COMPOSITES TECHNOLOGY

APRIL 2012 | VOL. 18 | NO. 2

Composite Airfoil Design

WINGSAILING

BMC Formulation Flexibility in Direct-SMC

Thermoplastic Composite Wind Blades

COMPOSITES 2012 Product Showcase

FABRICS

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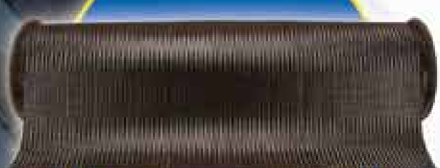

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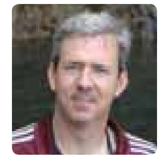
COVER PHOTO

An autonomous (self-controlled rather than remotely controlled) unmanned sea vessel (AUSV), the HWT X-2 prototype pictured here is a 50-ft/15.4m long *Contour 50* composite trimaran, with a 41-ft/12.5m beam, a narrow center hull and two outrigger hulls. Its all-composite WingSail, designed by Harbor Wing Technologies (Seattle, Wash.), captures up to 1.7 times the wind power of soft sails (see p. 46).
Source | Harbor Wing Technologies

Twisting in the wind



The federal renewable energy production tax credit (PTC), which provides a subsidy for producers of electricity from wind energy sources, is set to expire Dec. 31, 2012. By now, you are probably aware that the U.S. Congress refused on March 15 to approve a one-year extension, and a bipartisan group promptly introduced a new bill, that same week, calling for a *two*-year extension. And you probably also know, based on this (and whatever transpired since) that the PTC is a political hot potato, with many Republicans calling for an end to all energy subsidies, and many Democrats calling for PTC continuation to avoid job losses. What we don't know is where this will all end.

The PTC was born in 1992, designed to help prop up what was, at the time, a fledgling wind energy industry. Since 1992, the U.S. Congress has renewed the PTC in one-, two- and three-year increments, with the last coming in 2009. The PTC provides a $0.022/kWh credit for producers of electricity from wind energy sources. The duration of the credit is 10 years after the date the facility is placed into service.

Manufacturers of wind turbines and blades, such as Vestas, Gamesa, GE, TPI Composites and others, point to the PTC as a primary driver of wind energy development in the U.S. and want it not only extended but made permanent. Their argument is that the PTC provides a stable, business-friendly environment for wind energy development and makes wind a competitive energy source. Without the PTC, the wind energy environment will be unstable and its growth in the U.S. will slow — leading eventually to layoffs. The American Wind Energy Assn. (Washington, D.C.) says 37,000 jobs could be lost if the PTC is not renewed.

> The federal renewable energy production tax credit (PTC) has become a political hot potato. Where will it end?

Opponents of the PTC argue that wind is not now and never will be competitive with natural gas and that not only is the subsidy a waste but Americans would save billions of dollars, as well, if wind produced no energy at all. Further, opponents argue that renewable energy sources will never provide more than a fraction of the energy required by Americans.

Whatever your politics, it is true that the PTC has stimulated wind energy growth, and this has served the composites industry well. It's also true that the wind energy industry, sans PTC, will not wither and die. Wind energy is more cost-competitive than it used to be, and will only become more so. The problem is that the wind industry is global, and if the U.S. can't provide a stable wind market, then China, Brazil and Germany can and will — if turbine manufacturers tire of American uncertainty, then they will pick up their toys and go play somewhere else that's more stable.

The variable that's most intriguing in this argument is the cost of energy. When looking at natural gas, coal, solar, hydro, nuclear and other sources, wind stacks up favorably. According to the Energy Information Admin., conventional natural gas is $66/MWh, hydro is $86/MWh, conventional coal is $95/MWh, wind is $97/MWh, advanced coal is $109 and nuclear is $114/MWh.

If you believe that it's incumbent on us to develop multiple energy sources, it's hard to look at the cost of wind and say that it's unaffordable and out of reach and, therefore, not worth the investment — whether commercial or governmental.

Jeff Sloan

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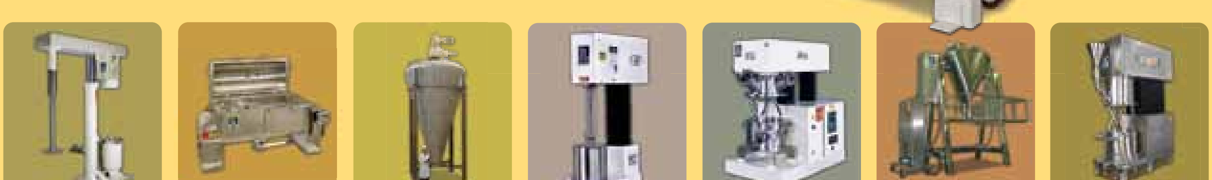

ROSS

COMPOSITESWORLD

Commercial ground transport: A very present opportunity

Bio | Bob Lacovara

Bob Lacovara is the principal at Convergent Composites (Perkasie, Pa.), an industry consulting firm. He is the former technical director of the American Composites Manufacturers Assn. and is a Composites Hall of Fame inductee. Lacovara has been in the composites industry for more than 40 years and has authored articles in numerous publications.

The business model for innovation is driven by market needs. Where there is a need, an opportunity is awaiting discovery with the development of differentiating or disruptive technologies. At this juncture, the transportation sector is primed for this kind of evolutionary leap, and composites could propel that next round of advancement. In fact, the business model can be derived from the laws of physics.

Ultimately, it takes money to power vehicles, money in terms of the energy conversion that is required to accelerate mass and overcome air resistance. The energy conversion for city driving is dominated by Newton's Second Law: *The acceleration of a body is directly proportional to the net force on it and inversely proportional to its mass.* This is expressed as $a=F/m$. Of the available fuel energy, 84 percent is consumed by friction, heat loss, drivetrain and other losses, and another 15 percent is required for standby acceleration of the mass. Only *1 percent* of the expended energy actually moves the passenger. We need to revisit an important question: *Is the purpose to move a 3,000-lb vehicle or to transport the occupants?*

> In the quest to improve vehicle aerodynamic efficiency, Class 8 tractor-trailer trucks are the low hanging fruit.

The traditional approach to reducing vehicle weight is to make the vehicle smaller. When the materials and production methods don't change, the only path to weight reduction is to use less material. That translates into the reduced surface area of a smaller vehicle. In Europe the cultural and economic barriers to ownership of small cars have been breached, and today, small is the norm. That is not the case in North America, where a combination of geography, use patterns and the cultural overlay still make a small car look like a deprivation.

The latest buzzword in the automotive advancement lexicon is "lightweighting," as in reducing vehicle mass. Herein, composites offer the opportunity for automotive manufacturers to decouple size from weight.

The auto manufacturers are listening … *sort of*. They are interested but have trouble seeing past their established technologies: metal stamping and welding robots. Ultimately, Newton will prevail because we can't escape $a=F/m$. If the opportunity is to be realized, however, the composites industry has to step up to the plate in two areas: (1) we need less-expensive carbon fiber if we expect to compete with steel on a specific-strength basis, and (2) we need to develop faster processing methods than are currently available. The opportunity for this disruptive advancement lies before those who dare to address the laws of physics.

In the case of highway driving, the equation shifts, because energy conversion is dominated by aerodynamics. The resistance of a body moving through the fluid environment of air is known as the *drag coefficient (Cd)*. At highway speeds, an energy reserve of about 14 percent is required to overcome aero-drag resistance in cars, and large trucks can consume as much as 20 percent of expended energy in the task of displacing air.

Here is something to consider: EPA fuel mileage requirements and CAFE averages are calculated for vehicles moving at a speed of 55 mph. This benchmark speed, however, is a throwback to the Nixon Administration's one-time national speed limit. Today's posted interstate speed limits are 65, 75 and, sometimes, 80 mph. And in reality, 69 percent of traffic *exceeds* a posted 55-mph limit, 54 percent exceeds a 65-mph posting and 46 percent travels faster than the 75 mph limits. The fact is that drivers routinely travel at 75 to 85 mph on our national highways. At 75 mph, fuel usage is about 23 percent *lower* than the EPA benchmark. Government and manufacturer fuel consumption calculations revolve around 55 mph, but we *should* be building vehicles that are aero-tuned for a more realistic 75 mph.

In the quest to improve vehicle aerodynamic efficiency, Class 8 tractor-trailers are the low-hanging fruit. Although passenger-vehicle improvements will require as yet undeveloped advancements in material costs and production methods, *all* of the technology necessary to dramatically improve truck efficiency is already in place and readily available.

Today's trucks are a variation on a theme established more than 100 years ago. The morphology of truck design stems from the horse and wagon and the early 20th Century adaptation of the internal combustion engine to self-powered vehicles. These evolved characteristics include a large, flat radiator; accessories that protrude into the airstream; and a side-by-side seating configuration in the cab.

These design features were not an issue when most traffic moved at 35 mph. They were, maybe, a small consideration when 55 mph was the highway standard. But at 75-mph highway speeds, the aerodynamic drag loss is very significant.

Old-style, squared-off trucks with mirrors, exhaust stacks and myriad other accessories in the airstream have a Cd in the area of 0.87+. The latest models feature some modest aerodynamic restyling that has reduced drag loss to somewhere near 0.75, depending on the trailer configuration. With that in mind, here are the big-picture statistics: ►

- The U.S. fleet has 2.2 million Class 8 trucks in service.
- Class 8 trucks drive 60 billion highway miles a year.
- At an average of 6.1 mpg, they consume more than 9.8 billion gal of diesel fuel per year.
- The annual fuel cost is more than $50 billion (USD).

Now consider this: If the Cd could be reduced to 0.48, it would result in an increase in fuel mileage from 6.1 mpg to 8.6 mpg. The savings in fuel costs would be $12 billion per year, added directly to the trucking industry's bottom line. And that translates into substantially less imported petroleum as well.

So how do we create a 0.48 Cd truck? First, we redesign the cab for single or tandem, rather than side-by-side, seating. The vast majority of trucks operate with only one driver onboard, offering the opportunity to reduce the current frontal volume of the cab. Next, we eliminate the large vertical radiator that produces a high drag area. There are alternative cooling configurations that can minimize frontal openings. Then we eliminate all the exterior bling hanging off the cab. Rear-view video, proximity radar and synthetic vision systems are currently available as off-the-shelf automotive technologies, and the cost of these systems is well within the scope of the savings yield. Finally, we incorporate the necessary gap and air-dam sealing into the trailer to reduce underbody airflow.

All of the technology necessary to build a 0.48 cD Class 8 tractor-trailer rig is readily available, and composites can play a major role in this disruptive transformation. Unlike with automotive production, carbon fiber-reinforced composites are not required for heavy truck advancement. Glass fiber-reinforced composites can effectively produce the necessary aero-shapes. Additionally, currently available molding methods are in sync with truck production volumes.

Technically, then, the stage is set, and composites can fill the redesign gap *right now*. But practically, there remains a cultural issue within the trucking community. At odds with the idea of saving $12 billion a year with aerodynamic improvements is the commercial ground transport industry's general perception of what a truck should *look* like. If we are to see technology flow successfully into disruptive advancement, we must collectively overcome this traditional view by actively promoting this new vision within the community of vehicle manufacturers and end-users.

> All of the technology necessary to build a 0.48 cD Class 8 truck is available, and composites can play a major role in this disruptive transformation.

In the end, Newton and fluid dynamics will win. The opportunity for composites professionals is to hasten the day. | CT |

Composites WATCH

Automotive alliances, infrastructure innovations and construction contracts signal the composites industry's progress on the road to recovery.

AUTOMOTIVE

Composites make inroads into CAR DESIGN/PRODUCTION via partnerships

Early in 2012, three agreements were struck between automakers, their suppliers and composites manufacturers to promote the use of composites in automotive design and construction.

In recognition of the fact that lightweighting is a key strategy in auto industry efforts to produce more fuel-efficient cars, the Center for Automotive Research (CAR, Ann Arbor, Mich.) has launched the Coalition of Automotive Lightweighting Materials (CALM), a new effort to accelerate the development of *mixed* material solutions that will reduce vehicle weight. CALM's mission is to help automotive companies discover how best to use available composite, plastic and lightweight metal materials. Through collaborations with carmakers, CALM aims to overcome the challenges of integrating composites with metals in design, joinery and structural validation.

"The aluminum and plastics/composites industries are developing advanced materials to help automakers design lighter and safer cars," notes Dr. Jay Baron, CAR president and CALM director. "By working together we can accelerate the application of these progressive materials and solutions." Notably, CALM has the support not only of organizations that count major composite-materials suppliers as members, but also The Aluminum Assn.'s Aluminum Transportation Group and the American Chemistry Council, the combined membership of which numbers more than 200 companies.

One of CALM's first tasks will be to meet with the engineering groups at major auto OEMs to understand their mass-reduction strategies and challenges. This information will be used to educate supplier groups so they can be mindful of the needs of each car company as they develop technology solutions.

Elsewhere, Gordon Murray Design (Shalford, Surrey, U.K.) entered into a technical partnership with carbon fiber manufacturer Toray Industries (Tokyo, Japan) to develop composite technologies for automotive applications. The agreement stems from the launch of Gordon Murray Design's two-seat electric car, *TEEWAVE AR.1*, commissioned by Toray and unveiled at the Tokyo Motor Show in December 2011. The collaborators will focus on several key areas with regard to further development of Gordon Murray Design's *iStream* manufacturing system. The agenda will include joint materials and processes R&D as well as exploration of additional opportunities for Toray's materials in the automotive sector.

The *iStream* process is a simplified automotive assembly design scheme that makes it possible to locate a new manufacturing plant in a space *20 percent* of that now required for a conventional assembly line. When implemented, the new scheme is expected to reduce capital investment in the new assembly plant by ~80 percent.

The *TEEWAVE AR.1* vehicle is representative of Toray's approach to sustainability and high efficiency. The car uses a range of Toray's automotive products in its construction, including carbon fiber composites and what Toray describes as "advanced eco-materials." The vehicle weighs only 846 kg/1,865 lb (that includes its lithium-ion battery pack) and features carbon fiber composite body panels and advanced crash structures. Toray says it wants to pursue the concept of a lightweight hybrid chassis structure, with advanced safety and high cost-efficiency characteristics.

Meanwhile, composites manufacturing innovator Quickstep Technologies (N. Coogee, Western Australia) is continuing the PRESCHE Project, a joint development endeavor announced late last year with automaker Audi AG (Ingolstadt, Germany). Supported by the German government, the partners intend to develop new manufacturing solutions for cost-effective volume production of composite auto parts. The project goals include a 30 percent reduction in the cost associated with existing manufacturing methods. The strategy will combine previously independent composite manufacturing technologies, including Quickstep's Resin Spray Transfer (RST) technology and the patented Quickstep Process, an out-of-autoclave technology that uses heat-transfer fluid in fluid-filled trays to rapidly cure advanced composites. RST involves robotically spraying a heated liquid resin directly onto a mold tool, which solidifies on contact with the tool surface. Then a dry fiber preform is robotically placed onto the sprayed solid resin. The layup is vacuum bagged and then loaded into the Quickstep curing system, where the layup is heated under pressure, the resin reliquefies and wets out the fibers and cures to produce a Class A finish, says the company.

Quickstep has nearly completed an RST development program in Australia, funded by the Australian Government's Climate Ready Program. The company's managing director, Philippe Odouard, says the launch of the PRESCHE program in Germany represents an enormous opportunity for the company to mature its RST technology in partnership with Audi and others. PRESCHE will run until October 2014 and is expected to culminate in a demonstration part-production project, followed by a detailed economic evaluation. The ultimate goal is high-volume, low-cost composite component manufacturing that will enable the auto industry to deliver lighter vehicles with reduced fuel consumption.

