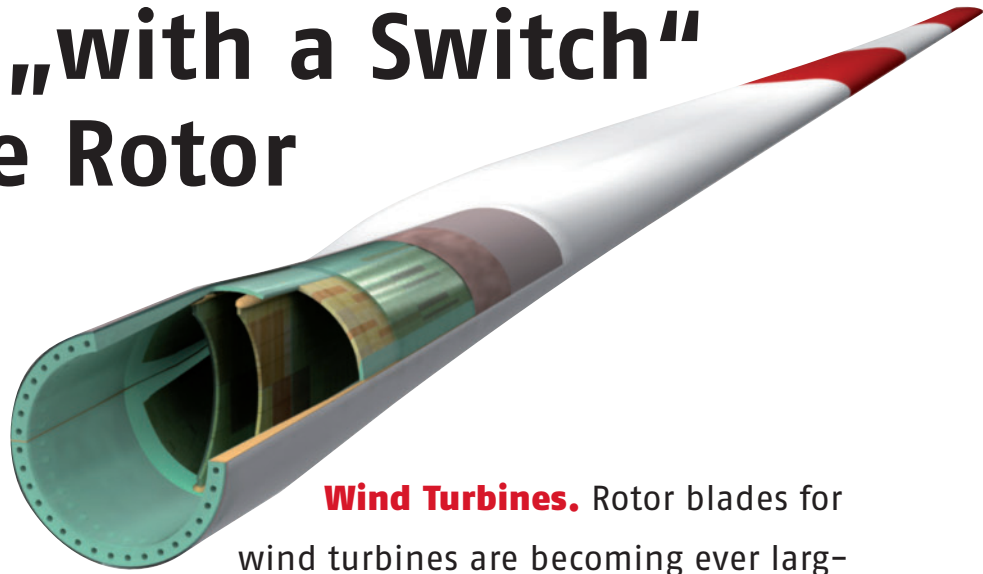


Hardeners „with a Switch“ Improve Rotor Production

A rotor blade of a wind turbine
made from fiber-reinforced epoxy
resins (all photos and references: BASF)



Wind Turbines. Rotor blades for wind turbines are becoming ever larger

and heavier. In spite of these weight increases the technological limits have nowhere near been reached. The necessary material properties can now be achieved using innovative fiber composite materials based on epoxy resin systems. A specially optimized hardener system also allows for significantly shorter cycle times and so increases productivity.

GREGOR DAUN

The boom in wind energy generation continues unabated: At the end of 2008 wind turbines with a total capacity of 120 gigawatts (GW) were operational worldwide, compared to 2007 that represents an increase of nearly 30 %. In their report “Offshore Windparks in Europe” the accountancy company KPMG came to the conclusion that “the wind energy industry is currently the sector with the most dynamic growth worldwide”. There are already 80 countries that use wind for electricity generation. According to the estimates of the World Wind Energy Association (WWEA, Bonn, Germany) wind power already generates more than 1.5 % of total electricity production. Germany occupies first place followed by the USA, Spain, China and India. These countries account for three quarters of the capacity installed. The WWEA believes that it should be possible to meet the complete electricity requirements of the world population with wind and other renewable resources by

2040. According to this a rapid expansion of wind energy would be the correct answer to the current financial crunch and ongoing energy crisis.

At the moment two trends dominate the development of wind energy – turbines are growing ever larger in order to generate more power at individual locations and wind power is moving offshore. Repower and Enercon are the first manufacturers to offer 5 and 6 megawatts (MW) output respectively. Rotor diameters are correspondingly impressive. The Repower 5M has a rotor diameter of 126 m with the individual rotor blades being 61.5 m long. The Enercon E-126/6 MW has similar dimensions: rotor diameter 127 m, blade length 58 m. However,

these immense dimensions are apparently not the limits of what is possible. Enercon is already investigating whether, based on the E-126, 8 MW of output can be achieved. Other designers are currently considering 10, 12 or even 15 MW. The target for 2020 is 20 MW. It is precisely this vision which the European project UpWind, which started in 2006 and will run until 2011, is following. UpWind is the most important project for European research cooperation in the field of wind turbine development. The new giants are intended in particular for offshore use because there the wind blows more strongly and consistently.

