Wind turbine blade production – new products keep pace as scale increases

The wind energy industry is one of the fastest-growing consumers of fibre reinforced plastics in the world. Production challenges are compounded as the scale of wind turbines continues to climb. Blades, among the most complex parts to mould, now exceed 80 m in length and are getting longer. Freelance journalist Richard Stewart reports on new products and processes developed to meet the needs of utility-scale blade producers.

Standard utility-scale wind turbines, designed to produce 1-3 MW of electricity are fitted with three blades of 30-50 m (100-165 ft) in length. Blade production is labour intensive. Outer laminated shells are supported by a spar cap or main spar, serving as the central spine of the blade. Reinforcements are typically 70-75% E-glass by weight, infused with epoxy or unsaturated polyester resin. Blades are commonly moulded in halves, then joined using an epoxy adhesive.

Glass fibre reinforcements are typically laid in the mould as dry stacks by hand. Balsa, structural foam and engineered three-dimensional materials are used as cores in blade construction to support the outer blade shells. Epoxy prepreg materials of E-glass, carbon fibre and hybrids are used by some manufacturers, especially in the production of longer blades.

FRP components must be durable enough to stand up to harsh weather such as seen in this picture of Vestas wind turbines during winter in Germany. (Picture courtesy of Vestas Wind Systems.)

Tonnes of composites in the sky

The world's largest wind turbine producer is Denmark's Vestas Wind Systems. One 80 m long blade bolted to the hub of the company's 7 MW offshore wind turbine weighs 35 tons. The three-blade assembly measures 164 m (538 ft) in diameter and puts a lot of fibre reinforced plastic (FRP) composites up in the air.

Vestas uses carbon composites to produce the blades, enabling them to be slimmer, stiffer and lighter than fibreglass. That reduces the load on the turbine and makes it more efficient.

Spain-based Gamesa, another global market leader, also uses carbon fibre/epoxy prepreg materials in its most advanced turbines. Gamesa's 4.5 MW turbine, described as the most powerful wind turbine for the onshore market, towers 120 m (394 ft) up in the air. It is powered by unique Innoblade® blades, measuring 62.5 m (205 ft) long. They are segmented, enabling them to be assembled in the field.

The largest manufacturer of blades for wind turbines in the world is Denmark-based LM Wind Power. Operating 12 production facilities on three continents, the company recently produced its record-longest 73.5 m (271 ft) long blades for the growing European offshore wind market using E-glass and polyester resin in a vacuum assisted resin transfer moulding (VARTM) resin infusion process. The blades are designed to be mounted on a 6 MW wind turbine manufactured by Alstom of France.

LM Wind Power has been working with glass fibre and polyester to produce blades for wind turbines since 1978, "stretching the capabilities" of the materials to achieve the best possible balance between price and performance, the company relates. LM involves its suppliers closely in the production processes in order to optimise resin and reinforcements for vacuum infusion.

Wind blades ready for finishing at an LM Wind Power blade manufacturing facility in China. (Picture courtesy of LM Wind Power.)

The result, claims the manufacturer, is a very strong, uniform laminate with no air bubbles and rapid hardening, which has reduced production time by several hours. With reinforcing fibres, the focus is on tensile strength and the overall weave and structure of glass-fibre mats, as well as the chemical sizings on the fibre. Fibre mats used by the company are easier to handle and are less expensive than prepregs, relates the manufacturer.

"Epoxy is three times the price of polyester and requires a considerably more expensive production process, including heating of the moulds," LM observes. "We've decided to focus instead on optimising cheaper technology to reduce the overall price of wind energy while maintaining the same good performance properties."

One manufacturer of polyester resin systems is Switzerland-based DSM Composite Resins. Its Synolite™ polyester resins are said to offer performance improvements over other traditional unsaturated polyester and epoxy resins.

Burgeoning wind market

The wind energy industry represents great growth opportunities for composites material suppliers and wind turbine manufacturers. Market researchers at Lucintel predict that the global market for composite materials in wind turbine production will reach US$3.95 billion by 2014.