AUTOMOTIVE

New HEV pickup showcases composite BODY PANELS

Motive Industries Inc. (Calgary, Alberta, Canada) announced a new design for pickup trucks with the Feb. 1 introduction of the 2012 *Bison*, which features a hybrid-electric powertrain and composite body panels. *Bison* is targeting the compact to midsized light truck class, where it will compete

Source | Motive

with the Ford *Ranger*, the Chevy *Colorado*, the Toyota *Tacoma* and the Honda *Ridgeline*. Motive notes that a major benefit of the composite-bodied pickup is the ability to have a profitable low-to-medium production run of anywhere between 500 and 25,000 vehicles. The company argues that light truck model production runs of more than 100,000 units are, in many ways, becoming difficult to manage as OEMs struggle to meet the challenges presented by continuously developing technologies and unpredictable market trends as well as the tooling investment required for stamped steel. In many cases, says Motive, the costs for a part's composite tooling can be a fraction of the cost of the metal-stamping tooling it would require. The reduced cost of tooling permits an OEM to manufacture a vehicle in smaller numbers and still make a profit.

PEOPLE BRIEFS

Sandvik Coromant (Fairlawn, N.J.) has announced the appointment of **John Israelsson** as president of the new business division, Market Area Americas. **Jamie Price**, currently the VP of sales, will succeed Israelsson as president of Sandvik Coromant USA. Israelsson will be tasked with growing sales and increasing product synergies in North and South America. Price will assume responsibility for the company's operations, sales and marketing, strategic planning, development, expansion and profitability … Polymera Inc. (Hebron, Ohio) announced Feb. 14 that wood/natural fiber polymer composite material scientist **Dr. Derek Tsai** will lead development of advanced formulations for the company's natural fiber-reinforced wood polymer composite (WPC) materials. Tsai, Polymera's newly appointed VP of material development, is one of North America's leading experts in forest products and WPC material science. He will be developing material blends targeted to a wide array of applications, including construction, automotive, furniture and windows.

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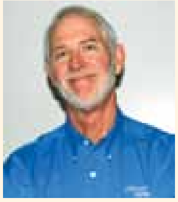

Bill Hasenjaeger
Product Marketing Manager
CGTech

A Practical Discussion of the Abilities and Limitations of Automated Fiber Placement (AFP)

EVENT DESCRIPTION:

Automated Fiber Placement (AFP) equipment has become significantly faster and more reliable and, now that AFP technology has been proven for a variety of parts, more companies are considering AFP equipment to replace their existing processes. But before they do, it is important to learn AFP's capabilities and limitations.

This presentation will discuss the challenges and rewards of using AFP. It will describe the interaction between part programming and machine functionality, and how it is affected by part geometry, ply boundary shapes, lay-down path trajectory, material limits, and the physical behavior and mechanics of the fiber placement head and machine.

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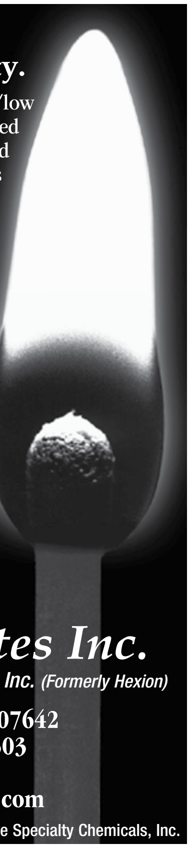
BIZ BRIEFS

Ashland Performance Materials (Dublin, Ohio) announced Feb. 10 the formation of a strategic alliance with **Acell Srl** (Milan, Italy) to foster North American market development for Acell's sheet molding compound (SMC)-based sandwich panel processing technology. The Acell foam and processing technology offer fabricators an opportunity to compete in new applications that require panel technology, such as entry doors, exterior sheathing for commercial buildings or residential roofing. The panels can be tailored in any number of ways to meet weathering, strength, insulation and fire-resistance requirements. Under terms of the alliance agreement, Acell will partner with Ashland to identify new customers and market opportunities in North America.

The Braj Binani Group (Kolkata, India), completed on Feb. 1 the acquisition of **3B-the fibreglass co.** (Battice, Belgium), reportedly for €275 million ($370 million USD). 3B has production capacity of 150,000 metric tonnes/yr (330.7 million lb/yr) in Belgium and Norway, and it reportedly will build a new production plant in Tunisia with an annual capacity of at least 50,000 metric tonnes (110.2 million lb). The goal of the acquisition, says Binani, is to create a vertically integrated fiberglass company with state-of-the-art technology and innovation capabilities and continue 3B's focus on wind, thermoplastics and performance-composite markets. The fiberglass acquisition follows another Binani buy on Jan. 27, 2011, when it signed a merger agreement with **Composite Products Inc.** (CPI, Winona, Minn.), known for inline compounding and molding of long fiber-reinforced thermoplastics.



BIZ BRIEFS

European production of wood-plastic composites (WPCs) has grown rapidly over the past five years. The annual production total in 2010 had already reached 193,000 metric tonnes (nearly 425 million lb). A new report by WPC industry consultant **Hackwell Group** (Tunbridge Wells, Kent, U.K.) forecasts continued growth through 2015, to almost 360,000 metric tonnes (793.7 million lb) per annum. That figure represents an average yearly growth rate of 13 percent but also indicates that growth will slow compared to that seen from 2005 through 2010 — a slowdown attributed to continuing difficulties in European economies.

According to the report, decking is by far the largest WPC application category, having captured 75 percent of the nonautomotive output, but the arguments for using WPC in other applications are strong. Much of the predicted growth is still expected in other construction applications, including siding or cladding, fencing and window applications. Moreover, Germany, France and Belgium are among the most significant European locales for WPC production.

Injection-molded products have been successful in diverse end-uses, including paper manufacturing applications and musical instruments, as well as vehicle and shoe parts, while various other processing technologies have been adopted in the automotive sector, which consumes 30 percent of the output. Furniture components offer considerable potential for WPC in the medium term, and a number of products already have been successfully marketed. In addition to those originating in Europe, WPCs imported from the U.S. and Asia have become increasingly important, particularly in the construction sector.

AUTOMOTIVE

Lamborghini's carbon dream

On March 5, at the 2012 Geneva Motor Show, Automobili Lamborghini introduced the *Aventador J*, a 515-kW/700-hp two-seater said to be the most expensive Lamborghini ever made. And it makes use of carbon fiber composites in several new and striking applications.

Described as "extreme" and "uncompromising" by Lamborghini president and CEO Stephan Winkelmann, the car is "the most radical open supersports car of Lamborghini's history." Based on the series-production 2011 *Aventador LP 700-4,* Lamborghini's new twelve-cylinder model, the open-cockpit *J* is based on a largely new carbon-composite monocoque design that includes safety bars behind the seats. The absence of a roof, windshield and other closed-cabin components drops its dry weight even lower than the *LP 700-4's* frugal 1,575 kg/3,472 lb.

Radically new, the *J* seats are made in two pieces (front and back) of Forged COMPOSITE, which are bonded together. The front section is cobonded with patented Carbonskin, a *flexible* carbon fiber composite made of woven (2x2 twill) carbon fibers soaked with a special epoxy resin that stabilizes the fiber structure yet keeps the material soft. Developed in-house, Carbonskin reportedly conforms to complex shapes and satisfies Lamborghini aging and wear requirements, says Lamborghini's advanced composites development center leader, Luciano De Oto. In the *J*, the seat fronts and all other cockpit surfaces are clad in Carbonskin. Oto was mum about its use in future car models but says it's likely that there will be other potential applications for the material, such as luggage.

Other composite features include a front-end-dominating carbon fiber air scoop; five-spoke aluminum wheels with carbon composite inserts that function like small fans to optimize brake ventilation; and front and rear bumpers supplemented with carbon fiber fins that act as flow deviators to achieve a significant increase in the vehicle's downforce at both the front and the rear. Additionally, the car's engine cover consists of a carbon-fiber framework, with two large openings that lay bare both cylinder banks of the car's V-12 engine.

INFRASTRUCTURE

Metal-matrix composite-cored POWER CABLE installed in Texas

Source | 3M

Guadalupe Valley Electric Cooperative (GVEC) in south-central Texas has become the nation's first rural electric cooperative to install 3M Aluminum Conductor Composite Reinforced (3M ACCR) electrical-transmission cable, an advanced overhead transmission conductor for grid applications, developed by 3M (St. Paul, Minn.). GVEC's Feb. 8 announcement noted that the 2.8-mile/4.5-km, single-circuit 138 kV line provides power for the city of Schertz, situated about 20 miles/32.2 km northeast of downtown San Antonio. 3M's high-capacity ACCR conductor replaces a conventional steel-cored ACSR conductor on this line.

The utility deployed the lightweight, low-sag, high-capacity cable on a transmission line that links two substations. Use of the cable enabled GVEC to increase the line's capacity by more than 60 percent without enlarging towers or widening the right of way. Rene Hernandez, a GVEC system engineer, says the new conductor was chosen after an extensive review of the transmission load issues and the economics regarding replacement and addition of steel transmission structures: "The higher-ampacity conductor afforded GVEC the additional capacity needed to meet the planning requirement, at a substantial savings to the GVEC membership."

3M ACCR is now in use by major utilities and municipal power companies throughout the U.S. and in Europe, Asia and South America. Introduced for commercial use in 2005, 3M's innovative metal-matrix composite conductor was developed with the support of the U.S. Department of Energy, which tested the conductor at its Oak Ridge National Laboratory (ORNL) in Tennessee, and with early contributions by the Defense Advanced Research Projects Agency (DARPA). The conductor's strength and durability result from its metal-matrix composite core, composed of aluminum oxide (alumina) fibers embedded in high-purity aluminum. It has the durability and longevity of traditional steel-cored conductors and better thermal performance, which reduces line sag. According to 3M, all U.S. and international ACCR installations, some in place for more than a decade, have operated successfully, thus far, with no failures.

BIZ BRIEF

Luxury automaker Bentley Motors (Crewe, Cheshire, U.K.) and **Sigmatex UK Ltd.** (Runcorn, Cheshire, U.K.) recently completed a research and development program to study the difference in fabrication costs between a composite solution and a known aluminum solution for construction of an automotive structural element. In the study, a sample A-pillar node was fabricated by means of two composites processes. One process employed the Bentley automated fiber deposition process, producing an impregnated preform that was finished in a compression molding press. The other method involved the Sigmatex One Piece 3D weaving process with subsequent resin infusion. In this study, the technically superior composite solution was produced using the 3-D woven preform and the resin infusion process. The study calculated the cost savings realized from the process, when compared to processing costs for the aluminum pillar, at €5/kg for this automotive application. The study, the companies say, demonstrates that 3-D woven preforms can be cost-competitive in automotive applications even in low-volume manufacture of parts with complex shapes.

INFRASTRUCTURE

Maine firm continues push into BRIDGE and PIER construction with two "firsts"


Source | DEI

Harbor Technologies LLC (Brunswick, Maine) reported on Feb. 8 that it has manufactured the world's longest composite vehicular-bridge support beam. Harbor Technologies constructed the beam for the Missouri Department of Transportation's Safe and Sound bridge replacement project. Safe and Sound, which started in 2009, aims to repair and replace 802 bridges in five years. To date, 672 bridge projects have been completed.

This particular beam design was created for one of three Harbor Technology bridge jobs, a single-span bridge replacement over Sons Creek on highway 97 in Dade County, Mo. Supporting the bridge deck are 105.6-ft long by 6-ft wide by 5-ft deep (32m by 1.8m by 1.5m) Hybrid Composite Beams (HCBs) that are, reportedly, the world's longest beams currently in use on a vehicular bridge. Harbor Technologies has been manufacturing HCBs, invented by John Hillman, since the first prototype beam was tested early in 2009. During the past decade, HCBs in a variety of sizes have been installed in Texas, New Jersey, Maine and Illinois.

The company also was in the news for recent work done on a project for Maine's Down East Institute (DEI, Beals Island, Maine), home to Maine's first public shellfish hatchery and a resource for education and research. Harbor Technologies built the components for a new, environmentally sound, all-composite pier structure that can handle a 30,000-lb (13,640-kg) heavy-truck load. The 100-ft/31m long, 30-ft/9.2m wide structure comprises piles, pile caps, decks and floats.

Using the HCB beams, the pier only required three "bents," or transverse support frames, on nine pilings to achieve the necessary load rating. The reduced weight of the composite components allowed the onsite contractor to use smaller, less costly leased equipment during the installation, which was accomplished in half the time required when traditional materials are used. The new structure is expected to last at least 100 years with minimal maintenance, despite exposure to the harsh marine environment. DEI's documentation of the installation process can be viewed at http://downeastinstitute.org/current-pier-project.htm.

BIZ BRIEF

Technical Fibre Products (Kendal, Cumbria, U.K. and Schenectady, N.Y.) has established the site of its new U.S. headquarters in Schenectady. According to a report published Feb. 17 in *The Business Review* (Latham, N.Y.), the move consolidates company operations formerly located in Newburgh, N.Y., Cincinnati, Ohio and Connecticut, creating 30 jobs and filling a vacant building in the Schenectady suburb of Rotterdam. The report says the company is spending $3 million (USD) to retrofit the building and install production lines for its high-performance, nonwoven veil products, fire-protection products and metal-coated fibers.

CONSTRUCTION

Vaulted composite ROOF PANELS cap Saudi railway station

Premier Composite Technologies (PCT, Dubai, U.A.E.) has been awarded a contract to supply the roofing and inner ceiling for the Madinah station, one stop on the Haramain High Speed Rail project. Currently under construction in Saudi Arabia, the 444-km/276-mile high-speed intercity transport system will link the major Saudi cities of Madinah, Mecca and Jeddah. PCT will manufacture the panels for a consortium that comprises Istanbul, Turkey-based Yapi Merkezi Construction and the Jeddah-based Saudi Binladen Group (SBG), the construction lead for the Madinah and Mecca stations.

The structural panels will be a sandwich construction, with a lightweight core between glass fiber/epoxy faceskins. PCT was awarded the job following work with project architects Foster + Partners (London, U.K.) that resulted in a successful prototype. It demonstrated that the complex design could be easily realized with composite materials and it could meet all fire and safety requirements. In addition, the lightweight panels should facilitate construction because they can be lifted easily into place during installation. The entire surface will require 2,048 panels, with a total surface area of 26,000m^2 (280,000 ft^2). Production will begin in June 2012, says the company.


Source | PCT

Composites NEWS

New powder coating technology for composites

InnoVoc Solutions, a division of Gordon Composites (Montrose, Colo.), announced on Feb. 16 the availability of what it calls breakthrough technology for powder coating of plastics, composites and other nonconductive substrates. The licensed technology makes nonmetallic substrates temporarily conductive, using a proprietary surface treatment that emits no VOCs or other hazardous byproducts.

The company's trademarked technology provides a hard finish that is typically tougher than conventional liquid paint,


Source | InnoVoc

using a low-cost process suitable for both automated inline coating and batch-booth quantities. The method produces composite parts that can be affixed to adjacent powder-coated metal parts, such as appliance handles and automotive parts.

Kevin Stay, president and general manager of Gordon Composites, says the technology used by InnoVoc Solutions is easy to implement and inexpensive. "Before the development of this technology, powder coating nonmetallic surfaces was possible, but the processes had manufacturing, cost and environmental limitations that restricted their use," explains Stay. "Powder coating is applied electrostatically, as a free-flowing, dry powder, and is then cured under heat to allow it to flow and cure. We can use the InnoVoc process with any engineered plastic that withstands cure temperatures in the range of 250 to 400°F [121 to 204°C]."

InnoVoc's technology was developed for high-performance composite limbs on modern archery bows. Composite limbs are attached to robust powder-coated aluminum risers and need to have the same appearance and durability as the riser. "With the new technology, we are able to use the same powder coating on both the aluminum risers and the composite limbs so they appear, and age, the same," says Stay. Reportedly, the bond between the coating and limb is so strong that bow fatigue performance improves significantly. Other successful applications include automotive parts, electrical switch plates and handles for appliances.