Rotor blades are growing ever bigger since a blade with twice the length covers an area that is four times the size and thus can capture four times as much energy. At the same time a blade with twice the length is generally four times as heavy. Whilst a 30 meter blade weighs 4 to 5 tonnes, a 60 m one weighs in at nearly 20 t. In spite of these increasing weights, particularly through the use of new materials such as carbon fiber composites the technical limits have nowhere near been reached. There are design concepts for 70 m blades and test rigs for blades of up to 90 m. At around 60 m in

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length the possibilities for glass fiber reinforcement have been pretty much exhausted. Beyond this carbon fibers are more often used, but they cost around five times as much.

Epoxy Resins Open the Way for Larger Rotor Blades

However, the limits at the top end are not set by the materials. The real reasons are economic in nature since the profitability of a turbine only increases to a limited extent with rotor diameter. Larger turbines are of course more efficient, but also more expensive to transport and erect so that their profitability is influenced by many factors that have great significance in rotor construction. In order to address these challenges BASF, Ludwigshafen, Germany, has developed tailor-made epoxy resin systems for the manufacture of large dimension rotor blades that have in the interim been approved by Germanischer Lloyd.

In Europe offshore expansion plans are now playing an important role in many countries. The report "Delivering Offshore Wind Power in Europe" by the Eu-

placed by more resilient materials based on epoxy resins in order to reach the necessary material properties for rotor spans in excess of 100 m. BASF has now succeeded in developing innovative epoxy resin systems that on the one hand allow the long production processing phase of ever larger rotor blades and on the other hand deliver short curing times in order to reduce cycle lengths. In this way individual cycles can be reduced by around 30 %.

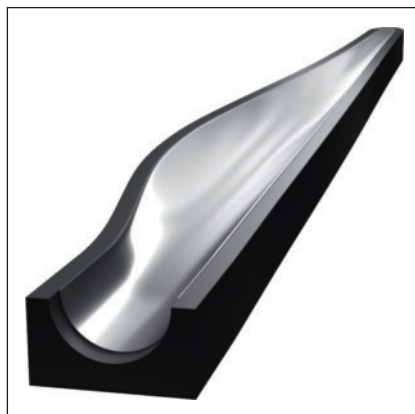


Fig. 1. A mold for producing fiber-reinforced rotor blades

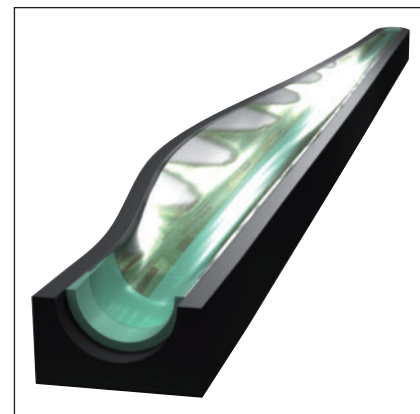


Fig. 2. Fiber mats impregnated in a mold with epoxy resin



Fig. 3. The outermost layer of the hollow blade fulfills the aerodynamic function

