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Zenos *E10* RCFRP Chassis: STRUCTURE … *with Style*

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COLUMNS

DEPARTMENTS

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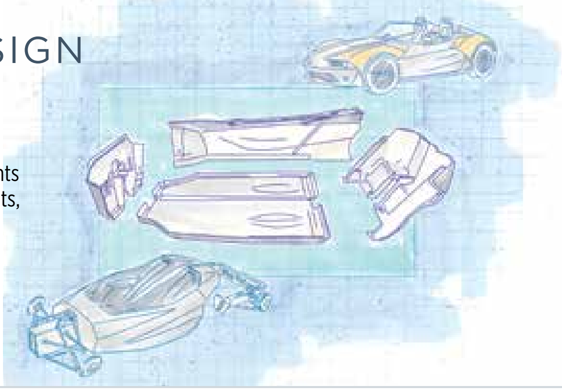
ON THE COVER

The conventional car chassis does the hard work, while cosmetic body panels collect all the accolades. Startup automaker Zenos Cars Ltd.'s (Wymondham, Norfolk, UK) *E10* street-legal racer demonstrates a chassis can be made beautiful enough to play a visible role in vehicle styling and make the car more affordable in the process. See how and why on p. 92.

Source / *evo magazine* / Photo | Dean Smith

FOCUS ON DESIGN



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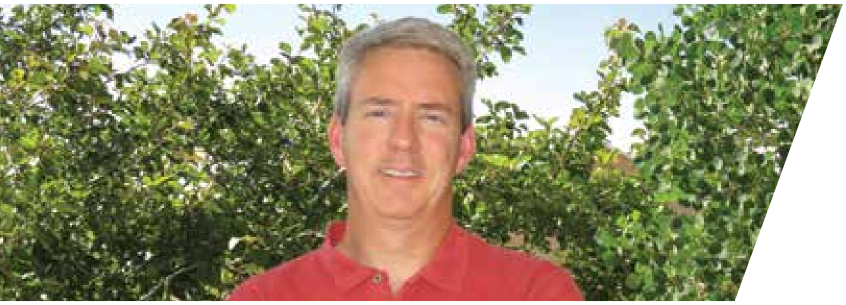


» There is, right now, no end market served by the composites industry that is as volatile and dynamic as the energy market. And because it encapsulates everything from oil and gas exploration to wind energy, its volatility and dynamism has been either extraordinarily beneficial or extraordinarily harmful to composites fabricators, depending on which end of the spectrum you find yourself.

Energy market volatility creates winners and losers.

As has been widely reported, and as is obvious to anyone who pays for gas to fuel their vehicle, the oil market is in the midst of massive oversupply that has depressed prices in ways that, just a few years ago, might have been unimaginable. As I write this, in mid-April, a barrel of crude oil is hovering around $40, and this is *up* from January 2016, when it dropped to $30.83. And both of these numbers are mere fractions of the $92.74 that a barrel of oil was fetching as recently as July 2014. Since then it has been — literally — all downhill.

Although this dramatic price drop has been a boon to consumers, pushing gasoline prices to near historic lows (adjusting for inflation), it's had negative consequences as well, particularly in the oil patch: Many smaller oil exploration and production firms have succumbed to bankruptcy, throwing thousands of people out of work. And for composites fabricators who serve the oil market with the manufacture of highly engineered downhole consumables like the plugs used in hydraulic fracturing (fracking), the news has been just as bad.

The irony here is that the United States has been, in many ways, an unwitting culprit in the oil price depression. After years of dependence on foreign suppliers to feed our demand for oil, the "energy independence" mantra was finally answered with a full-blown commitment to fracking, beginning in about 2006 and peaking in 2014-2015, making the US, today, the world's single largest producer of oil. If you throw in the fact that Iran can now sell its oil into the global market, there seems to be very little light at the end of this price tunnel.

At the other end of the volatility spectrum is the wind energy industry, which is in the midst of substantial and rapid expansion that shows no signs of abating — almost in inverse proportion to oil's decline. Indeed, the American Wind Energy Assn. (Washington, DC, US) issued in April its report on 2015 wind activity in the US, and the results are impressive. In 2015, the US wind energy industry installed 8.6 GW of electricity generating capacity in 20 states, the third most ever in a single year and a 77% increase over 2014. Wind led new plant installations, representing 41% of all new capacity, beating out solar (28.5%) and natural gas (28.1%). Further, 9.4 GW of wind capacity is under construction in 2016, and another 4.9 GW is in advanced development. The US state of Iowa currently derives 31.3% of its electricity from wind, making it the first state to top the 30% mark. Altogether, 10 states derive at least 10% of their electricity from wind.

Globally, the data are even more impressive. According to the Global Wind Energy Council (Brussels, Belgium), the world installed 63 GW of wind energy in 2015, with 30.5 GW of that in China alone. Europe added 13.8 GW, led by Germany at 6.0 GW. All told, the world is running on 432.4 GW of wind energy, and by 2019 that number is expected to exceed 665 GW. The top 10 wind energy producers are China (145 GW, by *far* the largest), US, Germany, India, Spain, UK, Canada, France, Italy and Brazil. In short, that's a lot of composite wind blades.