COMPOSITES 2012 | HIGHLIGHTS

As ACMA's annual conclave convened in North America's gambling capital, show exhibitors and attendees placed their bets on better days.

After an East Coast appearance in Ft. Lauderdale, Fla., in 2011, the American Composites Manufacturers Assn.'s (ACMA, Arlington, Va.) annual exhibition and convention returned to Las Vegas, Nev., this year, running Feb. 21-23 at the Mandalay Bay Convention Center. The COMPOSITES 2012 show theme, "It's All About Tomorrow's Business," mirrored the mood of exhibitors and visitors alike. Looking forward to new opportunities trumped looking back at lost opportunities. *Confidence*, that key but hard-to-measure factor in recovery from a recession, was evident among those who displayed their wares in the aisles.

CONFERENCE COMMENT

In line with the general spirit of optimism and industry growth at the event, presenters at ACMA's technical conference shared some insights on current research and development efforts. Jeff Martin of Martin Pultrusion Group Inc. (Oakwood Village, Ohio) explained his company's work in the area of pultruding with two-part polyurethane (PU) resin, in contrast to traditional thermosets. PU resins generally provide higher mechanical properties than the standard thermosetting resins typically used in pultrusion, including better shear, transverse tensile and impact values. When two-part PUs are used, pultruders can dispense with some of the more costly reinforcements, such as fabrics, that otherwise are necessary to ensure that the part achieves the desired strength. The part wall thickness also can be reduced, with a corresponding reduction of part cost. And PUs *don't* require styrene (see "Styrene controversy update," below). Although an injection die, rather than a resin bath, is a necessity and, therefore, hardware costs are higher, Martin contends that the payback is a part that performs better and opens up huge markets for pultruders, including shelving and ladder rails.

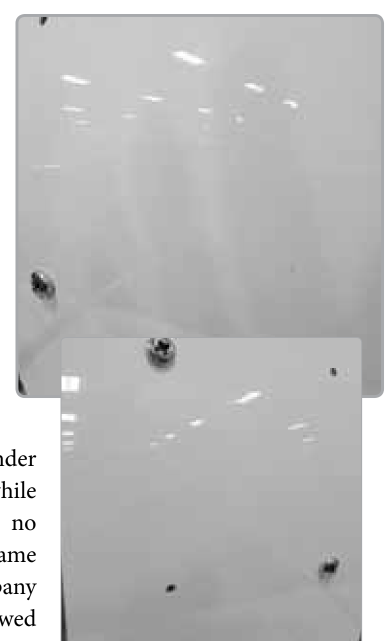
RECYCLED CARBON FIBER PRODUCTS

Materials Innovation Technologies (MIT, Lake City, S.C.) introduced MIT-RCF, a wet-laid, nonwoven blanket of randomly oriented intermediate-grade carbon fibers, with areal basis

weights of 50 g/m² to 500 g/m², which is made from unused prepreg scrap reclaimed from 787 *Dreamliner* production and currently resold in roll-goods form. MIT is working on providing this material in several varieties, including one that commingles thermoplastic/carbon fibers, stitch-bonded forms from **Vectorply Corp.** (Phenix City, Ala.) and a prepreg. The carbon fiber prepreg in original form sells for about $35/lb. MIT's roll-goods product goes for $20/lb. When it is molded with epoxy, it offers a tensile strength of 369 MPa, tensile modulus of 37.6 GPa, flex strength of 556 MPa and flex modulus of 36.4 GPa.
www.emergingmit.com | www.vectorply.com

CRACK-RESISTANT SURFACE COATING

HK Research (Hickory, N.C.) introduced a new polymer called Revolution, a gel coat-like material that offers 6 percent elongation and excellent water and UV resistance. To demonstrate the polymer's flexibility, HK Research mounted two laminates in its booth, one using the Revolution polymer and one using traditional gel coat. Both were mounted under bending stress; traditional gel coat showed cracking under load (top photo), while Revolution showed no cracking under the same load (inset). Company tests reportedly showed that Revolution, when it does crack, self-limits crack propagation and minimizes damage.



www.hkresearch.com

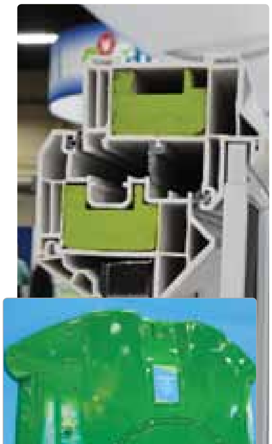
What's more, polyurethane resin formulators are addressing PU processability to improve fiber impregnation and increase pultruder line speeds, says Michael Connolly, product manager at Huntsman Polyurethanes (The Woodlands, Texas). Connolly's paper included news about an interesting software-based modeling tool for pultrusion die and line optimization. It won the Best Paper Award in the "Pultrusion" category.

Another compelling presentation was given by Dr. Brahim Benmokrane, a professor at the University of Sherbrooke in Quebec, Canada. He described a new project in which one level of a 40-year-old, two-way flat slab parking garage was rehabilitated using *only* glass fiber-reinforced polymer (GFRP) reinforcing bars — roughly 40,000m/24.5 miles of bar products — to achieve a construction industry first. Benmokrane says the new slab is performing as predicted, based on in-situ monitoring instrumentation, and he predicts that the slab life could extend to 100 years.

STYRENE CONTROVERSY UPDATE

ACMA offered several conference sessions designed to bring composites manufacturers up to speed on styrene's recent listing in the *12th Report on Carcinogens* (*RoC*), issued in June 2011 by the National Toxicology Program (NTP) under the U.S. Department of Health and Human Services (HHS). ACMA lobbied heavily to keep styrene, an important polyester crosslinking component, out of the *RoC*, arguing that the NTP's chemical ►

POLYURETHANE INJECTION AND PULTRUSION



Bayer MaterialScience LLC (Pittsburgh, Pa.) emphasized its polyurethanes, focusing on the process flexibility of this material. Dominating the booth was a large (121 ft^2/11.2m^2) combine roof module (bottom photo), molded by Romeo RIM (Romeo, Mich.) using its new long-fiber injection press from **KraussMaffei** (Florence, Ky.). Also on display was a composite wind turbine root ring, two prototype airfoils and a high-pressure hydrogen storage tank, molded via resin transfer molding (RTM) and resin infusion. Bayer also featured two pultruded polyurethane window products — a Graham Architectural Products (York, Pa.) GThurm window frame and Deceuninck (Hooglede-Gits, Belgium) INNERGY window stiffener (top photo). **www.bayermaterialscience.com | www.krauss-maffei.com**

assessment process is flawed and employs bad scientific practices. ACMA now is working to get styrene removed from the *RoC* (see “Learn More,” p. 23).

On hand was George Cruzan, president of Bridgeton, N.J.-based ToxWorks, who has worked with ACMA to fight the *RoC* listing. He reported the latest styrene toxicity data and offered his thoughts on the prospects of delisting the material. His detailed presentation reviewed, in particular, genetic components involved in styrene metabolism in mice, rats and humans. In short, he said that new human/animal data contradict the NTP conclusion regarding potential styrene toxicity, and the weight of evidence indicates styrene does not cause cancer in humans. NTP will consider delisting a material if data support the action, but Cruzan said emphatically that “NTP will never delist styrene, no matter what the data say,” suggesting that the NTP is determined to keep styrene on the *RoC* regardless of contrary information.

The U.S. National Academy of Sciences has agreed to review some of the styrene toxicity data. If the Academy agrees with ACMA that styrene is not a threat, that fact might force some change, via Congressional political pressure, within NTP that could lead either to styrene delisting or a change in how NTP assesses chemical toxicity.

ACMA also announced that it has developed a Risk Communications tool kit for composites manufacturers who want or need to communicate with employees and community members about the risks associated with the use of styrene. John Schweitzer, senior director for government affairs at ACMA, told audience members that manufacturers that use styrene would benefit from a proactive program that reaches out to the community and employees about the materials used in their facility and the risks they pose. Information about the Risk Communications tool kit is available on the ACMA Web site at www.acmanet.org/resources/riskcomm.cfm.

ON THE SHOW FLOOR

In the exhibit hall, the Awards for Composites Excellence (ACE) product display area was, once again, awash with interesting concepts and innovations. One example was a new press-based curing system with *rubber-coated* tools (PCRT) presented by Avanti Composites, a division of Kintz Plas-

FLAME-RETARDANT/SMOKE-SUPPRESSANT FILLER

Huber Engineered Materials (Atlanta, Ga.) has developed Micral AM550 alumina trihydrate (ATH), a finely ground flame retardant and smoke suppressant with a median particle size of about 5.5 microns. Features of the ATH include viscosity stability, controlled thickening, fast dispersion, good mechanical properties and good process flow in glass fiber composites. **www.hubermaterials.com**

tics (Howes Cave, N.Y.). As an out-of-autoclave (OOA) alternative, the process allows molders to use less costly tooling and shorter ramp times, at a fraction of autoclave energy costs.

Another example was from Acell (Milan, Italy). The company presented the Compass House concept, a modular prefab housing design. Intended for emergency housing after disasters or other quick-build applications, the concept incorporates the company's patented compression molded panels. Ashland Performance Materials (Dublin, Ohio) highlighted its new strategic alliance with Acell in North America to promote Acell's sandwich panel processing technology (see "Learn More"), based on low-pressure compression molding of sheet molding compound (SMC).

And a new glass/polyester pallet, on display from Plastics Research Corp. (Ontario, Calif.), was made in a compression-molding process that reportedly produces extremely uniform parts, an outcome critical to shipping operations that use robotic/automated palletizing methods. The pallets also conform to food-handling regulations and are much more durable than current wooden pallets.

Elsewhere in the hall, many new products were on offer. Entropy Resins (Gardena, Calif.) and Dixie Chemical (Pasadena, Texas) showed new bio-based resin systems with high percentages of bio-content. New reinforcements were evident at the Chomarat North America (Anderson, S.C.) booth, which highlighted its new C-Ply Bi-angle material developed by Dr. Steven Tsai at Stanford University, and at the Wm. T. Burnett & Co. (Statesville, N.C.) booth, where Polyweb C — a commingled nonwoven glass mat with polypropylene resin material — was exhibited as a thermoforming option. Dust collection and shop air-quality equipment was also at the forefront, as shown by vendors that included Dustcontrol Inc. (Wilmington, N.C.), Eurovac (Concord, Ontario, Canada and North Ridgeville, Ohio) and Nederman Inc. (Westland, Mich.). Hennecke Inc. (Lawrence, Pa.), a supplier of production equipment for polyurethane core technologies, announced the establishment of a new customer test center at its Aachen, Germany headquarters for high-volume, high-pressure resin transfer molding (HP-RTM). | CT |

CW LEARN MORE compositesworld.com

Read a much expanded version of this report online | http://short.compositesworld.com/8fyoisSn.

Read more about styrene's path to the *Report on Carcinogens* in "Styrene: Issues & implications" | *CT* February 2012 (p. 25) | http://short.compositesworld.com/7rkRvIAk.

Read more about Acell's low-pressure compression molding process in "SMC sandwich panels: Lean process opens doors" | *CT* February 2012 (p. 32) | http://short.compositesworld.com/KeUV5dzY.

Read more about C-Ply Bi-angle reinforcement fabrics in "Improving laminates through anisotropy and homogenization" in *CT*'s sister magazine *High-Performance Composites* | *HPC* July 2011 (p. 9) | http://short.compositesworld.com/NszadkNW.

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Formulation flexibility | DIRECT-SMC

Consortium applies inline-compounding technology to reinvent sheet molding compound.

The direct, or inline-compounding (ILC), process has been a major boon to thermoplastic composites during the past decade. Direct processing has driven significant growth in the use of such materials — particularly glass-reinforced polypropylene (PP) — at the expense of both sheet-form chopped glass-mat thermoplastic (GMT) and pelletized long-fiber thermoplastic (LFT) technologies, even when the latter feature higher-temperature engineering-resin matrices.

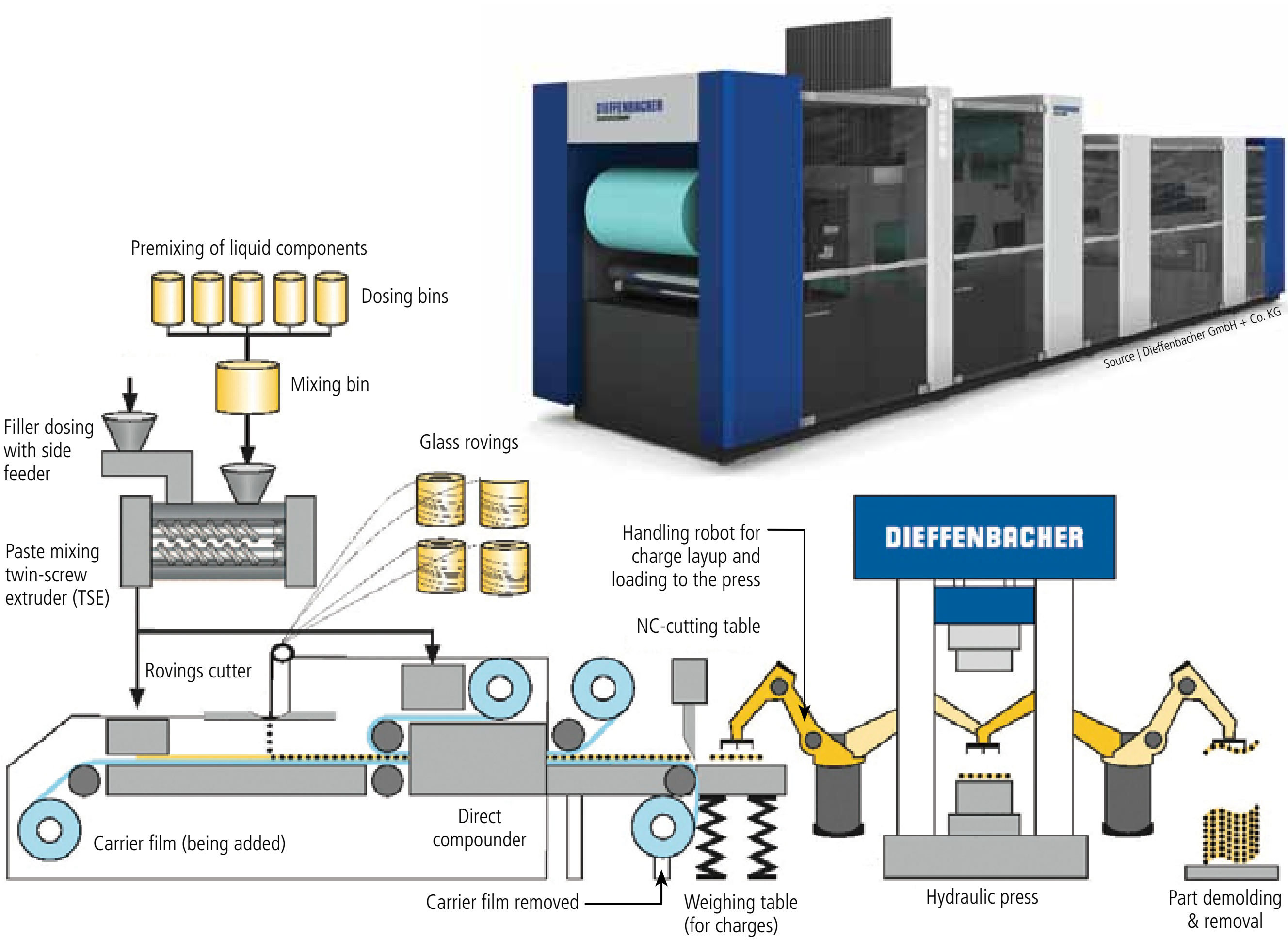
As ILC technology for Direct-LFT (D-LFT, a/k/a LFT-D in Europe) has continued to evolve, machinery OEMs and researchers have found ways to incorporate not only longer glass fibers, but also continuous-fiber rovings and woven fabrics that boost mechanical performance, thus enabling D-LFT to compete directly with high-performance fabric-reinforced GMT and conventional sheet-molding compound (SMC). Resin suppliers have contributed to the expansion of D-LFT technology via polyamide (PA) and other higher temperature engineering resins. Although there is no doubt that innovation will continue on the thermoplastics side of the market, ILC is now being *re*-applied on the thermoset side — where, it could be argued, direct compounding began — to form SMC in a new way that brings unique benefits to processors and end-users.