The global wind energy market is expected to grow at an average rate of 14% per year in terms of new capacity installation in the next five years, Lucintel forecasts in a new market report.

The US wind power industry led the world in annual wind power capacity additions from 2005 through 2008, but since then China has outpaced the US and emerged as the biggest market for wind power capacity, the company says. And the push for alternative electricity production continues elsewhere. The largest offshore wind farm in the world is scheduled for completion off South Korea's coast in 2016.

Carbon fibre composites are expected to play a larger role in wind blade production. In the US, wind energy is expected to be a larger market for carbon fibre and other advanced composite materials even than aerospace, owing to the expansion of offshore installations, according to Lux Research. The US and China will continue to be the top markets for wind turbine sales through 2020, says SBI Energy in a new study.

A mould is prepared for infusion of a blade shell-half at Gamesa's wind blade manufacturing plant in Navarra, Spain. (Picture courtesy of Gamesa.)

Synolite 1790-G-3 is well-suited for vacuum infusion of wind turbine blades, exhibiting improved wet-out of fibreglass reinforcements and enabling faster production cycles and room-temperature curing, says DSM. The resin is also said to demonstrate very low exothermic heat development in thick laminates for lower mechanical stress in the blade and longer mould life.

Epoxy resin systems

Dow Formulated Systems has developed Airstone™ epoxy resins and hardeners with reduced peak exotherm during curing for wind blade production. Airstone 780E infusion resin is said to provide extended pot life, fast curing and shortened cycle times. Fabricators are able to control resin curing properties, optimising cycle times without compromising the strength and integrity of the blade structure, says Dow, which expects to make Airstone infusion systems available commercially in 2012.

Momentive, formed in 2010 from the merger of Momentive Performance Chemicals and Hexion Specialty Chemicals, offers Epikote™ and Epikure™ epoxy systems for wind turbine composites. They offer ease of processing, excellent fracture toughness, good fibre impregnation properties and outstanding thermal stability, the company relates. Momentive epoxy systems are available in formulations tailored to a variety of processes, including RTM and VARTM resin infusion, hand lay-up and prepregging.

Sika Deutschland GmbH offers Biresin CR83 epoxy resin for wind blade production. The resin is said to be well-suited to this application due to its low viscosity, good wetting characteristics and variable pot life. In trials, the resin infused a fibre lay-up in half the time of a typical competitive infusion system and provided 100% wet-out of the fibres, Sika relates. Three hardeners of different reactivity are available to vary the pot life.

Swancor of Taiwan has developed an epoxy resin system, SW2511-1, for VARTM processing of wind blades. The resin is said to offer low viscosity, adjustable gel time and low exothermic temperatures, reacting at room temperature without additional pressure. Gel time of 9-10 hrs for SW2511-1 compares to 6-7 hours for traditional epoxy systems, while its exothermic peak temperature of 35-40°C compares to 50-70°C of other epoxy systems, Swancor relates.

Gurit offers a range of composites products for wind blade production, including the PRIME™ 20LV Epoxy Infusion System. This offers much reduced viscosity and longer working time than traditional epoxy resins, says Gurit, noting that the resin is ideal for infusing very large parts with complex reinforcements in one operation. The PRIME system is said to maintain exceptionally low exotherm characteristics, avoiding premature gellation in thick sections and extended life of mould tools. It is available with a range of hardeners to control working times and cure speeds.

The MAG Rapid Material Placement System automatically sprays in mould coatings and cuts and lays in glass and carbon fibre materials. (Picture courtesy of MAG IAS.)

California-based Materia has developed Proxima™, a proprietary thermoset resin system as an alternative to epoxy resins in wind blade production. Metathesis catalyst technology was used in the development. Metathesis enables chemical compounds to be synthesised with greater efficiency under less stringent reaction conditions and with reduced by-products, says the company. Proxima resin is said to provide greater toughness, lower weight and a smaller carbon footprint at a lower cost than epoxy systems used for wind blade production. Its lower viscosity enables faster infusion rates than traditional resins, says Materia.