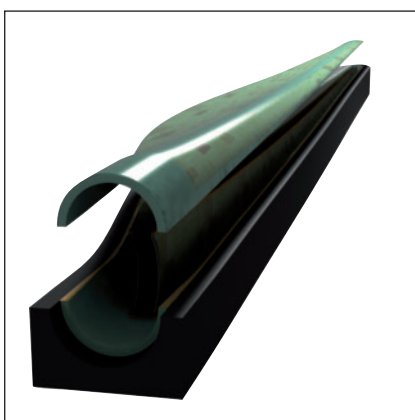


Fig. 4. Final assembly of the two cured halves of a rotor blade

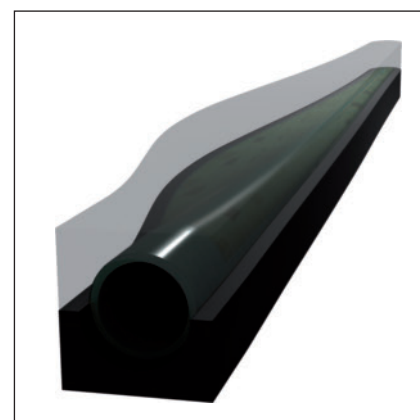


Fig. 5. Manufacture of a blank rotor blade in a closed mold

ropean Wind Energy Association (EWEA, Bonn, Germany) predicts that by 2020 wind farms with around 20 to 40 GW of capacity will be connected to the grid. By the end of 2008 plants with a capacity of 373 MW had been installed and this year is supposed to see 1,050 MW with continued breakneck growth after that. Siemens Wind is expecting new installations with a total capacity of 4,200 MW to be put up in 2014.

Against this background material suppliers face clear challenges, particularly for the manufacture of rotor blades. This has seen conventional polyester resin based composites increasingly being dis-

The forces that act even on a 40 m blade are enormous. Alongside weight loads of around 70 kN, which is the equivalent of 5 VW Golfs, and the rotational speed dependent outwards acting centrifugal force it is particularly the tangentially acting wind forces, which are dependent on wind speed, that can produce flexural moments of some 6,000 kNm at the blade root, the equivalent of the leverage of eleven VW Golfs on the blade tip. In order to meet these requirements it is epoxy resin systems that are predominantly used and in which mainly glass fiber mats are used for reinforcement. Rather than being woven together these

layers are stacked next to one another or in multiple layers and bound with a few threads in order to minimize bending of the fibers. Alongside this carbon fibers are also used, however in much smaller quantities as they are not only more expensive but also only available in limited quantities. Other materials such as aramide or basalt fibers have played no part as yet. In the manufacture of large blades the fibers or fiber mats are soaked with two fluid components, the resin and hardener that

react with each other after heating in a mold to form a very strong polymer. The complete system comprising the matrix and fibers makes a fiber composite material that delivers the necessary mechanical stability.

Latent Hardener Systems Raise Productivity

There are four principle techniques for impregnating the fibers. In laminating the dry mats are impregnated manually one after the other using rollers dipped in the epoxy resin systems. Infusion technology uses a vacuum to suck the epoxy resin sys-

tems into the dry mats laid up in the mold (Figs. 1 and 2). The third possibility is to soak the mats outside the mold and let them pre-cure before laying them in semi-rigid form in the mold for final curing (prepreg technology). For round and long components the fibers are impregnated and wound onto a mold before being cured using thermal energy (filament winding technology).

Using these four technologies it is normally possible to manufacture all of the main components of a rotor. This includes in particular the thick multi-layer blade root that transfers the force to the hub as well as the internal spars and spar caps that take up the major part of the

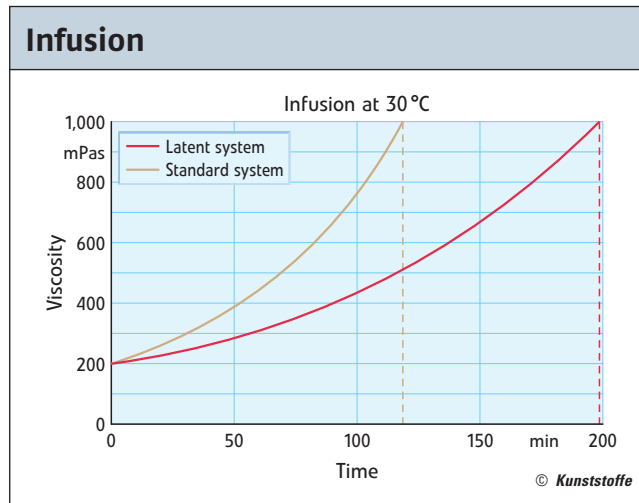


Fig. 6. Latent hardener systems allow for faster infusion of the epoxy resin in the mold and a longer pot life than a standard system