BMC and SMC

If SMC could be said to have a cousin, it would be bulk-molding compound (BMC). The resemblance is striking; both technologies have thermosetting matrices and both are available with unsaturated polyester and vinyl ester matrices (BMC also comes with a phenolic matrix). Each is reinforced with chopped glass and uses mineral fillers. SMC typically has a higher percentage of glass reinforcement and is stiffer; BMC typically has higher mineral-filler loadings, so it is less costly. Both offer good dimensional stability and have decent impact strength, broad chemical resistance and good thermomechanical properties. Further, they can be painted, plated or stained and can achieve a Class A automotive finish. Each is produced as a semifinished product prior to molding, but here the differences emerge: BMC is produced in bulk, or log, form; and SMC is produced as calendered sheet stock that is subsequently cut to specific sizes. SMC is generally compression molded, and BMC can be shaped via injection, compression or transfer molding — processes that are capable of supporting medium- to high-volume production. Both materials typically reduce mass by 20 to 30 percent vs. comparable aluminum or steel parts, and they do so at lower tooling costs. Both

Source | Dieffenbacher GmbH + Co. KG

Since June of 2010, a fully functional Direct-SMC pilot line built by Dieffenbacher GmbH + Co. KG has been in operation at the Fraunhofer Institute for Chemical Technology (ICT). Here, researchers manually deflash the structural inner shell of a D-SMC rear liftgate for a compact automobile.



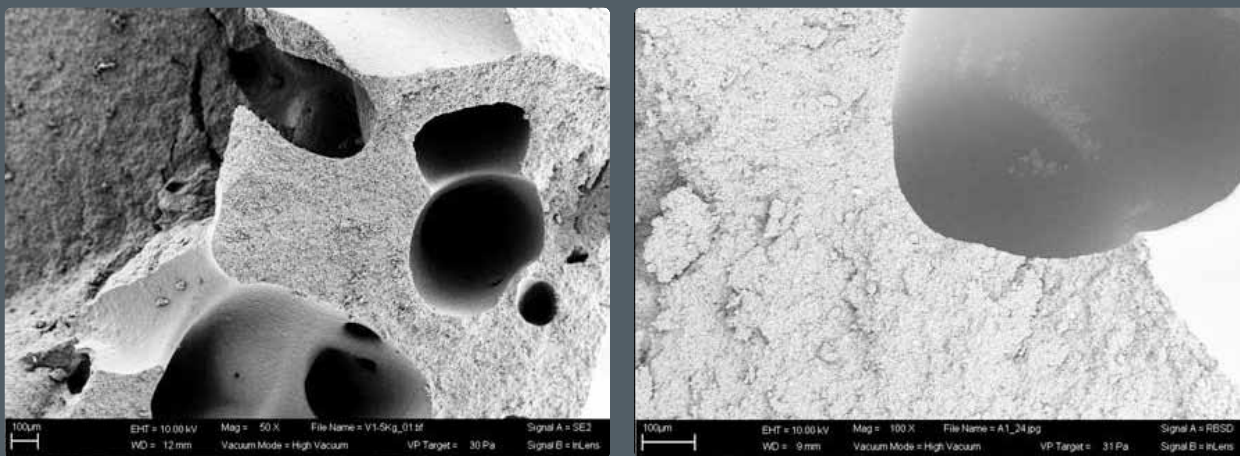
The D-SMC process begins with mixing of liquid raw materials. Then solid ingredients are added gravimetrically from side feeders. The resulting mixture is fed into a twin-screw extruder (TSE) for mixing. Next, the extrudate is split into two equal streams and transferred into doctor boxes on a second TSE. There, continuous glass rovings are fed in over a series of rollers and distributed across the width of the extrudate. The distributed fibers are cut and compounded between sheets of the resin/filler paste where *force-wetting* enables a high fiber-volume fraction (FVF) to be achieved. The glass-reinforced extrudate leaves the die at a set thickness and is exposed to microwave energy at an elevated temperature to accelerate maturation. Finally, the carrier film is peeled off, sheets are cut to size for a given charge pattern and then moved, via conveyor belt, to the side of the press. There, a robot loads the charges into the tool, which closes and a part is molded. ■

are used in automotive and ground transportation (automobiles, pickups and heavy trucks), building/construction, gardening/agricultural and appliance/electrical-component applications.

Although most SMC and BMC in North America and Europe are generally purchased in standard formulations from compounders, BMC does offer processors that have the right equipment the opportunity to compound at the press shortly before molding — an option used in China. ILC gives processors a broader opportunity to tailor reinforcements, fillers and other additives to achieve the properties required for a given application. For high-volume applications, this can be less costly than purchasing precompounded materials. The ability to adjust the formulation on the fly also saves time and grants more control to the processor. These attributes make it easier for molders to create custom compounds for short production runs and allows them to modify properties more quickly during preliminary part development and/or when field data for commercial products indicate that properties need adjustment.

DIRECT-SMC

Now, thanks to the work of a European consortium, it is possible to combine the lower cost and formulation flexibility of BMC with the higher mechanical performance of SMC in a hybrid process called Direct-SMC (D-SMC, also called direct-strand molding compound). Developed by research house Fraunhofer Institute for Chemical Technology (Fraunhofer ICT, Pfinztal, Germany), machinery OEM Dieffenbacher GmbH + Co. KG (Eppingen, Germany) and resin supplier DSM Composite Resins AG (Schaffhausen, Switzerland), the process eliminates the need for the several-day maturation period required with conventional SMC and reduces production delays. With D-SMC, the commonly lengthy interval between compounding raw ingredients and demolding finished parts can be shortened to minutes. ►



Source | Fraunhofer Institute for Chemical Technology

Characterization work shows the D-SMC material is very similar to conventional SMC and BMC, with one exception: Compound consistency is greater than is typically achieved via the dissolver process used to produce conventional SMC, an improvement credited to the use of the twin-screw extruders. Microscopy verifies D-SMC compounds (sample shown on right) have fewer air inclusions and achieve very fine and homogeneous filler dispersion. ■

"By design, D-SMC is a continuous (not batch) process in which raw materials are compounded into sheets that are cut into charges and then molded directly afterwards," says Tobias Potyra, operations manager at the new Fraunhofer Project Centre at Western University (FPC@Western, London, Ontario, Canada) and one of the original researchers on the project at Fraunhofer ICT. "Owing to the closed-loop nature of this system, it is possible to guarantee a high and constant level of quality that is more challenging to achieve with conventional SMC."

He notes that scrap is reduced, which has a positive effect on component costs. Because it is no longer necessary to wait days for material to mature, the time and cost of storing precompounded materials are eliminated. Processors also gain greater flexibility in terms of raw material selection and get close to real-time control over formulation changes. "And with the closed machine path used to produce D-SMC," Potyra adds, "styrene emissions can be better controlled, making it easier to comply with health and safety regulations."

Erik Reuther, new business development manager – automotive at DSM Composite Resins, outlines the team's challenge: "SMC is formulated with up to a dozen raw materials, so a major point we needed to address as we began designing a 'just-in-time' SMC process was how to dose and compound the material accurately and consistently."

The process in its current form, therefore, begins with automated dosing and mixing of the liquid raw materials (e.g., unsaturated polyester resin, low-profile additive and peroxides). Then, solid ingredients (release and thickening agents, and fillers, such as calcium carbonate) are added gravimetrically from a side feeder. The resulting mixture is fed into a Dieffenbacher twin-screw extruder, which forces liquid and solid components together to form a homogeneous compound. Next, the mixture is split into two equal streams and transferred into doctor boxes on the direct compounder. There, continuous glass rovings are fed, cut and spread between the top and bottom layers of the resin-filler paste as they come in from the doctor boxes. To achieve consistent dispersion, the sandwich of paste and fiber strands is run through a degassing and impregnation roller section, where fiber wetout takes place. The impregnated material then moves through a rapid-maturation zone where, in a temperature-controlled environment, the chemical thickening of the D-SMC material takes place within a few minutes. At the end of the zone, the D-SMC is cooled to ambient temperature and moves directly onto the automated numerically controlled (NC) cutting table, where it is cut into the required charge pattern and subsequently laid up to form the charge load for the compression molding process. A robot picks up the charges and places them in the open tool of a compression-molding press, which then closes and molds the part. Depending on the sheet width, throughput and material formulation, the complete cycle — from compounding through molding — can take as little as 15 minutes.

Dieffenbacher has developed its new dedicated SMC Directline equipment to automate ILC during the D-SMC process. The first pilot line has been in operation at Fraunhofer ICT for more than a year, where it has produced material for numerous formulation and molding trials. Characterization shows that the D-SMC material is very similar to conventional SMC, except that the compound consistency is greater because the twin-screw extruders are more effective than the dissolver process typically used to produce conventional SMC.

Microscopy verifies that D-SMC compounds have fewer air inclusions and achieve finer and more homogeneous filler dispersion than conventional SMC. Consortium members continue to evaluate and report the effects of machine and formulation changes on the technology. A second SMC Directline system has been commissioned for FPC@Western, which is set to open in the third quarter of 2012 for North American composites development.

DIRECT BENEFITS

"The main idea of direct technology for thermoset compression-molded composite parts was to establish a continuous, integrated process chain with seamless process control, from raw material to ready-molded parts," recalls Dieffenbacher's technical director, Matthias Graf. "From the fiber-reinforced thermoplastics side, we have seen the shift from precompounded pellets and GMT sheet stock to a direct processing technology. Since SMC can be considered to be a thermoset type of LFT-D, the idea was to follow a similar process." Although Dieffenbacher is one of the inventors of D-LFT and sells ILC units that are coupled to its large compression presses to compound and mold D-LFT parts sequentially, Graf shares the credit for D-SMC's success, thus far, with its consortium partners. "We formed a team representing the best in each field of machinery, resin chemistry and research to get D-SMC to work," he points out. "No single company could have achieved this alone."

Capable of a high degree of automation, the continuous D-SMC process is fulfilling its promise. It provides full line control, visualization and documentation from compounding through molding. Moreover, it saves considerable energy and costs by eliminating previous transport and storage steps; it provides reproducible fiber impregnation and consistent, Class-A quality; and it allows individual recipes to be optimized for all ingredients. Notably, D-SMC also provides opportunities to increase fiber-volume fractions for more demanding applications. Given these benefits, D-SMC offers not only a greater degree of formulation freedom for compression-molded composites but also provides opportunities for SMC molders to fight for market share lost to D-LFT composites during the past decade.

Intriguingly, DSM's Reuther concludes, "GMT is quite similar to SMC and, therefore, a development to a direct process like D-LFT is considered as a logical next step." If a direct-GMT process is in the works, then the composites industry could see another game-changer. | CT |

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Source | ÉireComposites

The first commercial application of ÉireComposites' one-piece blade technology is not its original goal: a reinforced thermoplastic construction. Instead, the 12.6m blade is made using a powder epoxy matrix and the company's heated ceramic/thermoplastic tooling, and is designed to increase the reliability and efficiency of wind turbine manufacturer ACSA Eólica's new A27, a 225-kW turbine.

Thermoplastic wind blades:

TO BE OR NOT?

Will future wind blades incorporate thermoplastic composites? It depends on whom you ask.

Not long ago, thermoplastic composites (TPCs) were heralded as the future of wind turbine blades. Recyclability, ease of repair and, especially, short mold cycle times made TPCs very attractive to blade manufacturers as they struggled to keep up with an all-time high demand. The global economic slowdown, however, tempered that expectation. And persistent questions remain about processing TPCs on such a large scale as well as TPCs' static and fatigue properties, moisture uptake and cost.

Several groups have led technology development, each publishing results of what they believe is the optimum path forward. A team directed by Dr. Harald Bersee at Delft University of Technology (TU, Delft, The Netherlands) has developed anionic polyamide 6 (APA-6), a *reactive* thermoplastic — that is, a thermoplastic that processes like a thermoset. APA-6 now seems poised to play a part in the continued expansion of blademaker Global Blade Technology (GBT, Wieringerwerf, The Netherlands). Meanwhile, ÉireComposites (Galway, Ireland) has successfully produced a 12.6m/85-ft long blade using another reactive thermoplastic, cyclic butylene terephthalate (CBT, developed by Cyclics Corp., Schenectady, N.Y.), and unique processing technology. Yet, despite attempts to develop these materials for production of large (greater than 40m/131 ft) wind blades, others in the wind industry no longer seem so sure that TPCs' potential benefits can be realized at a reasonable cost.

NOT YET IN DENMARK

Holding to this latter view is LM Wind Power (Kolding, Denmark). When the blade specialist announced its Blade King program in 2008, with Danish partners Aalborg University (Aalborg), Risø DTU (Technical University of Denmark, Roskilde) and Danish thermoplastics supplier Comfil (Silkeborg), the program was to last five years, with the ultimate goal to cut large wind blade production time in half by using new material systems. The project screened many materials including thermoplastics, eliminating most, and published papers that conclude no TPC material is ready to be used for fabricating large wind blades. Risø DTU says it continues work in this area, as does Comfil, but on a different level, which it will not detail further due to nondisclosure agreements.

Dr. R.T. Durai Prabhakaran, Materials Research Division at Risø, has surveyed current research on a range of possible thermoplastic commingled yarns, prepregs and reactive polymers for wind blade fabrication (see Table 1) and has published, with the help of Dr. Hans Knudsen at Comfil, several papers that discuss the issues preventing their technology readiness (summarized in Table 2). The development work, to date, has used vacuum consolidation as the processing method, which shares the same basic steps as current infusion/prepreg fabrication using glass/thermoset composites: layup of material, application of vacuum, molding at elevated temperature and cooling. Processed in this way, Prabhakaran claims, thermoplastics present a number of problems that negate their potential benefits:

They require processing at 300°F to 500°F (150°C to 260°C), which typically mandates more expensive materials (e.g., metals, ceramics, polyamides) for already massive tools.

The cooling rate possible with current large wind blade tooling does not match what is needed for thermoplastics. It was observed, at both Risø and Comfil, that for a 5-mm (0.2-inch) thick thermoplastic laminate, cooling takes an hour to two hours due to the limitations of the tooling system used. Prabhakaran asserts that cooling rates of 8°C/min to 100°C/min are required to enable the formation and degree of crystallinity necessary for semicrystalline thermoplastics to achieve structural properties and to prevent embrittlement, which results when crystallization occurs too slowly.

Because moisture uptake is a problem, thermoplastic materials must be well dried before processing and monitored to ensure the moisture content is less than 50 parts per million (ppm). Unfortunately, APA-6 has the highest moisture absorption of the polymers studied. Unless it is thoroughly dried, Prabhakaran contends, it will not react during infusion and "will yield partial/no polymerization," which translates into reduced properties.

The same material system from different suppliers — which differs only in terms of modified polymers (the chemical formulations differ) and the sizing on the fiber surface — produce large differences in material properties. Prabhakaran suggests that current research into optimal fiber surface treatments and sizing for thermoplastic composites will need to continue because the fiber-to-matrix bond is such a key factor in static and fatigue properties.

