Composite materials for wind power turbine blades

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Energy is an essential ingredient of socio-economic development and economic growth. Renewable energy sources like wind energy is domestic and can help in reducing the dependency on fossil fuels. Renewable energy resources, of which wind energy is prominent, are part of the solution to the global energy problem and reduce the CO₂ emission. Wind turbine and the rotorblade concepts are reviewed, and loadings by wind and gravity as important factors for the fatigue performance of the materials are considered. Composites are discussed as candidates for rotor blades. The fibers and matrices for composites are described, and their high stiffness, low density, and good fatigue performance are emphasized. This presentation will explore properties of carbon fiber, the advantages/disadvantage between CFRP and competitive materials as GFRP.

Keywords: airfoil, wind turbine blade, carbon fiber, composites, CFRP, power

1. Introduction

Windmills have been assisting mankind to convert the energy contained in wind to many other useful forms for the last three thousand years. In the early 70s, the serial production of GRP (glass-fibre reinforced plastics) rotor blades a length of 17 metres was developed on small systems, starting in Denmark. In the initial phases, the achieved performance was approximately 10 kilowatts but now we are able to attain magnitudes of 8 to 10 Megawatts. Today’s wind turbines are capable of converting a great amount of energy in the wind into electricity. This is due to blades which are developed using state-of-the-art aerodynamic analysis and other performance-enhancing equipment. The wind turbine performance improvement is the key to increase the length of the blade. The wind blades to make are needed extremely high loads, high stiffness and high-strength structural materials. The environmental load of electricity produced from wind power generation is the most favourable, so you can expect a bright future.

2. The wind blade functions

Main components of wind turbines:
- Rotor – generates aerodynamic torque from the wind
- Nacelle – converters the torque into electrical power
- Tower – holds nacelle and rotor blades up in the wind and provides access to the nacelle
- Foundation – ensures that the turbine stays upright

The presentation mainly focused on the turbine blade.

If the blowing wind can turn the blade, we will receive electricity from the generator that is attached to it. A lift force is produced when air moves over an airfoil (Bernoulli-equation) (Fig. 1).

Fig. 1.

The pressure difference on the airfoil makes the wind turbine blade turn. This way the wind turbine achieves the basic rotation. Wind turbine blades turn at a very low rate of rpm. So before the low speed shaft connecting to the generator the speed is increased in a gearbox (planetary gear set, speed ratio ~ 1:90) to achieve the high speed ratio. The moving wind turbine blade also experiences the relative wind velocity as is shown in Fig. 2. [12].
As the blade velocity increases to the tip the relative wind speed become more inclined towards the trip. The blade has a lot of air foil cross-section consisting of different sizes and shapes from the root to tip. This means by the manufacturing that a continuous twist is given to the blade from the root to tip. Therefore the wind turbine is positioned in a pitched manner in order to align with the relative wind speed.

Wind turbine always be aligned with the wind direction. Wind velocity sensor on top of the nacelle measures the wind speed and direction. The deviation in the wind’s direction yawing mechanism to correct the error (picture). According to the wind speed the relative velocity angle of the wind also changes. A blade pitching mechanism turns the blades and guarantees a proper alignment of the blade with the relative velocity. Thus the blades are always at the optimum angle of attack with the relative wind flow. Pitch control mechanism keep the rotation speed of a turbine constant for changing wind speed. This is necessary to keep the rpm of the generator constant.

The swept area increases by approximately the square of blade length. Spinning blades cause wind behind turbine to rotate. Faster moving blades tip cause less rotation and have less wake rotation losses. The longer the turbine blades to achieve the goal.

3. Wind turbine power

The wind power depends on the wind speed. During excessively windy (cut off speed ~ 80 km/h) the brake arrest wind blade rotation (Fig. 3).

The power of the wind turbine

\[ P = \frac{1}{2} \eta \rho A v^3 = \frac{1}{2} \rho \pi r^2 v^3 \]

where:

\[ P \] – Performance of wind turbine,
\[ \eta \] – Efficiency of wind turbine,
\[ \rho \] – Air density (1.2 kg/m³),
\[ A \] – Swept area of wind turbine (A = L²\(\pi\)),
\[ L \] – Length of blade,
\[ v \] – wind velocity.

To gain a good insight into wind turbine efficiency assume that you are measuring wind speed at upstream and downstream over wind turbine. The wind speed at the downstream is much smaller than the upstream because the blades absorb some kinetic energy from the wind.

The efficiency of wind turbine (\( \eta \)): Energy out/ Energy in.

The concept would also allow the blades to spread out when the wind is blowing lightly to capture as much power as possible.

A portion of the kinetic energy of wind the turbine blades converts the torque work (M= F x r). The wind turbines theoretically of the wind kinetic energy is 59.26% (Betz's law) exploits (Fig. 4).
The ability to "add a few meters" to a wind turbine blade set is far from simple. Theoretically, blade weights increase as a cubic function of blade length when similar designs and processes are used. The use of alternate materials, most notably carbon fiber, can help reduce the weight penalty associated with increasing blade length.

4. The wind blades loads

The main load of blades is the aerodynamic load in flap wise direction. This trust force produces the torque, so a power. The turbine blade sheet is parallel to the rotation sheet to blades. The high loads due to the blades tip moves toward the tower. The blades collision to the tower can be eliminated with a large sheet directional rigidity of blades (Fig. 6) [8].