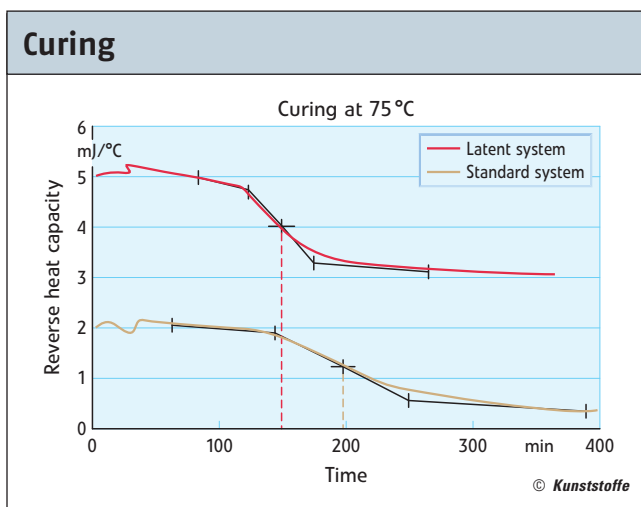


Fig. 7. The latent epoxy system cures faster than a comparable standard system

forces acting along the length of the blade (Title picture). The third component is the outer layer (Fig. 3) of the in principle hollow blade that fulfills the aerodynamic function and is either cast along with or bonded to the root and internal structure (Figs. 4 and 5).

The modern infusion systems used in the wind energy sector are comprised of two parts, the resin and a hardener. Normally amine formulations are used for curing since they are well suited to the requirements for mechanical stability and processability. The new BASF system also uses this class of substances. Immediately before the infusion both components are mixed together in a pre-defined ratio and at this point the pot life or processing time clock begins to tick since the reaction between the two components begins slowly and increases at higher temperatures. However, in order for infusion to work well the viscosity of the system has to be correct. For this reason so-called reactive thinners, which reduce the viscosity, but at the same time form part of the cross-linking reaction, are in-

cluded in the formulation. The actual cross-linking or curing of the resin is achieved by the amines reacting with the epoxy groups to form a three-dimensional network. This reaction is dependent on the reaction temperature, but can be influenced by the use of additives such as accelerators.

Turbine manufacturers, who are now concentrating on offshore plants, are for the most part targeting the use of large blades in excess of 50 m length in order to make most effective use of the more consistent wind out at sea. In the case of large structures such as the outer skin of the blade processors using infusion technology face a dilemma. On the one hand the epoxy resin system should react slowly in order to completely fill the mold before it begins to gel (Fig. 6), on the other hand once it has been heated up the epoxy resin system should react rapidly so the mold can be made available for the next blade as quickly as possible (Fig. 7). In order to square this circle it is possible to go down a chemical route – first slow and then fast – using so-called la-

tent systems. Here some of the hardeners become thermally activated after passing a boundary temperature having previously been “asleep”.

Further Economic Advantages

The first rotors based on latent hardeners are already in use. These newly developed hardener systems can be easily adjusted, thereby simplifying the whole process. Below the line this means higher quality, better process stability and a lower scrap rate. Up until now depending on external factors such as temperature several hardeners had to be mixed together. In this case as well the new Baxxodur system offers significant advantages because it can be used over a considerably greater range of temperatures. This means that the hardener formulations do not have to be changed and adjusted every day. Not the least of this is that stock control can be greatly simplified as only a single hardener needs to be held in the warehouse.

Additional tasks in the epoxy based fiber-reinforced composite segment are further improvements in the core mechanical properties and in fiber matrix adhesion. This is aimed at enhancing the existing property profile that latent systems already offer in the fabrication of rotors, that is high mechanical strength, significantly reduced cycle times and higher productivity. ■

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