IN DEFENSE OF REACTIVE POLYAMIDE

Dr. Julie Teuwen, however, believes that the issues in Table 2 are mostly due to processing thermoplastics as a powder coating, and many are simply not applicable to APA-6, which is processed as a low-viscosity liquid that undergoes a slightly exothermic temperature-activated reaction. At TU Delft, Teuwen worked with Bersee on APA-6 for more than five years and recently published her thesis, "Kinetics and Processability of Thermoplastic Composite Wind Turbine Blades." In it, she explains that APA-6 is not greatly affected by speeding up *or* slowing down its cooling rate (Table 2, issue 2): "APA-6 undergoes crystallization and polymerization simultaneously, with roughly half of its crystallization formed at this point. When cooling, crystallization continues. But, due to the toughness of the material, no matrix cracking occurs as it does with CBT." Likewise, Teuwen says that Table 2,5 applies to CBT but *not* APA-6. "Because the viscosity of APA-6 is 10 times lower than that of epoxy, it really does not have problems with wetout and compaction in thick laminates," she asserts. Teuwen reportedly has infused APA-6 ►

TABLE 1 — Compression Properties — Glass Fiber (GF) Reinforced Thermoplastic Composite Systems

Material	Fiber Volume Fraction (%)	Compression Modulus (GPa)	Compression Strength (MPa)	Strain to Failure (%)	Melt Temperature (°C/°F)	Processing Temperature (°C/°F)
Prepreg Tapes (Unidirectional)						
GF/PP	50.9	36.2 ± 0.3	335 ± 64	1.0 ± 0.2	160/320	210/410
GF/ m-PET	49.5	32.9 ± 1.6	372 ± 17	1.2 ± 0.1	127-140/ 261-284	170/338
GF/PA6	50.5	48.1 ± 1.6	619 ± 36	1.3 ± 0.1	220/428	260/500
GF/PBT	46.0	31.3 ± 2.1	517 ± 20	1.6 ± 0.1	228/442	240/464
Commingled Yarns (Unidirectional)						
GF/PP	50.5	41.4 ± 0.4	359 ± 13	0.9 ± 0.1	180-230/ 356-446	
GF/ L-PET	49.5	40.9 ± 1.9	601 ± 91	1.5 ± 0.2		220/428
GF/PA6	47.8	39.1 ± 1.5	577 ± 17	1.5 ± 0.1		
GF/PBT	50.0	37.5 ± 3.2	601 ± 29	1.7 ± 0.1		250/482
Reactive Polymers						
GF/ CBT160	50.0	36.2 ± 0.8	487 ± 61	1.4 ± 0.2		200-230/ 428-446
GF/ APA6**	46	39	634	1.7		180/356
Reference Laminate						
GF/ Polyester	50	38	570	1.5		

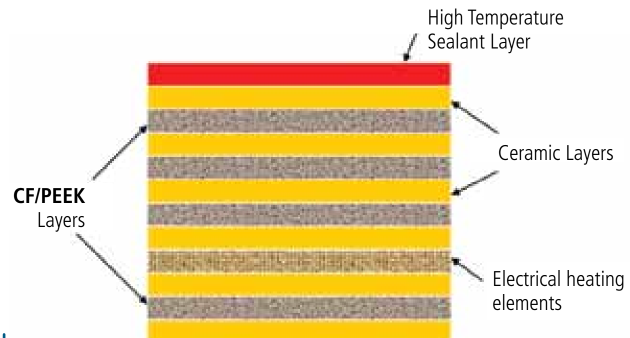
*SOURCE: R.T. Durai Prabhakaran, RISØ DTU; ** Taken from Dr Haralad Bersee's publications.*

TABLE 2 — Issues with Reinforced Thermoplastic Composites for Wind Blades

1.	Difficult-to-process 200°C material in 40m-60m molds with large thermal expansion and higher energy input leads to higher overall blade cost.
2.	Requires faster heating and cooling rates than are possible with current tooling/process equipment; 8°C/min to 100°C/min cooling rates are required for crystallinity to achieve sufficient properties.
3.	Tooling and processing equipment must ensure drying to maintain moisture content < 50 ppm to guarantee complete polymerization and minimize defects.
4.	Ongoing research to improve fiber/matrix chemical bond via fiber sizing is needed to enhance mechancial properties and fatigue resistance.
5.	Compaction and complete polymerization of thick laminates (e.g., 100-mm root sections) while maintaining fiber volume, fiber alignment and wetout.
6.	Lab-scale thermoplastic joining techniques, such as welding, are unproven in production-scale or shop-floor environments.

SOURCE: R.T. Durai Prabhakaran, RISØ DTU

Source | ÉireComposites



ÉireComposites' new large-blade tooling uses alternating layers of ceramic cement and carbon fiber/PEEK, with embedded heating elements. Half of a blade root mold used to make the root at right is shown at top left.

Source | ÉireComposites

This cut-away root section of a 12.6m blade shows how the carbon fiber/PEEK/ceramic composite tooling produces a one-piece blade with no gluelines, using powdered epoxy resins cured at 180°C in eight hours. The attached thermal image made during cure shows that the cure cycle is characterized by even and consistent thermal distribution (top right).

laminates to 50 mm/2 inches thick with good results. "However, for thermoplastic powder-coated materials like CBT, getting a sufficiently high cooling rate in the center of very thick laminates is an issue and could result in lower mechanical properties."

"*Neither* material is perfect," Teuwen admits. CBT is less moisture sensitive, but APA-6, she says, has a broader processing window, and it can be used in an infusion process similar to those familiar to wind blade manufacturers. With regard to the requirement for stringent drying processes (Table 2,3), Teuwen insists, "We don't have a drying cycle. We simply store the material in the plastic bags in which it is shipped, remove it when we are ready to process, melt it and infuse."

Teuwen also participated in the development of a chemically reactive glass fiber sizing that reportedly has almost tripled the moisture-conditioned properties for unidirectional glass/APA-6 laminates, improving the drop in static properties from dry as molded (DAM) to wet conditioned (WET) from 41 percent down to 17 percent (see top chart, p. 33). Even without the optimized fiber sizing, Teuwen says, APA-6 compares well with epoxy in static properties for woven glass fiber laminates (see middle chart, p. 33) and outperforms melt-processed PA-6 (nylon) in dynamic fatigue (see bottom chart, p. 33). Further, APA-6 retains the toughness of PA-6 *and* it achieves a *higher* interfacial bond strength, which improves fatigue strength. This is expected to improve with the optimized sizing, and fatigue testing to demonstrate this is in process.

According to an October 2010 presentation by Teuwen and Bersee, APA-6 was originally chosen because of its low viscosity (10 cps), its processability at a low temperature of 150°C to 180°C (302°F to 356°F), its worldwide availability and its low price — €2/kg to €3/kg ($1.20/lb to $1.80/lb) — for performance. But during her thesis research, Teuwen's original 90-minute *cure* cycle at 180°C/356°F was adjusted to more closely resemble current wind blade infusion, starting with a lower-temperature infusion of 90°C to 110°C (194°F to 230°F), followed by an elevated cure between 140°C and 160°C (284°F and 320°F), with a *total* cycle time that did not exceed 90 minutes. In this way, very large areas have sufficient time to wet out and overall properties are maximized. Dr. Teuwen reportedly has achieved unidirectional laminates with 60 to 68 percent fiber volume fractions and less than 1 percent void content, but also volume fractions closer to the industry target of 54 percent.

A 1.0m/3.3-ft long blade section demonstrator was produced in the laboratory, from infused APA-6 components, including a leading edge, a trailing edge, a two-part box beam spar, leading edge ribs and trailing edge ribs. These parts were resistance welded to form a one-piece assembly (see photo series, p. 34). Future plans include development of better fatigue testing equipment, to enable testing of multiple samples simultaneously, and fabrication of a 1.8m/5.9-ft long blade demonstrator.

Teuwen now is with GBT, which evolved indirectly out of Dutch blade manufacturer Aerpac. In the mid-1990s, Aerpac already had achieved a 24-hour production cycle. Fifteen years later, GBT was formed with the goal of taking another large step. Says CEO Jan Willem van der Werff, "While there are still mechanical hurdles to overcome, the promise of a much faster production process, plus the promise of easier and cheaper in-field repair processes, could lead to yet another avenue to help reduce the cost of energy."

The company offers engineering, design and process consulting from its Dutch headquarters, and full blade production is scheduled to begin this year in The Netherlands and the U.S., the latter at a 45,000-ft²/4,181m² manufacturing facility in Evansville, Ind. In October 2011, GBT announced a contract with Gamesa (Vitoria, Spain) and a developmental partnership with Aeronautica Windpower (Plymouth, Mass.). GBT will build production molds and prototype 26m/85-ft blades for Aeronautica's AWP 54-750 wind turbine, targeted for installations in Ohio. GBT also will develop the complete manufacturing process for Aeronautica Windpower.

THERMOPLASTIC BACK TO THERMOSET

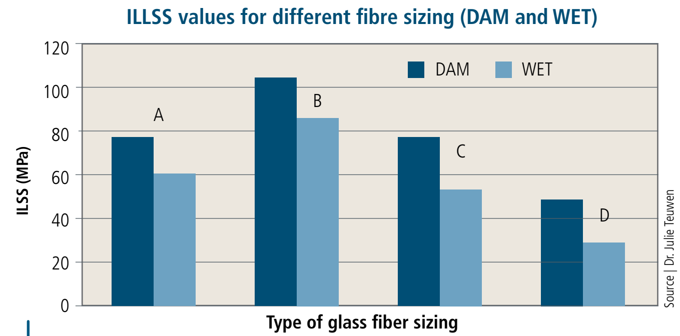
While the Dutch see great promise in APA-6, ÉireComposites found it difficult to process and eventually chose CBT instead. "We evaluated all available options in thermoplastics with varying results," says Patrick Feerick, joint managing director of ÉireComposites. "APA-6 required a very long drying cycle to remove moisture, which prevents polymerization," he notes, "and the only way to get it into the fibers was by a type of RTM that required the injection pipe to be heated."

Feerick and his team saw this as too difficult and costly for large wind blades, which would require numerous heated injection points. "CBT is the only material that is close to being ready for use in wind blades," Feerick contends. "The other materials need a fundamental change to the chemistry to be less sensitive to moisture and also be available in a form that does not require premelting, storing in heated containers and mixing at point of injection." He points out that CBT is less sensitive to moisture and comes as a one-part powder, which eliminates the need to mix it in an activator before injection. "It can also be applied as a film on the surface of the fiber mat," Feerick explains, "thus eliminating injection, which is more user-friendly for molding large parts."

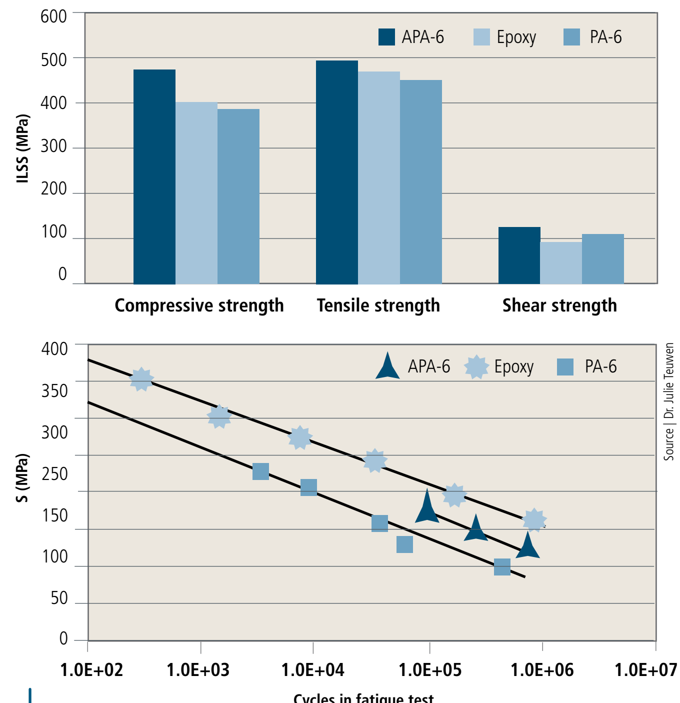
ÉireComposites' 2008 GreenBlade program set out to reduce large wind blade cycle time by two-thirds using thermoplastics. It demonstrated this by molding a complete 12.6m/41-ft long wind blade in one shot with no adhesives in six hours. CBT was applied as a film onto the surface of glass fabric supplied by partner Ahlstrom Glassfibre (Helsinki, Finland) — unidirectional tapes for the spar cap and webs and biaxial 0/90 fabrics for the skins. These semipregs were layed up into molds and enveloped in a sacrificial vacuum bag; the force of the vacuum held each blade part's shape (e.g., spar cap, shear web, shell half) while the blade was assembled in the final production tool. Compatible with the CBT, the bag film did not alter the properties of the final structure. An additional vacuum bag was then placed inside the assembly and vacuum applied to the full structure.

Polymerization took place when the assembly was heated to 200°C/392°F, the sacrificial vacuum bags melted into the layup and the component parts joined to create a one-shot 500-kg/1,102-lb blade with a fiber volume fraction of 50 percent. "Thus, we demonstrated a blade manufacturing process where the main production tool is occupied for only six hours," says Feerick, "because preforming is carried out separately, ideally in parallel, cutting production time significantly."

What made this possible was the further development of ÉireComposites' patented MECH tooling system to enable processing at 200°C to 400°C (392°F to 752°F) without the issues of thermal expansion and with sufficiently fast heat-up and cool-down rates. The new tooling is formed from alternating layers of ceramic cement and carbon fiber-reinforced polyetheretherketone (PEEK), with electrical heater elements embedded close to the tool surface within a ceramic



Of the four different glass fiber sizings evaluated by TU Delft, B showed a three-fold improvement in the WET properties, reducing the static property drop from dry as molded (DAM) to wet conditioned (WET) unidirectional glass/APA-6 laminates to 17 percent, down from a previous 41 percent.



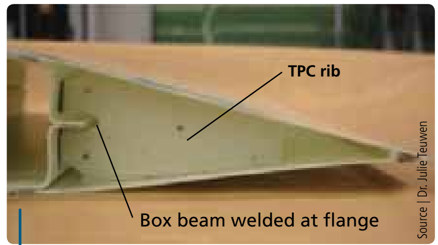
APA-6 compares well with epoxy in static properties for woven glass fiber laminates even without optimized fiber sizing, and outperforms melt-processed PA-6 (nylon) in dynamic fatigue (bottom), while matching its toughness.

layer. Because the ceramic becomes rigid at 60°C/140°F, tooling can be built on inexpensive patterns, removed from the pattern after this initial lower temperature cure and then processed to full temperature (200°C to 400°C) via a freestanding postcure. The tooling's heat-up rate is controlled by varying the electric power to the heating tape. An electrical wattage density of 10 KW/m² proved suitable for processing CBT, bringing the tool surface to 200°C in less than 10 minutes.

Feerick comments, "This tooling is ideally suited for processing reactive thermoplastic polymers, like CBT. However, there remain a number of issues that have to be addressed before it can compete with existing materials and technologies." He explains that overall cycle times are long due to the necessity for drying, and that there is


Source | Dr. Julie Teuwen

All of the parts for this lab demonstrator were resistance welded to form a one-piece blade.



Source | Dr. Julie Teuwen

Top and bottom box beam halves were welded along right and left flange extensions.


Source | Dr. Julie Teuwen

Leading and trailing edges were then welded to the box beam to form a flush shell surface.

too much variation in viscosity due to the currently used production technology.

CBT availability is also an issue. Feerick believes the entire 5 million to 6 million lb/yr (2,268 to 2,722 metric tonnes/yr) capacity of Cyclics' CBT plant in Schwarzheide, Germany, would be consumed by just *one* product line if any of the major wind turbine OEMs adopt it, and adding capacity would cost Cyclic hundreds of millions of dollars. Feerick's team also doubts CBT's ability to form a true one-piece blade via a one-shot process for today's largest blades.