Vinyl ester for blades

AOC produces a range of closed mould resins for wind blade composites, including bisphenol A epoxy-based vinyl ester, isophthalic and orthophthalic polyester and general purpose polyester. The resins are formulated to address a range of processing, performance and cost requirements. The general purpose unsaturated polyester, R920-E Series, is a high-value pre-promoted resin for fast fibre wet-out and infusion speed. High-performance, high elongation vinyl ester resin in the R013-A Series offers the strength of epoxy and the cycle time of polyester, while R015-G Series is a highly reactive vinyl ester resin for ultimate strength and stiffness, providing fast infusion time, notes AOC.

DSM has developed a range of low viscous vinyl ester resins for the production of wind turbine blades. When combined with glass reinforcement with the proper sizing, it is said to provide at least the same mechanical performance as epoxy-based systems. The resin enables fast cycle times and can be cured with normal low active MEK peroxides, notes DSM.

Derakane™ 601-200 epoxy vinyl ester resin from Ashland Performance Materials is said to improve cycle times by 25% versus epoxy resin systems in infusion processing of wind blades. The resin narrows the

Moulding wind turbine blades to meet growing US demand

Molded Fiber Glass Companies (MFG), a leading North American contract manufacturer of wind turbine components, recently shipped the 1000th set of 37 m (121 ft) long blades for 1.5 MW turbines from its facility in Texas. MFG produces blades as long as 40 m as well as other wind components at plants in five locations. The company expects to start producing 50 m blades in 2012, according to Gary Kanaby, MFG Director of Sales for Wind Energy.

"Some manufacturers use carbon fibre composites in the long blades, which require higher strength and reduced weight," he relates, noting that MFG is not currently using carbon fibre in wind blades but may in the future. "I think the trend is to have more carbon composites in the longer blades to match the increased loads."

The company produces wind blades using glass reinforcements, foam core and epoxy resins, both infusion and standard grades. A kitting plant near its blade facility in Gainesville, Texas, pre-cuts the reinforcements and packs them into kits by the order in which they will be placed into the mould, Kanaby relates.

Blade manufacturing takes four days, starting with a 24-hour moulding cycle to produce the blade shell halves and bond them together. On the second day, secondary bonding, trimming and drilling is accomplished. The assembled blades are primed and painted on the third day and finished for shipping on the fourth. Automated equipment is used to cut and drill the root end. Painting is done with automated spraying equipment, notes Kanaby.

MFG also supplies spare and replacement composite parts for wind turbines, conducts inspections and offers repair and maintenance service by WES, its service company. Most of the work is done up-tower on platforms, to avoid the high cost of removal of blades and other components from the wind turbine for servicing, he adds.

A wind turbine blade positioned in the automated paint facility in an MFG blade manufacturing facility. (Picture courtesy of MFG.)

performance/price gap between low-priced unsaturated polyester resins and high-priced epoxy resins, says Ashland. Derakane 601-200 cures much faster than straight epoxy and can provide cost savings of 25-30% per blade over epoxy systems, the company claims.

Reichhold offers a pre-promoted bisphenol-epoxy vinyl ester resin for wind blade production in its Dion® Impact 9102-75 series. It is formulated to provide reduced viscosity and improved curing for enhanced performance in infusion of large structural reinforced composite wind blades. Also available from Reichhold is Polylite® 32850-00 series, an orthophthalic unsaturated polyester resin, pre-promoted and formulated to provide reduced viscosity and improved curing for infusion of large wind blades.

New Bayer PU systems

A new polyurethane (PU)-based composite technology developed by Bayer MaterialScience LLC is said to dramatically improve fatigue and fracture toughness over epoxy-based systems used in the production of longer wind blades. The material incorporates Bayer's Baytubes® carbon nanotube reinforcement technology, which improves the fracture toughness by as much as 48% – double that of epoxy, the company says.

