 OUT-LIFE

SPRINTresin systems are catalysed in a very similar way to resins used in prepregsand therefore the out-life requirements of SPRINTare the same as those for prepreg [8].

CONCLUSION

In this review paper we have discussed about the different wind turbine blade materials available for use and the recent technology for making the wind turbine blades and updates about wind turbine blade materials. There are several different materials and techniques are available for the wind turbine material but we discuses here some recent of them to aware and update the blade manufacturing area for wind turbines.

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