Thus, ÉireComposites began looking for other materials. Indeed, alongside its TPC blades, ÉireComposites now offers a unique *thermoset* alternative, using its ceramic carbon fiber/PEEK composite tooling to enable one-piece wind blade production using powdered epoxy technology (see "Learn More," p. 35). Feerick claims that this thermoset alternative can cut overall blade production cycle time by 65 percent, based on actual processes in use today, and is not limited in terms of part size. The first commercial application is a 12.6m/41.3-ft blade for ACSA Eólica's (Las Palmas de Gran Canaria, Spain) A27, a 225-kW turbine.

OLD MATERIALS, NEW DESIGN

Like GBT, Blade Dynamics (New Orleans, La.) aims to improve the cost and reliability of wind energy, but it sees TPCs as the wrong choice for next-generation blades. The company claims that its new Dynamic 49 (D49) blade — a 49m/161-ft long, 5,880-kg/12,963-lb structure formed from glass/ and carbon fiber/epoxy — offers the performance of a 100m/328-ft diameter rotor with the mechanical loads of a 93m/305-ft rotor. Contributing to the load relief is a new blade root section design that reportedly cuts weight in this area by up to 50 percent. The first D49 was shipped from the company's Michoud Assembly Facility in January, and serial production will be scaled up this year.


Source | Blade Dynamics

Blade Dynamics' D49 blade is segmented, with an elongated spar to which multiple skin panels are attached, each with an integral bulkhead, eliminating separate ribs. This reduces tooling and transportation costs. Its unusual root-section (inset) cuts blade root weight by up to 50 percent.

"We began four and a half years ago with the intent of dramatically improving the turbine rotor through design, engineering and processing," says Blade Dynamics sales director, Theo Botha. "We are focused on reducing the delivered cost of wind energy by applying advanced composites technology." Botha says the key to what differentiates Blade Dynamics is founder Paul Rudling, who propelled composites technology forward for 30 years in both marine and wind energy via continual technical development as founder and head of SP Systems. "We integrate materials and manufacturing process innovation into the blade design process," says Botha, "which is why we have spent so much of our time until now in development. The technology must be proven."

"We use well-proven, industrial composite materials, because despite being performance focused, we are massively risk averse," Botha admits. "We have absolute confidence in our materials and processes. And even though the speed of building the blade is important, what the customer really wants is reliability and lower cost of energy. So the goal becomes to deliver the performance of larger rotors, but without the weight and cost penalty, and simultaneously targeting reduced maintenance and downtime." Botha explains, "All of the other turbine components remain the same, but because you have a larger lightweight rotor, you are increasing annual energy production (AEP) by 6 to 12 percent."

These benefits are gained through the D49's *design*, which is radically different. First the blade is *segmented*. Its May 2011 U.S. patent describes an elongated spar to which plural skin panels are attached along its length to form the upper and lower blade skins. Each skin panel is made with an integral bulkhead, which supports it on the spar, eliminating the need for separate ribs. The design relocates joints to minimize stress, addressing traditional maintenance areas like trailing edges. Because the segments are molded on smaller tools, capital expenditures are reduced for tooling *and* blade transport, and blade quality is easier to control.

Quality problems increase exponentially with scale," Botha notes, asserting that "if you have blades made in a very inconsistent fashion, they age and wear differently, which then creates asymmetric loads on the gearbox. The result is more wear and tear and more downtime for maintenance and repairs."

Second, the company's polymer coating, BladeSkyn, is expected to protect D49 blades for 20 years and improve energy capture efficiency by reducing surface friction, minimizng ice formation and dirt pick up.

Third, and most important, is blade root technology that the company calls "revolutionary." Botha explains, "The current state of the art in wind blade root sections is essentially screwing or gluing into an end-grain composite section with T-bolts, which results in a heavy, thick laminate." The disadvantages include weight, cost and difficulties in processing that waste time.

"We have developed patented technology to reduce the stress concentration effect of each bolt while generating very high pull-out strength." Botha cites an M-30 (30-mm/1.18-inch diameter) bolt root pull-out design with an allowable strength of 570 kN (57 tons). He says, "Our new technology combines very high strength with very low stress concentration in a component that can be laminated right into the layup and infused easily. Now you have a much lighter root because you need so much less laminate." Bonding no longer drives the failure mechanism; fiber now takes the load. "Fatigue performance is exceptional," he claims. "The root now outlasts the bolt."

Currently used in the D49, the blade root innovation, no doubt, will be employed in a rumored blade for a rotor much larger in diameter than 100m/328 ft. Botha also sees this technology as applicable anywhere one would bolt into a composite.

BALANCING ACT

In its latest annual *Wind Turbine Trends* report, MAKE Consulting (Boston, Mass.) contends that the issue of lifecycle cost "has placed new burdens upon wind turbine OEMs, driving innovation in turbine architecture, component design and serviceability to achieve the lowest possible cost of energy." Indeed, this is likely to be the deciding factor between thermoplastic- and thermoset-based material selections and designs. MAKE partner Dan Shreve predicts "The technologies that achieve the *best balance between price and performance* will gain the widest adoption." **| CT |**

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Read more about ÉireComposites' ceramic composite tooling innovation for production of thermoset composite blades in *CT's* sister magazine *High-Performance Composites* | "Big parts? Big tooling breakthrough" | *HPC* March 2012 (p. 36) | http://short.compositesworld.com/LGEyk4LO.

Source | voestalpine Plastics Solutions

Spare wheel well

FUNCTIONAL INTEGRATION

Gas-assist injection molding enables one-piece, one-shot thermoplastic composite/metal hybrid.

In most passenger cars, there is a recessed storage space in the trunk for a spare wheel-mounted tire, a jack and a lug wrench. Traditionally produced in stamped steel, and more recently in aluminum, this spare wheel well (SWW, also known as a spare wheel *baffle*) is a large, heavy, tub-like component that also plays a role in vehicle structure and crash safety. Because it is exposed to the elements, its underside is prone to corrosion. That means it's an excellent candidate for composite-for-metal conversion.

Indeed, European and Asian automakers have been doing such conversions on select platforms for almost two decades. Initially this was done on vehicles with low annual production volumes (150,000 or fewer). The lower tooling costs for composite tubs vs. metal tubs had an immediate positive impact on the OEMs' bottom lines. As confidence in such conversions grew with experience, the composite tubs were extended to vehicles with moderate build volumes (150,000 to 300,000). Today OEMs are considering them for even higher volumes.

A significant step forward in composite SWW development was recently taken with a new material/process combination that debuted on the 2011 model year *Audi A8* luxury sedan from Audi AG (Ingolstadt, Germany). It might well be the first use of short-glass pelletized thermoplastics in a SWW and is said to represent new levels of functional integration and weight reduction in this application.

The Audi tub structure is a hybrid — a 60 percent short-glass-reinforced, flow-enhanced polyamide (PA) 6 resin (Durethan BKV 60 supplied by LANXESS AG, Leverkusen, Germany) comolded with a long perforated aluminum strip. The combination is gas-assist injection molded by voestalpine Plastics Solutions (Putte, The Netherlands), which produces the one-piece tub in one shot.

The tough tub weighs only 9 kg/20 lb, yet it carries 70 kg/154 lb of additional components — seven times its own weight — including a full-size spare tire/wheel, a battery, a car jack, an air-suspension compressor and other electronic control units (ECUs). It reduced the part count from the steel benchmark of 15 to 1, and it

Composite spare-wheel wells have taken another step forward with a new material/process combination that made its debut on the 2011 model year *Audi A8* luxury sedan from Audi AG.

cut capital investment by 70 percent and cut part cost and weight by 30 percent each, all without sacrificing ease of assembly. Further, the mass reduction is said to be equivalent to a CO_2 emissions reduction of 499 kg/1,100 lb annually. But the full impact of this development is best appreciated against the backdrop of composite SWW history.

BEGINNING WITH THE BACK STORY

Switching from metals to composites in this application brings benefits to automakers, tier integrators and even consumers. The low tooling costs are particularly attractive on small-volume or niche-model vehicles. The part weight usually drops 30 to 50 percent, boosting fuel economy. Secondary operations (e.g., priming and painting) can be reduced or eliminated, and system costs tend to be about 20 percent less, on average.

Owing to the increased design flexibility and parts consolidation that is possible with plastics, composite SWW tubs can offer more ergonomic features and greater stowage capacity, yet they take up less packaging space in the trunk area without raising processing costs. Because polymeric materials are well known for their sound-damping properties, composite SWWs reduce noise/vibration/harshness (NVH) values. The quieter ride is a real plus, particularly on luxury platforms. Of course, rust and galvanic corrosion issues that plague metal parts are eliminated, and composites offer better resistance to dings and dents. Composite SWWs also enhance energy management during rear- or side-impact crash events.

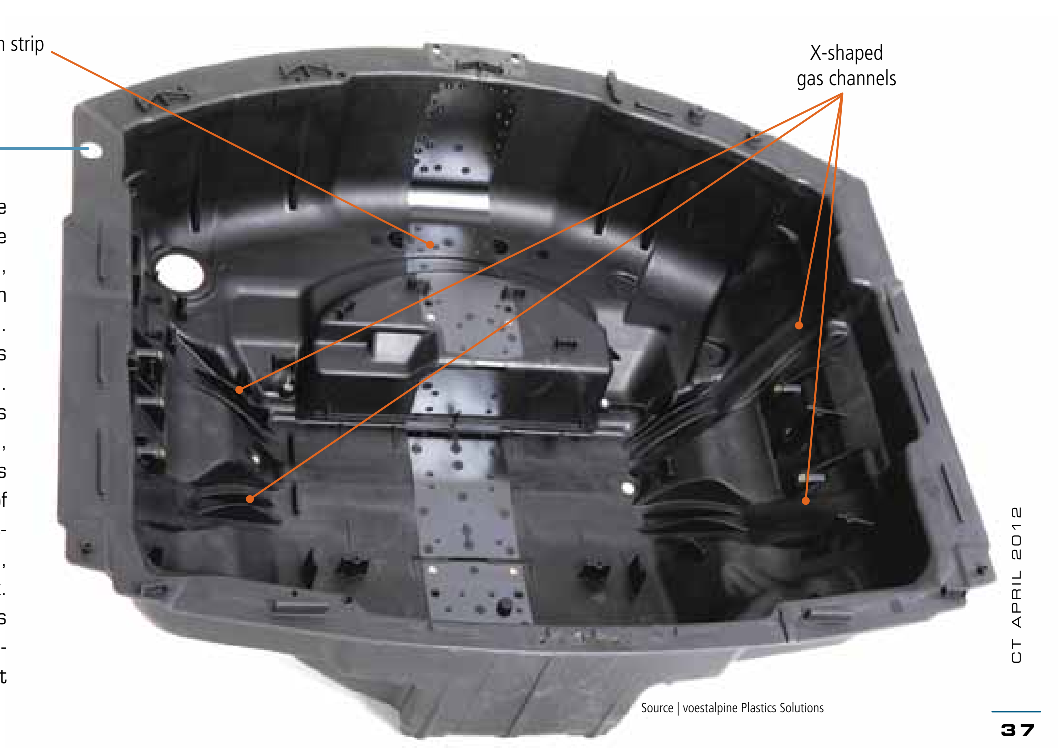
The switch also provides some benefits during vehicle build. Because most composite SWWs can't handle E-Coat (electrodeposition coating) temperatures, they aren't affixed to the body-in-white (BIW) as early as metal units, making it easier for line workers to access wiring and other components in this area of the vehicle prior to trunk closeout. Ironically, installing the SWWs later can reduce assembly line space requirements and costs by eliminating a station normally used to close out E-Coat drip holes in metal SWW pans. Also, in many plants, the same robot that installs the windshield can install the composite SWW because both applications can make use of the same adhesive.

Over the years, a number of different composite material and process options have been tried, beginning with compression-molded sheet molding compound (SMC). To further reduce weight and cost and to increase production speed for a greater volume of vehicle builds, SWW technology moved to compression-molded glass mat thermoplastic (GMT), then to compression-molded direct long-fiber thermoplastic (D-LFT) followed by injection-molded pelletized LFT — all with polypropylene matrices.

Each of the resulting composites offered its own set of benefits and challenges in the application.

On the plus side, SMC was durable, rustproof and relatively easy to paint. It also exhibited high stiffness and strength and the thermal and chemical stability to survive E-Coat, so it could be mounted directly to the BIW early in the build sequence. Like all composites, SMC provided the opportunity for parts consolidation and increased functionality via molded-in design features, while reducing the total tooling costs for a given platform vs. metals. On the minus side, however, it was less tolerant to damage than reinforced thermoplastics, and it was prone to brittle failure in a crash. And although SMC was lighter than aluminum or steel, it was the heaviest of the composites that have been used.

GMT was lighter, and it processed faster than SMC because there was no need to wait for crosslinking. To keep the weight ►



The result of a three-year collaboration between Audi and voestalpine Plastics Solutions engineers, the hybrid composite SWW module's unique features include two gas channels that form an "X" shape, bisecting the part (easily seen from reverse side, in Steps 4 & 6, p. 38). During initial molding, inert gas is pumped into the tool to form the tubes. This removes material from the part's neutral axis (where it's doing no work), yet increases stiffness and reduces weight. Also unique is the thin strip of perforated aluminum, which is insert-molded during the injection cycle, bisecting the SWW tub, front to back. The strip secures the car's battery, and is mechanically fastened to the body-in-white, creating a path-to-ground that prevents static-discharge issues.

1 The raw materials: short-glass-reinforced, flow-enhanced polyamide (PA) 6 resin in pellet form (supplied by LANXESS AG) and a long perforated aluminum strip (inset) arrive at voestalpine's factory.

3 A technician reviews the process settings on a press control panel prior to starting a molding cycle.

5 Looking down from top of the press at the core side of the tool, which is already preloaded with threaded inserts and the perforated aluminum strip.

2 Threaded inserts (2x3 M6-type), which are used for mounting the finished SWW to the vehicle chassis, are robotically loaded into the press between cycles.

4 A view of the open press shows the cavity side of the two-part tool. The "X"-shaped gas channels can be seen clearly.

6 The open press, with platens pulled back, shows the molded part, still on the core side of the tool, which shortly will be removed by a robot.

and section thickness down, tub designers could integrate unidirectional glass and fabric-reinforced charges selectively in areas that require higher mechanicals. GMT was more damage-resistant than SMC or metals and had superior crash performance (with ductile failure modes). However, because it was sold as a semifinished sheet product, GMT proved to be a relatively expensive option.

D-LFT and pelletized LFT also vied for market share. They helped reduce part costs, but often at the expense of added weight, due to the increased section thickness and/or the need for steel or aluminum reinforcement to bolster stiffness. All the polypropylene-based thermoplastic offsets lacked the thermal stability necessary to survive E-Coat, so it was necessary to install them later in the vehicle build sequence. They also were very difficult to paint. Fortunately, integral pigmentation (generally in basic black) eliminated the need for that operation.

The *Audi A8* SWW module, the result of three years of close development work between Audi engineering and voestalpine, sports a number of unique design aspects that mitigate the negatives of other material and process combinations and earned it SPE Central Europe's 13th Automotive Innovation award in the Body Exterior category in late 2010. Chief among the design features are two large gas channels in an X shape that bisects the part (running from the driver side to the passenger side of the vehicle). These channels are produced during the initial phase of molding when inert gas (nitrogen) is pumped into the tool to form the tubes. Not only does the gas-assist process remove (hollow out) material from the neutral axis (where it's doing no work) in an otherwise solid-walled injection part, but it also simultaneously increases stiffness *and* reduces weight. As an extra measure of safety, a strip of perforated aluminum is insert molded during the injection cycle. It bisects the tub width (see photo, p. 37). In the event of a severe crash, the strip restrains the battery and ensures that it stays in place.