The new composite material has also been shown to exhibit superior processing and handling properties, which can lower total manufacturing costs by as much as 16%, Bayer adds. The development was funded by Bayer, the US Department of Energy and Molded Fiber Glass Companies (MFG) in a public/private sector partnership. Bayer is working to manufacture, test and certify full-scale prototype blades in collaboration with wind industry experts, the company notes.

Bayer and MFG researchers have been comparing the performance characteristics of Bayer's Baydur® resin infusion polyurethane systems with those of epoxy and vinyl ester-based composites for wind blades. While other polyurethane systems are designed for fast throughput and fast gelling/fast demould properties, Bayer's systems are designed to provide the lower viscosities and longer gel times needed for moulding very large wind blades. Test results show that the new polyurethane-based systems outperformed epoxy and vinyl ester samples in tensile fatigue, interlaminar fracture toughness testing and fatigue crack growth testing.

Enhanced glass reinforcements

Reinforced Plastics (RP) asked Onur Tokgoz, Wind Energy Global Business Leader at 3B-the fibreglass company, about the company's activities in the wind energy market and its new glass reinforcement for wind turbine blade manufacture, Advantex® SE2020.

RP: How does 3B determine the needs of wind turbine blade manufacturers, and what are these needs today?

3B: One of the pillars of 3B's strategy is to be a key wind energy solution provider. Since 3B was formed, we have been investing heavily in R&D and resources to better understand the wind energy market.

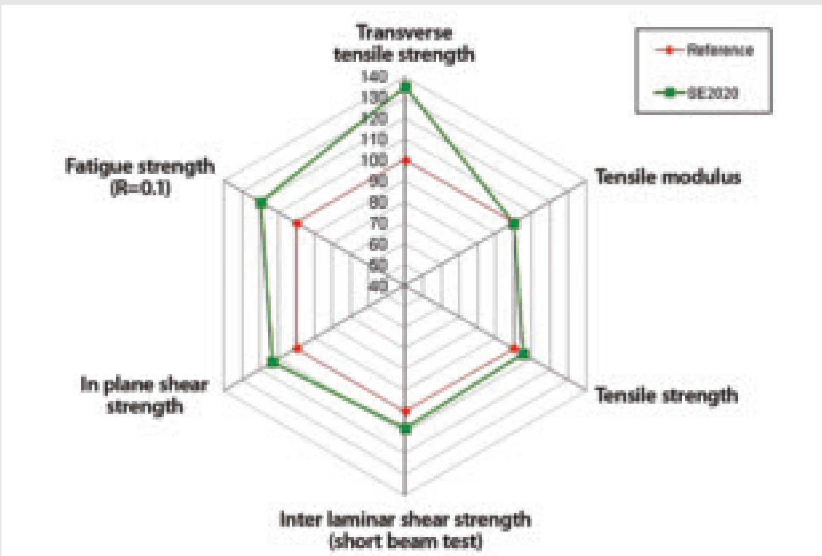
To determine the needs and the challenges that wind blade manufacturers are confronting, 3B has been focusing on the entire value chain by creating a loop between the raw material manufacturers and the OEMs (wind turbine manufacturers in this case). We are in very close contact with all upstream parties linked to the wind turbine manufacturer, including the blade manufacturers and designers (vertically integrated or independent), weavers and resin manufacturers.

In recent years, the wind energy market has been facing several challenges, one of them being bigger turbines. Multi-megawatt (MW) and therefore bigger turbines are almost a standard design nowadays due to the rapid growth of the offshore wind power market. The need for bigger turbines brings the need for longer blades. Since blade lengths have been significantly increasing the challenges for designers have become more significant as well such as blade weight, stiffness and performance. These challenges have triggered designers to search for better performing and enhanced raw materials to respond to their needs for the reinforcement of longer blades.

RP: How is 3B answering these needs?

3B: By combining state-of-the-art Advantex glass fibre technology together with an expert understanding and a very competitive *savoir-faire* of sizing technology 3B is able to offer enhanced material solutions which respond to the needs of wind blade manufacturers.

Furthermore, by working hand in hand with the entire value chain of the wind energy market, 3B has been able to identify and



Typical SE2020 relative properties vs. current sizing in unidirectional (UD) epoxy laminate. (Source: 3B.)