The plane of the turbine blades are parallel to the rotating basis. The high load causes the blade tip is moved towards the turret. The collision of a large tower paddle board directional stiffness eliminated. The other loads on the blades made the gravity in edgewise direction (Fig. 7).

5. CF and CFRP features

Lightness the key to the future. There is virtually no alternative to lightweight constructions: carbon fibres, the black wonder fibres that are superior to steel and aluminium in almost all respects when it comes to cutting weight. And, in terms of stability and lightness, carbon-reinforced plastic is simply unbeatable. The aerospace, automobile and wind-power industries have been aware of this and have been using...
carbon fiber reinforced polymer for many years. Without it, much of what we nowadays regard as given – from Formula 1 racing cars, via the Airbus A350 to the innumerable large wind turbines – would not be possible. The quantity of CF (Carbon Fiber) to other structural material is a little, but many specific area key important (Fig. 9).

The global Carbon Fiber market

6. Carbon fiber

The excellent mechanical properties of composites with a thin fibrous materials in the array relative to a significantly higher strength and, secondly, in accordance with the load direction are arranged in a large number of matrix imbedded fiber structure (anisotropic) results (Fig. 10) [1].

<table>
<thead>
<tr>
<th>Material</th>
<th>Density, p, g/cm³</th>
<th>Strain, E, %</th>
<th>Tensile strength, MPa</th>
<th>Spec. tensile strength, GPa</th>
<th>Tensile stiffness, E, MPa</th>
<th>Spec. tensile stiffness, GPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon fiber</td>
<td>1,8</td>
<td>0,5-1,5</td>
<td>3600-7000</td>
<td>150-380</td>
<td>200-900</td>
<td>12-28</td>
</tr>
<tr>
<td>Glass fiber E</td>
<td>2,6</td>
<td>2,5</td>
<td>2450</td>
<td>60-90</td>
<td>70</td>
<td>2,7</td>
</tr>
<tr>
<td>P-Aramid</td>
<td>1,44</td>
<td>3,5-5,2</td>
<td>2900</td>
<td>180-250</td>
<td>60-120</td>
<td>5-10</td>
</tr>
<tr>
<td>Steel</td>
<td>7,8</td>
<td>1,8</td>
<td>1500-2800</td>
<td>20-36</td>
<td>200</td>
<td>2,6</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2,7</td>
<td></td>
<td>70-700</td>
<td>18-36</td>
<td>70</td>
<td>2,6</td>
</tr>
</tbody>
</table>

7. Carbon fiber production and characteristics

Most of the carbon fiber is used reinforced composite. The growth of demand and production capacity of carbon fibers is shown in Figure 11.

The structure of carbon fiber from the atomic structure to the composites are shown in Fig. 12.

The engineering practice previously used for steel, the strength and stiffness values given in pascals (N/m²). The density of composites more lighter than steel, so advisable the specific strength (free breaking length) and specific stiffness to use (Fig. 12) [2].
The properties and the price can be very different in the different types of carbon fiber (Fig. 13).

**8. Composites properties**

Composites differ from traditional materials in that composite parts comprise two distinctly different components — fibers and a matrix material (most often, a polymer resin) — that, when combined, remain discrete but function interactively to make a new material, the properties of which cannot be predicted by simply summing the properties of its components. In fact, one of the major advantages of the fiber/resin combination is its complementary nature. Thin high-tech fibers, for example, exhibit relatively high tensile strength, but are susceptible to damage. By contrast, most polymer resins are weak in tensile strength but are extremely tough and malleable. When combined, however, the fiber and resin each counteract the other’s weakness, producing a material far more useful than either of its individual components (Fig. 14).

**9. Wind blade architecture, the spar caps structure**

In many areas, the rapidly growing use of CFRP production of wind blades to dominate the field (Fig. 15).
Reinforced Polymer) with UD (Uni Directionally) fiber orientation. Wind blade is some of the world’s biggest constructions (fig. 16).

Fig. 16

Global wind installations were 54.6 GW in 2016, some 14% lower than the record 63.6 GW installed in 2015. In 2016 to implement the ten largest wind turbine capacity increase investment in the country’s pie chat illustrated.

10. Market characteristics of wind turbines

Global wind installations were 54.6 GW in 2016, some 14% lower than the record 63.6 GW installed in 2015. In China, the most active wind power market, annual wind installations fell from 30 GW in 2015 to 23 GW in 2016 (fig. 16).

The wind turbines can be placed on land (onshore) at sea (offshore fix and float). The greatest wind blade (d=180 m) constructed offshore, the water depth 10-50 m. By countries wind power capacity in 2015 and has an installed capacity shown in Fig. 18.

Fig. 17

The world wind power capacity and the increase of the annual variation in the 17. Figure illustrates [10].

Fig. 16

Europe wind investments rise 5% on offshore surge. Europe's total installed wind capacity was 153.7 GW at the end of 2016. Wind power provided 10% of Europe's power last year (Fig.19).

Fig. 18

Fig. 19
11. Conclusion

To lower the cost of energy from wind turbines, designers have focused on the power-generating capacity of each turbine. Carbon fibre-reinforced plastics make it possible to create even larger and better optimised rotor blades for wind power systems. They have lengthened blades to capture more wind. The size of these gigantic blade length has increased 10 per cent annually and doubled approximately every seven years. Automated manufacturing processes will be further developed to reduce costs and improve quality. Further, performance, aerodynamics and aero acoustics will also be improved. And we will have large, divided blades which will enable the challenges of transportation and installation to be solved more easily.

References

[12] www.google.hu How do Wind Turbines work?