DEVELOPING THE PART

A division of Austria-based steel conglomerate voestalpine AG, voestalpine Plastics Solutions specializes in the design and manufacture of structural and semistructural injection- and compression-molded plastic products. The company also has expertise in plastic/metal hybrids (PMHs), like the *Audi A8* SWW module. It supplies leading automotive and truck customers throughout Europe, as well as solar, mobility and industrial-packaging markets. Early goals for the development team included parts consolidation, increased

7 After the completed part from Step 6 is demolded and moved to the shop floor for post-mold finishing; a robot places the aluminum strip (seen here in place) and the inserts for next shot in tool. ■

8 The demolded tub is placed on a turntable before proceeding through stations that stamp it with the primer expiration date, and plasma treat then prime its underside. ■

9 Next, the part is moved to an evaporation box where primer volatiles flash off. After a short stay, the tub is removed and is taken to the next station. ■

10 Adhesive is applied to the underside of the tub. ■

11 The tub is laid on a table where a noise-absorption pad is pressed into the adhesive, forming a bond. ■

12 The demolded and trimmed part, ready for shipping. ■

Source (all step photos) | voestalpine Plastics Solutions

functional integration and cost and weight reduction. However, Audi engineering also wanted the composite tub to provide greater torsional, tensile and flexural stiffness to counterbalance loss of stiffness in the rear of the BIW that can result when an aluminum tub is replaced by a composite tub.

"Given the requirement that we had to make the module stiffer, as well as lighter and lower in cost," recalls Frank Voge, voestalpine's business development manager, "we spent a lot of time working with materials suppliers, design and simulation firms, and toolmakers to evaluate different materials and process combinations to see which selection met our targets most efficiently."

The process included some design-of-experiments work and many simulations as designers looked at multiple options involving glass mat and glass rovings, steel inserts and, on the processing side, compression molding, water injection and other methods. Thermosets were considered, but Voge notes that thermoplastics offered more opportunities for functional integration. Notably, polypropylene was eliminated because its elastic modulus is lower than that of polyamide. "In the end," he says, "the solution that allowed us to get the best combination of stiffness, mass and cost was a glass-reinforced polyamide part produced with gas-assist injection molding."

"Gas-assist injection allowed us to selectively increase stiffness at critical locations while lowering mass," reports Jeroen Dictus, voestalpine's project manager for Audi projects. "Injection molding, of course, is always best for parts consolidation and increased functionality, since it allows numerous features that are impossible to form in metal stampings or difficult to do in compression molding to be designed in from the start." Injection molding also enabled the company to mold in a variety of inserts, including all supports, brackets and mounting hardware. This simplified fixturing and postmold assembly. "And by selecting higher loading levels of a short-glass thermoplastic rather than lower loadings of long or continuous glass," he notes, "we could mold a much more complex part that filled the tool properly without any feed throat restrictions."

The PA 6 yields a tough part with high fatigue strength and a thinner nominal wall than polypropylene would have permitted, says Dictus, adding that it also offers good abrasion resistance and reduced NVH values. And the polymer provides a very good surface finish that can be painted easily. "It also has a continuous-use temperature range that is 80°C higher than polypropylene."

Because the part was designed from the start for gas-assist rather than conventional solid injection molding, there was no need for ►

intermediate prototype tooling, which kept the program costs down and helped move the development timeline along. The team started with a soft (aluminum) gas-assist tool to validate the concept and went immediately to a hard (P20 steel) tool for series production.

"Designing the tool from the start for gas-assist injection was more logical," says Michiel Nieuwenhuize, sales account manager at voestalpine, "because this way, the design uses just two injection ports/valve gates instead of as many as 23, which would otherwise have been required to mold a part of this size and complexity. In effect, the gas channels act like huge hot runners or flow assists, preventing premature freeze-off during the fill portion of the injection molding cycle."

Each sizeable valve gate is outfitted with a needle-sealable hot runner tip. This part is critical to ensure that the inert gas doesn't back out of the gas channel and move into the barrel of the injection molding unit during the pack and hold portions of the injection cycle. The team also found, by means of numerous filling simulations, that the positioning of gas channels and hot drops was critical to ensure uniform freeze-off and to control thickness in the hollow gas tubes that formed during molding. If the gas channels or hot drops are moved a little bit, the gas channels suddenly have nonuniform thickness profiles, or the part won't fully fill before the molten polymer solidifies, leading to short shots.

Owing to the geometric complexity and high level of functionality desired in the final part, the tub design features numerous undercuts, through-holes and other sharp design features that require significant tooling action (slides). In fact, the production tool, manufactured by Simoldes Aços SA (Oliveira de Azeméis, Portugal), is equipped with six hydraulic and two mechanical slides that are necessary to accommodate undercuts in the design. Two of the hydraulic slides are unique because a robot automatically loads 2x3 M6 threaded inserts (used to mount the SWW on the car chassis) into position at an angle directly on top of the two slides before each molding cycle. The tub is molded on a 2,700-ton press from KraussMaffei Technologies GmbH (Munich, Germany). Because of the high processing temperatures (thanks to the high-flow grade of LANXESS PA 6 resin), an excellent surface finish is achieved despite the high glass loading.

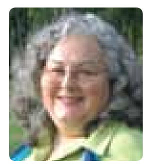
HYBRID REINFORCEMENT

A perforated-aluminum sheet metal stamping, used to secure the battery, is insert-molded into the SWW tub. During molding, the metal insert — 849 mm (33.4 inches) long; between 120 mm and 140 mm (4.7 inches and 5.5 inches) wide; and up to 289 mm (11.4 inches) deep — is mechanically bonded to the composite. The molten polymer flows into the insert's holes and partially encapsulates the profile, forming what essentially amounts to ribbing that prevents the thin metal stamping from buckling under the load. The resulting structure is a specialty that LANXESS pioneered in the European auto industry in the late 1980s. This PMH mixed-material system takes advantage of the best of each technology, offering excellent resistance to bending, compression and torsional loads (via optimum transfer of force between material systems), high energy absorption, dimensional stability and low part weight. It also further consolidates parts and reduces assembly steps while increasing design efficiency and freedom. Although it wasn't necessary in the case of the SWW tub, LANXESS developed a method for joining *multiple* steel stampings via specially designed buttons, which transfer loads from one stamping to the next, eliminating the need for welding.

One challenge the team faced with the stamping was consistently locating it within the part. In early trials, it was difficult to hold the strip in position during mold fill, because injection pressures were high (27,000 kN/m^2 or 27 MPa) and the flow front became turbulent as the molten polymer encountered the tool's complex geometry. To ensure consistent positioning, the team made use of extra in-mold fastening devices to hold the stamping in place. Another issue that the team faced was the size and positioning of the perforations in the aluminum stamping; their geometry proved critical to the creation of sufficiently high adhesion to prevent delamination. Reportedly, it took several iterations to arrive at the final design.

Upon demolding, automated postmold finishing operations apply a long-life paint primer and attach four M8 mounting studs and a noise-absorption pad where Audi will later mount the air-suspension compressor. This reduces secondary finishing at voestalpine's own facility while maximizing assembly efficiency for Audi. The SWW module arrives at the automaker's assembly plant with all subassemblies connected and ready to attach to the vehicle. The unit is adhesively bonded and mechanically fastened to the BIW after E-Coat. In fact, during vehicle assembly, both ends of the aluminum strip, which come up the sidewalls of the tub, are screwed into the BIW to create a path to ground and prevent static discharge issues. Further, the thermoplastic matrix permits end-of-life recycling.

Speaking about what this program means to voestalpine, sales director Huibjan Braafhart says, "This module was an important pilot project to show the market our full capabilities. Not only is our customer pleased with the results, but the program has generated strong interest among other automakers. We are working on next-generation innovative and value-added solutions that exploit the benefits of plastics and composites to reduce weight and cost and increase functional integration." **| CT |**



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Applications

HANDGUN HOLSTERS | Thermoplastic composites target extreme performance

Source | Safariland

Safariland LLC (Ontario, Calif.), a business unit of BAE Systems (London, U.K.), produces gun holsters for law enforcement and military personnel, as well as competitive shooters and firearm enthusiasts. Previously made of leather, the holsters are now fabricated from a proprietary composite that relies on a custom-formulated thermoplastic sheet product from **Boltaron** (Newcomerstown, Ohio) to impart strength and impact resistance.

Millions of holsters used by the military must withstand "normal" use temperatures in the Middle East of 125°F/52°C. But the greater challenge, says Scott Carnahan, a 30-year company veteran and current VP of category marketing in the equipment division, was to produce a holster that could resist deformation when left on a car dashboard at a temperature of 220°F/104°C on a hot sunny day.

Improved heat resistance was an important objective for Boltaron engineers when they custom-formulated the proprietary sheet. Originally developed by Rogers Holster Co. (a company acquired by BAE in 1984), the composite material is produced in a patented hot-laminating and adhesion process that combines nylon or urethane fabric with Boltaron's custom-extruded acrylic/polyvinyl chloride (PVC) alloy sheet. The thermoplastic is fire-resistant and exhibits better resistance to cold-cracking and impact damage than the competitive thermoplastic sheet that it replaced. The resulting composite better resists delamination.

The aluminum tools for the holsters are CAD-designed and then CNC-machined to the tight tolerances required for proper fit. Because most of the holster designs are gun-specific, Safariland works closely with firearm manufacturers to ensure that changes in gun designs don't dramatically affect holster fit and function.

Safariland buys sheets in thicknesses from 0.028 and 0.125 inch (0.71 to 3.18 mm) and reports that during processing they exhibit extreme formability, with reduced shrinkage and minimal thinning in deep recesses and on outside corners. When lamination and molding are complete, secondary operations include burnishing and smoothing part edges. Exterior color and texture, including Safariland's trademarked STX Basket Weave and Carbon Fiber looks and a plain leather appearance, are achieved by varying the thermoplastic sheet or the urethane or nylon cloth laminated to it.

"Safariland composites formed using Boltaron sheet deliver the performance expected by users of Safariland holsters in Alaska and Afghanistan alike," adds Carnahan. ■

PLY PLACEMENT | Largest laser projection system for wind blade manufacture

Following the recent installation of a 16-projector system for an aircraft fuselage application, **Assembly Guidance Systems Inc.** (Chelmsford, Mass.) recently delivered what it says is the largest unified laser-projection system of its kind, for wind turbine blade fabrication. Made of 20 projectors, the LASERGUIDE system, equipped with the company's Multitasking capability, enables multiple technicians to work independently and simultaneously in different zones of a large wind turbine blade tool.

During part fabrication, the LASERGUIDE system projects templates of light via laser onto the composite tool, outlining the exact location for layup of composite materials, and it does so in the proper sequence, according to the job's ply schedule. Technicians simply place plies within the projected template, which is based on three-dimensional design data, typically from CAD files. Each 18-lb/8-kg projector (mounted to existing structures or to fixed or portable stands) focuses the template image automatically and can project lines over a distance of 50 ft/16m with good resolution.

For wind turbine blade customers, a single computer supports the 20 projectors and eight remote controls. It is not necessary to synchronize multiple computers or wait for completion of other activities. For such a large integrated system, Assembly Guidance enhanced the system's Multitasking function: Each individual projector can display multiple templates, even from multiple jobs, simultaneously. This reduces the cycle time and brings operational and facilities costs in line with lean manufacturing practices, claims Assembly Guidance's president, Scott Blake.

Source | Assembly Guidance

The blade manufacturer selected the LASERGUIDE system following a year-long evaluation process because it reportedly outperforms competing systems in such areas as line visibility on challenging materials, such as mats and thick multiaxial glass fabrics. Additionally, the projectors are more easily positioned and are equipped with multiple remote controls. During the evaluation process, Assembly Guidance also provided customized solutions, technical support and applications aid for the blade parts. ■

Calendar

APR

April 16-19, 2012 **EWEA 2012**
Copenhagen, Denmark | www.ewea.org/annual2012

April 17-18, 2012 **SAMPE Composites Overview Seminar**
Anaheim, Calif. | www.sampe.org/events/2-daySAMPESeminar%2810%29.aspx

MAY

May 21-24, 2012 **SAMPE 2012**
Baltimore, Md. | www.sampe.org

May 24-26, 2012 **KOMPOIST COMPOSITE ISTANBUL**
Istanbul, Turkey | www.kompoist.com

May 28-June 1, 2012 **MCM-2012 – XVII International Conference on Mechanics of Composite Materials**
Riga, Latvia | www.pmi.lu.lv/html/Confinf.htm

JUN

June 26-28, 2012 **JEC Asia 2012**
Singapore | www.jeccomposites.com/events/jec-asia-2012

SEP

Sept. 10-15, 2012 **IMTS 2012**
Chicago, Ill. | www.imts.com

Sept. 11-13, 2012 **SPE Automotive Composites Conference and Exhibition (ACCE)**
Troy, Mich. | www.speautomotive.com/comp.htm

Sept. 12-13, 2012 ***TRAM3 2012 – Trends in Advanced Machining, Manufacturing and Materials**
Chicago, Ill. | www.tram-conference.com

Sept. 25-27, 2012 **Aircraft Interiors Expo Americas**
Seattle, Wash. | www.aircraftinteriorsexpo-us.com

Sept. 25-27, 2012 CW ****High-Performance Resins for Aircraft Interiors 2012**
Seattle, Wash. | www.compositesworld.com/events

OCT

Oct. 9-11, 2012 **Composites Europe 2012**
Dusseldorf, Germany | www.composites-europe.com

Oct. 15-17, 2012 **SAMPE China 2012**
Beijing, China | www.sampe.org

Oct. 22-25, 2012 **SAMPE Tech Conference**
North Charleston, S.C. | www.sampe.org

Oct. 22-23, 2012 CW *****CompositesWorld 2012: Materials, Markets, Manufacturing**
North Charleston, S.C. | www.compositesworld.com/events

NOV

Nov. 7-9, 2012 **JEC Americas**
Boston, Mass. | www.jeccomposites.com/events/jec-americas-2012

**part of IMTS Show **colocated with Aircraft Interiors Expo ***colocated with SAMPE Tech Conference*

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Sailing the sea with COMPOSITE WINGS

Autonomous sailing vessel patrols with patented WingSail technology.

Source | Harbor Wing

The HWT X-2, docked (top) and undergoing sea trials in California (bottom). Note the "balance beaks" protruding in front of the wing sail, which hold the electronic equipment that controls the two wing tails, to the rear of the wing.

Sailors have been furling and unfurling, and generally *wrestling* with voluminous sails for millennia. But naval architects and engineers for almost a century have pondered the concept of a simple *wing*. The most dramatic example is the huge rigid carbon fiber structure installed on the 2010 America's Cup winner, BMW Oracle's *USA*, which at 223 ft/69m tall is more than twice the length of a Boeing 747 aircraft wing (see "Learn More" p. 48).

Although sailboats powered by wings have proponents and naysayers, Mark Ott, the cofounder, director, executive VP and manager of Harbor Wing Technologies (Seattle, Wash.), contends that wings are clearly superior to conventional — what he calls *soft* — sails. "In terms of power, a wing is much more efficient than a soft sail," he says. "Per square foot, a wing delivers up to 1.7 times the power of soft sails with much lower drag and actuation force."

That's because a soft sail requires a fairly substantial breeze to get the vessel moving, and its movement in response to changing wind loads dissipates power and causes aeroelastic collapse and drag, slowing forward momentum. Further, when Harbor Wing paired its patented WingSail with its new HWT X-3 catamaran, the "goal was an *unmanned* sea vessel," Ott notes. Without a crew, "a soft sail setup wouldn't have worked." An *autonomous* (self-controlled rather than remotely controlled) unmanned sea vessel (AUSV), the HWT X-3 design has already earned accolades from the U.S. Navy and the U.S. Department of Defense (DoD), and the X-1 proof-of-concept catamaran and X-2 preproduction prototype trimaran have undergone intensive testing.

SAILING WITHOUT SAILS

As early as the 1920s, German engineer Anton Flettner conceived of vertical metal wings as substitutes for sails. John Walker, a British aeronautical engineer, designed the Walker Wingsail and launched the Wingsail-outfitted trimaran *Planesail* in 1966. He still supplies wing sails to commercial and recreational sailors (Shadotec plc, Salisbury, Wiltshire, U.K.). During the late 1990s, Harbor Wing's Ott, together with engineers David Hubbard and Dr. Sam Bradfield, designed *Volantis*, a radical multihulled open-ocean racer that, although never built, provided elements that formed the DNA of the HWT X-3.