Prepreg technology

Prepreg materials from Gurit are available in several lines. The WE91-1 prepreg, which is part of the WE and WT range of prepregs, is a high-flow, diuron-free epoxy prepreg well-suited to the manufacture of thick sections. The prepregs can be cured at temperatures as low as 85°C or with a faster (55 minute) cure at 120°C. Unidirectional (UD) glass prepregs are available in a wide range of E-glass fibre weights. Also available are a range of carbon fibre prepregs, which excel where high mechanical properties are required. In addition, Gurit manufactures SparPreg™ unidirectional prepreg with glass or carbon fibre for SPRINT®-quality blade production.

Hexcel, another global supplier of materials to the wind energy market, produces epoxy/carbon fibre and UD glass prepregs. Carbon prepregs can be a cost-effective option for very large diameter blades, the company says, since less material is required to achieve the same strength as glass. Hybrid reinforcements of glass and carbon are also available from Hexcel, which operates six prepreg manufacturing facilities worldwide. The prepregs use HexPly® M9.6G and M19G epoxy resins. M9G cures in 15-20% less time while exhibiting the same handling and mechanical properties, says Hexcel.

The company also supplies HexPly M9F formulated epoxy resin systems for wind blade production. The resins are designed for low pressure processing and permit a range of temperatures from 85°C up to 150°C. HexPly M11 and M11.5, both diuron-free, adding environmental benefits, have been developed for low-vacuum bagging processes and rapid cure cycles – 3.6 hours at 80°C or 8.7 hours at 75°C.

New reinforcements

A new range of fibre reinforcements engineered to provide optimum performance for the manufacture of wind turbine blades has been introduced by 3B – the fibreglass company. Each product is designed for specific resin systems. The first product in the series to be introduced, Advantex SE2020, is a single-end roving specifically engineered for epoxy polymer systems utilised in resin infusion or prepreg processes.

"At 3B, we focus on understanding the needs of wind energy OEMs by working hand in hand with the designers, the

resolve the need for improving the existing sizing technology for epoxy resin systems.

At 3B, we strongly believe wind energy will play a key role in the need for efficient power generation that is clean, reliable and cost effective, especially in light of the recent announcements concerning the reduction and eventual elimination of our dependence on nuclear power. To meet future needs and help reduce the cost per kWh, larger multi-MW turbines will become the norm, but these will require improved blade designs with enhanced materials to ensure their efficiency and productivity.

RP: How was the Advantex SE2020 roving developed, and what are its benefits over other products?

3B: Advantex SE2020 is a new single-end roving specifically engineered for epoxy polymer systems utilised in resin infusion or prepreg processes.

At present multi-compatible reinforcements are commonly used with different resin systems such as epoxy, unsaturated polyester, vinyl ester, etc. However by developing innovative and proprietary sizing technology focused on a specific resin family (epoxy), 3B is changing the rules of the game. By optimising the coupling of the reinforcement uniquely for epoxy resin systems 3B thereby achieves best-in-class composite properties.

Compared to conventional materials in the market place (see chart), 3B's new Advantex SE2020 roving for epoxy resin systems offers better wet out, therefore providing a more consistent laminate quality, a significantly improved resin matrix adhesion which delivers higher shear strength, and substantially greater interfibre strength. This, together with the resulting enhanced fatigue performance, makes the SE2020 roving the solution that designers need to greatly improve existing blades and, more importantly, to create the next generation of epoxy turbine blades.

Advantex SE2020 roving has been designed specifically for epoxy resin applications in the wind energy market. However, its attractive properties and superior mechanical performances together with very good hydrolysis resistance and inherent corrosion resistance will be of interest to many other epoxy resin composite structural applications such as pressure vessels, pipes, leaf springs, tidal turbine blades, etc.

RP: What other resin-specific reinforcements will 3B be introducing?

3B: Aligned with our strategy to be a key wind energy solution provider, 3B is pursuing efforts to bring to market additional new and enhanced reinforcement materials for wind turbine blades. These new developments to be introduced during the first half of 2012 will include both resin specific and high-performance properties such as high modulus glass for longer, lighter and stiffer blades especially designed for multi-MW offshore turbines.

RP: How does 3B see the processes used in wind blade manufacture changing over the coming years?

3B: Due to the ever-evolving needs of the wind energy market, primarily driven by the growth in the offshore wind market, the technologies used will also need to evolve.

The production of bigger components is leading to developments in processes and automation.

However, glass fibre is and will remain essential for the wind power industry going forward. Today, glass fibre represents a significant portion of the raw material making up a wind turbine blade with up to 70% of blade weight. Even in the case of carbon spar-cap blades, this ratio will not be lower than 45-50%.

Finally, due to the cost-performance ratio, glass fibre is the preferred option for the longer blades needed for offshore turbines and for multi-MW onshore turbines.

weavers and, ultimately, the manufacturers of turbine blades," the company says. "Collaborating with the entire value chain enables us to bring to market new benchmark rovings which further push the limits of glass fibre composite blade designs."

Compared to conventional materials, the new Advantex SE2020 roving offers better wet-out, providing a more consistent laminate quality and an improved resin matrix adhesion, which delivers higher shear strength and greater inter-fibre strength, adds 3B.

3D Preforms for root section resolve moulding challenges

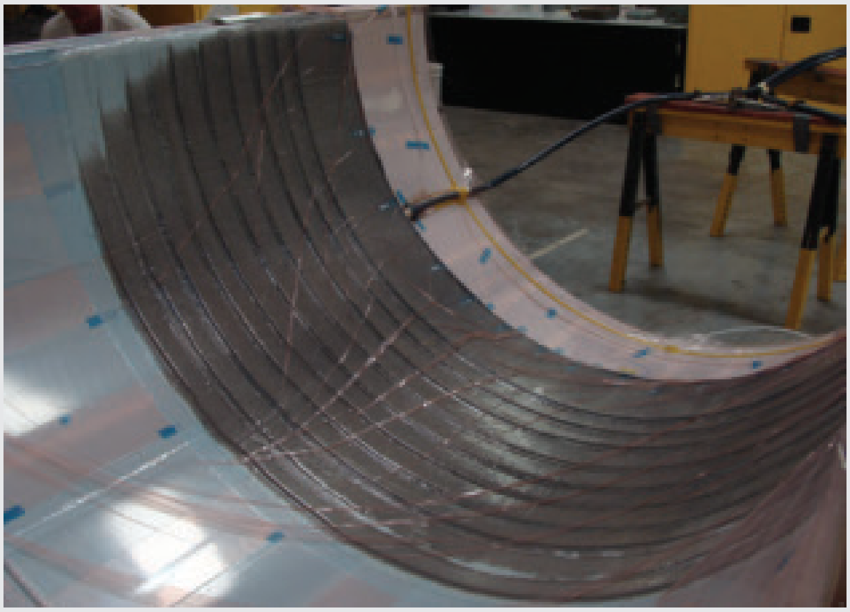
The thick root section of a wind blade – the end which bolts to the rotor hub of the turbine – presents processing challenges stemming from the many plies of material used to build up the composite – 100 or more layers of thin fabric, which can wrinkle during debulking. Root sections of large blades have got so thick that processors commonly mould them separately from the blade, in sections, then bond them together in a secondary operation.

To facilitate the production of the thick root section and help avoid common issues associated with infusing it, 3TEX, a North Carolina, USA, manufacturer of textiles and reinforcements for composites, developed RapidRoot 3D™ preforms. These are produced from layers of densely woven, thicker E-glass fabric, cut in increasingly longer lengths to provide the taper required for the root section.

"RapidRoot was designed specifically to address three major challenges faced by processors in infusing root sections," relates Don Wigent, Technical Product Manager, 3TEX. "It enables the placement of a lot of fibre very quickly; wrinkles are avoided because the plies are dense and stiff; and woven-in resin flow passages enable fast and thorough wet-out of all the plies."