Building on past wing concepts, Harbor Wing has, with its WingSail, advanced the science significantly, says Ken Childress, the company's executive VP of business development. "Our unstayed wing is free to rotate 360° around the mast, in *any* direction. It's a real departure from former designs, since the wing force is effectively uncoupled from the vessel below." The wing team included Ott, Hubbard — who helped design BMW Oracle's *USA* wing — and naval architect Duncan MacLane (MacLane Marine Design, Shelton, Conn.).

Ott explains that a monumental wing like the one used in the America's Cup wasn't appropriate for the X-3: "A lot of the America's Cup racing is theatrics. We had to have something more controllable, without stays, that would not overpower the platform [vessel], yet still be lightweight and robust." Harbor Wing started with a fixed mast or "stub axle," designed as a thick-walled,

HARBOR WING COMPOSITE WINGSAIL

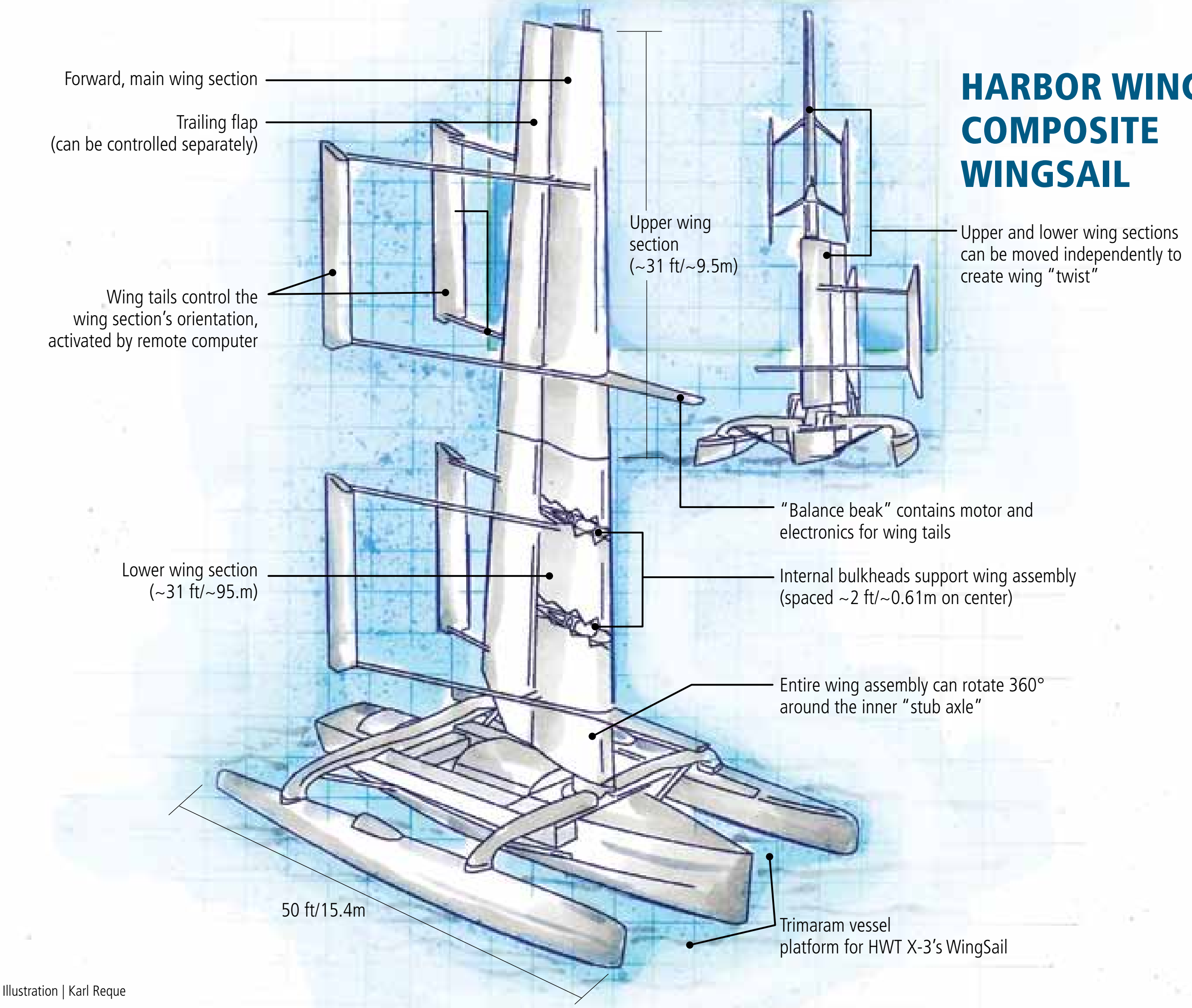


Illustration | Karl Reque

ENGINEERING CHALLENGE:

Develop a means to propel an unmanned surface vessel for reliable and maintenance-free performance.

DESIGN SOLUTION:

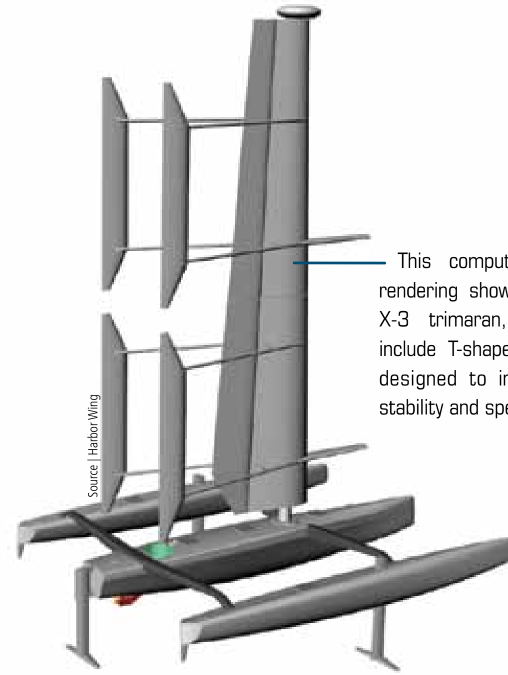
An all-composite rigid wing system, free to rotate 360° around a fixed mast and controlled by a computer.

tapered carbon fiber/epoxy cylinder mounted at the vessel's center of gravity, using finite element analysis (FEA) software. A significant percentage of unidirectional axial fibers would give very high longitudinal stiffness in order to handle and transmit thrust from the wing assembly to the vessel, without deforming under constant bending loads. The stub axle would support the wing's rigid all-composite, $800\text{-ft}^2/74\text{m}^2$ airfoil, which is made with internal "bulkheads" similar to ribs in an aircraft wing (see drawing, above) spaced approximately every 2 ft/0.62m and bonded to the wingskins. Selected bulkheads would be fitted with bearings to enable rotation. The entire wing assembly would slide down over the stub axle. The wing would have a forward "main" section with a leading edge, as well as a trailing flap, which could be moved separately for lift "shaping," as is done with an aircraft wing, explains Childress. To enhance control, the team divided the wing assembly itself into independent upper and lower sections. This *wing-on-wing* configuration allows the vessel to take advantage of wind *gradients* (differences in wind speeds), depending on height above the water. The split design effectively would give a rigid sail the ability to "twist" like a soft sail. In strong winds, the upper wing could be *reefed* (turned into the wind, or depowered) while the lower half still could provide propulsion.

To control the wing assembly, Ott's group devised and patented *wing tails* that extend behind the upper and lower wings. Connected to the stub axle at four bulkhead locations, the wing tails would be equipped with worm-gear-driven linear actuation motors controlled by the company's WingSail Control software (pat. pend.). "The twin tails are big lever arms," explains Ott. "We developed our proprietary sail-by-wire software to send signals to the wing tails to change the wing sail's orientation." The stub axle would be fitted with optical strain gauges to detect bending moments caused by the wind loads as well as thrust and overturning moments. That data would be interpreted, and appropriate commands would be sent to the wing tails five times per second to instantly adjust the wing surfaces so the mast and wings couldn't be overstressed. The software, says Ott, ►

Source | Harbor Wing

This photo shows the rigid WingSail during fabrication. Note the trailing flap (slightly yellow in the photo), the substantial carbon tubes that support the wing tails, and a bulkhead visible at left, inside the airfoil-shaped wing structure.



Source | Harbor Wing

This computer-generated rendering shows the entire X-3 trimaran, which will include T-shaped hydrofoils designed to increase craft stability and speed.

"achieved a very high degree of control and can do anything with the boat, including sail *backwards*." The tails' motors and battery would be housed in the "balance beaks," which extend forward of the wing.

AUTONOMOUS WITH COMPOSITES

The design was realized using a variety of composite materials selected to combat the harsh marine environment and minimize weight. High-modulus HR40 carbon fiber material, supplied by Grafil Inc. (Sacramento, Calif.), was selected for the stub axle to provide maximum tensile stiffness. The mast height and wing size is scalable to any application, says Ott, but for the X-2, the designers determined the optimum mast height as 62 ft/19m, with a base 18 inches/0.46m in diameter, tapering to 7 inches/180 mm at top. Hall Spars & Rigging (Bristol, R.I.) fabricated and autoclaved the stub axle on a male mandrel. The hollow axle accommodates wiring for in-mast sensors, such as cameras or radar.

The wing sail and tail parts are each fabricated by Composites Universal Group (Scappoose, Ore.) in one-piece, on male mandrels, using E-glass wet out with epoxy resin supplied by Newport Adhesives and Composites Inc. (Irvine, Calif.) and are cored with either Corecell styrene acrylonitrile (SAN) foam (supplied by Gurit UK, Isle of Wight, U.K.) or aluminum honeycomb, says Ott. Aramid fiber was incorporated into the wing leading edges for added impact resistance, and some carbon fiber was used in locations that required extra stiffness. The bulkheads are flat carbon fiber/epoxy plate stock, which is CNC-machined to shape. The wing tail arms are simple carbon/epoxy tubes. Secondary bonding (e.g., bulkheads to wingskins) was accomplished using epoxy adhesive from Pro-Set Inc. (Bay City, Mich.). RexNord (Milwaukee, Wis.) supplied the large, low-friction composite bearings that enable wing rotation on the stub axle.

The X-2 is a 50-ft/15.4m long *Contour 50* trimaran. It has a 41-ft/12.5m beam width, a narrow center hull and two outrigger hulls. Built by Contour Yachts (Erin, Ontario, Canada), it was engineered by yacht designers Morrelli and Melvin (Huntington Beach, Calif.) to carry the stub axle and WingSail. The vessel was modified by Knight and Carver Boatyard (National City, Calif.). "The HWT X-2 wouldn't have been possible without composites," notes Ott.

Custom hulls for the X-3 (full-scale production) version have been designed but not yet built, says Childress. The hull payload capacity for computer systems, radios and more, is ~1,500 lb/~682 kg. Childress reports that the HWT X-1, during tests in Hawaii, has successfully maintained course and station instructions and reached a top speed of >25 knots/29 mph. "Our wing configuration has less drag than a traditional bare mast and rigging when turned directly upwind, or feathered, so it's very safe. The computer automatically turns the wing into the wind during mooring so that the wing can't gain an angle of attack. And it's most definitely not fragile. It's built to hold up without ... maintenance for long durations."

If it is adopted by defense agencies, the X-3 could stay at sea for more than three months, particularly if it is outfitted with renewable power sources or energy-scavenging systems.

Beyond the DoD, Harbor Wing has heard from ferry operators, including Wind + Wing Technologies (Napa, Calif.), looking for wingsail-powered ferries in San Francisco Bay and Washington State. And commercial shippers (huge consumers of fossil fuels) and recreational boaters are keenly interested. For the latter, the WingSail on a manned vessel could be controlled easily, with a joystick, a Morse-type throttle or via computer touch screen. | CT |

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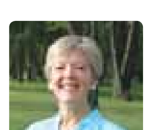

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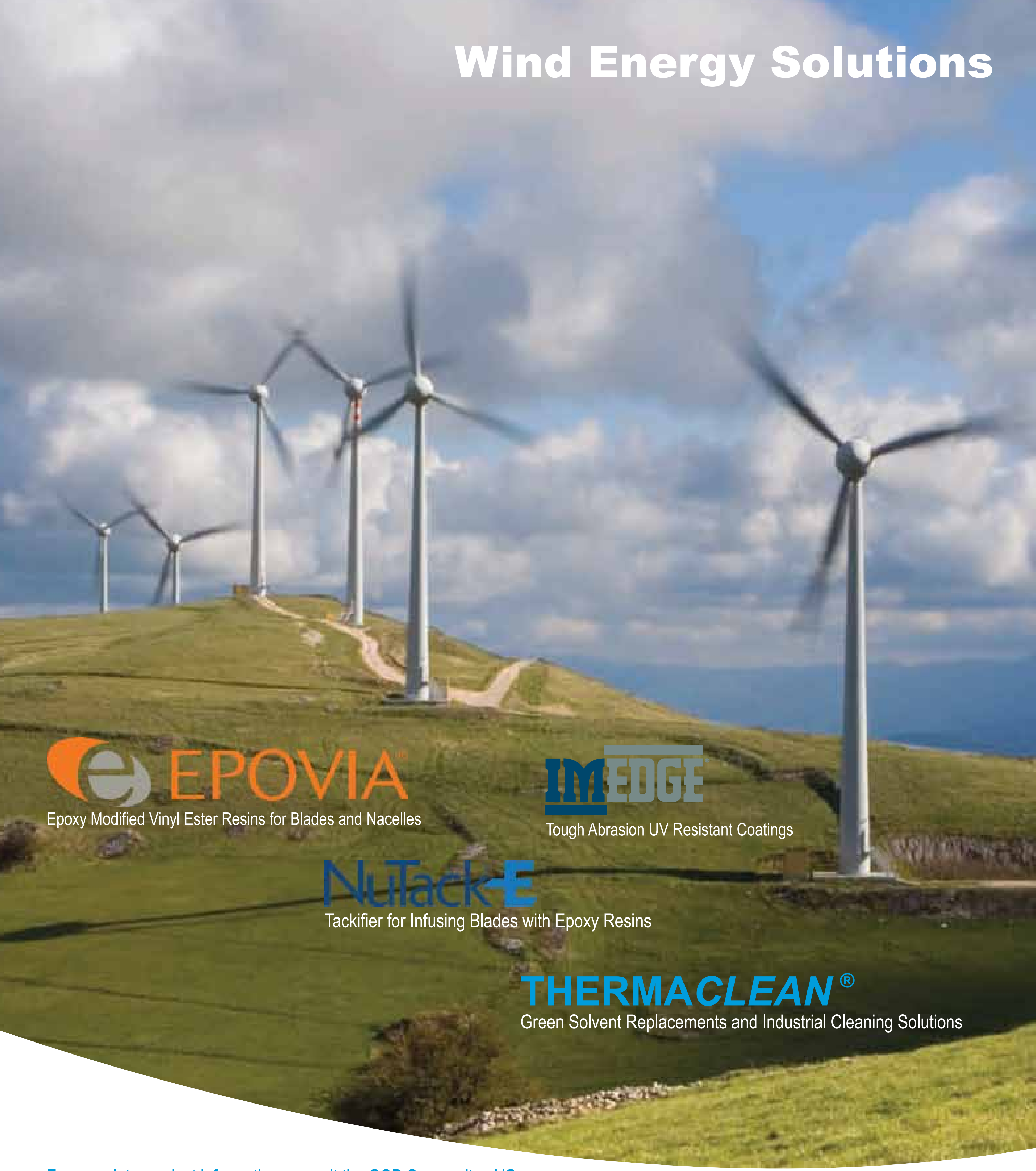
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