"There is no concern about unseen dry spots beneath the otherwise wet material," he adds. "No infusion media or plumbing is needed to achieve wet-out very readily and completely. It's a matter of scaling up the fibre reinforcement to match the scale of the part."

The company also offers speciality fabrics and other preforms for wind blade composites, including 3TEX UniGirder 3D Spar Caps, rope-like FilletBraid™ to fill gaps and corners in a blade lay-up, and woven joining elements in the shape of the joints being formed. Also available are patent-pending ZPlex™ Conformal Total Sandwich Preforms with PE foam that is stiff and strong like an I-beam yet flexible enough to conform to curved shapes of wind blades.



Resin is evenly infused through the thick tapered RapidRoot 3D Preform lay-up. (Picture courtesy of 3TEX.)

A new foam core system for wind blades, COMPAXX™700, was recently introduced by Dow Formulated Systems. The product is the first in a line of new core materials designed to help manufacturers extend blade life through the creation of high-performance sandwich composites. According to Dow, extensive sandwich panel fatigue testing showed COMPAXX 700 exhibits long-term dynamic behaviour and shear strength properties yielding lightweight composites with excellent mechanical strength and fatigue resistance. These properties, coupled with peel strength about three times higher than the historical reference of core material polyvinyl chloride (PVC) 60 kg/m^3, "create the intimate core-to-skin bond necessary to achieve blade durability," observes Dow.

The product has a specific roughness and surface grooving that help achieve the excellent bonding performance. In addition, COMPAXX 700 offers a high run-to-run consistency leading to predictable mechanical properties that structural engineers can use to create more precise blades, the company adds.

The new COMPAXX system is now available globally in commercial volumes.

PPG Industries produces Hybon® 2026 direct glass fibre roving, said to be well-suited for wind blades, in facilities in the USA, the UK and China. The roving is designed to provide the high mechanical performance required for critical structural designs while offering advantages in blade production. The reinforcement also provides excellent adhesion in multiple resin systems, high tensile strength and fatigue performance needed for demanding wind blade applications, relates PPG.

A fibre-reinforced composite core material for wind blade sandwich construction is available from Webcore Technologies. TYCOR® W5 is the latest product in the company's W line of core materials. E-glass fibre reinforcements are combined with low-density foam in an engineered architecture for vacuum infusion of blades. TYCOR saves

Offshore wind farm with 22 Bonus Siemens wind turbines fitted with LM 26.8 m blades. (Picture courtesy of LM Wind Power.)

about 1000 lbs (454 kg) per blade versus balsa core, says the company, enabling the production of longer blades without switching to costlier reinforcements. One customer realised a 9% reduction in the total bill of materials owing to the combined core and resin savings, adds Webcore.

Automating production

A CNC-controlled Rapid Material Placement System (RMPS) from MAG IAS, based in Kentucky, USA, offers integrated manufacturing capabilities for wind turbine blade production. The RMPS system consists of a gantry system with multi-axis end effectors capable of spraying in-mould coatings, dispensing reinforcement materials and applying adhesives automatically.

The RMPS system features a modular platform with a 10-roll magazine for reinforcing materials that cuts and dispenses plies of multiple widths into the mould. Material placement is rated at 3 m/s (10 ft/s). A pair of articulating powered brushes smoothes out the plies as they are paid out. The system also features laser and vision-based wrinkle detection systems. Two gantry systems adjacent to each other can produce a 45 m blade shell-half in less than two hours, with half the manual labour of conventional methods, the manufacturer relates. The lay-up system is said to be mechanically repeatable to within 2 mm, with application tolerance of ±5 mm. ■

Further information

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- 3TEX; www.3tex.com
- AOC; www.aoc-resins.com
- Ashland Performance Materials; www.ashland.com
- Bayer MaterialScience LLC; www.bayermaterialsciencenafta.com
- Dow Formulated Systems; http://epoxy.dow.com
- DSM Composite Resins; www.dsmcompositeresins.com
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