As difficult as the oil industry's downturn has been, we know that it won't last forever. In the meantime, it is gratifying to see a sustained commitment to wind energy development around the world, and the attendant carbon emissions benefits it offers. In any case, this volatility and dynamism is likely here to stay, which helps make the composites industry as interesting as it is.

JEFF SLOAN — Editor-In-Chief

The Flexible Flyer: How composites made velomobile history

» "I don't like paying for a door hinge," I said to the TV reporter as I opened up the flexible polycarbonate part of my velomobile door, "when I've already bought a windshield." At the time, I was trying to win the Practical Vehicle Competition of the International Human Powered Vehicle Assn. (IHPVA, Cutten, CA, US). After three entries, my trike, the *Car-Cycle X-4*, won in 1996, 10 years after the debut of the trike's running chassis at Expo '86 (see the Side Story on p. 8).

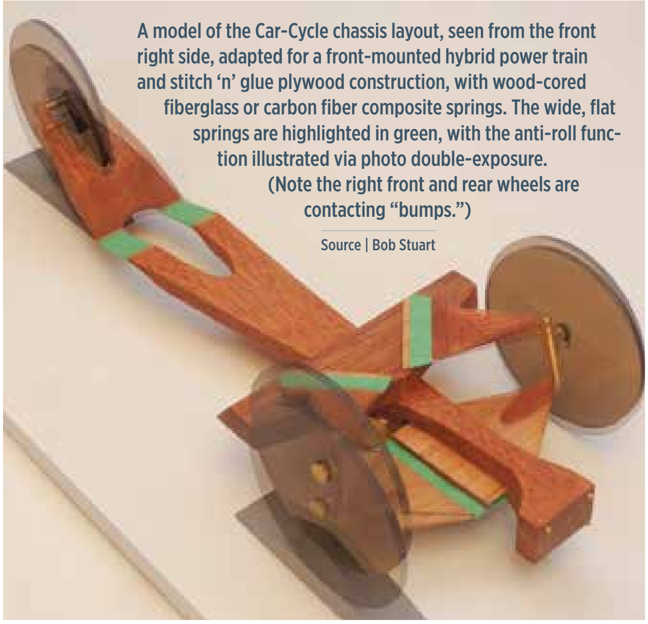
As my combination windshield/hinge hinted, I've always loved to get two or more uses from each part. This made the functional integration that is possible with *composites* very attractive, especially for the critical structures underneath. (Also, I was operating on a "student grade" budget, and big machine tools were out of consideration.) As a first prototype, the *X-4* tested many ideas, some of which solved problems that turned out to be negligible, but the main experiment — integrating the frame with the suspension — turned out to be a big, easy win. The ride is so good, it feels like magic.

Separating frame and spring functions makes them easier to design but then those separate parts are *heavier.*

I grew up on race-car suspension ideals, but really appreciate the clever space-saving and often simplified systems in modern "econobox" cars. With less focus on maximum traction, they can have more forgiving handling as well as a better ride, and I think this helps to develop the reflexes most needed to miss a pothole or a puppy that suddenly appears in the road. The constraints of a flexible frame design barely affect ultimate performance, while saving much weight and cost.

The history of springs used as locating members has been mostly uninspiring, except for all the Hotchkiss rear axles produced with steel leaf springs. The *Model T* Ford used a pair of transverse leaves to the axles, providing a rather wobbly connection to a twisty frame, but the wheels were kept in alignment by subframes, so it worked. The Fiat *Topolino* pioneered the use of *transverse* leaf springs as locating members for independent suspension, and donated many parts to the revolutionary rear-engine Cooper Formula 3 race cars, but problems with unwanted flexing appeared.

Automotive springs are unavoidably heavy: They must store enough energy to lift the frame from the bump stops, and their



A model of the Car-Cycle chassis layout, seen from the front right side, adapted for a front-mounted hybrid power train and stitch 'n' glue plywood construction, with wood-cored fiberglass or carbon fiber composite springs. The wide, flat springs are highlighted in green, with the anti-roll function illustrated via photo double-exposure. (Note the right front and rear wheels are contacting "bumps.")

Source | Bob Stuart

mountings generate high local stresses, which requires a heavy, reinforced section in metal. Composite leaf springs are far easier to produce in shapes that really fit the loads, and they can blend directly into the adjacent structure, with no fastener-related weight penalty. All we really have to remember is that a leaf spring should be arranged to respond to forces in one direction while resisting all others at nearly right angles. *Short, wide* springs are usually best, replacing the pivots on a control arm. I kept my spring sections short and distinct (as illustrated in the updated mockup of my *Car-Cycle X-4* suspension, above). With the aid of finite element analysis, however, it should be possible to *blend* them much farther into the more rigid parts, getting double duty from more of the material. In practical terms, the stiffness of the composite used in the frame can be gradually reduced toward the most flexible spring section, with no abrupt distinctions between "rigid frame" and "spring." By avoiding abrupt changes in stiffness, we employ more of the total material in the weight-intensive business of providing enough spring energy, and the load paths become very direct. This integrated structure is simpler and lighter, yet sacrifices nothing in terms of performance.

I missed a great two-for-one opportunity by not using *two* mounting lines on the main transverse leaf spring. This became »

SIDE STORY

The Car-Cycle X-4

Source | Bob Stuart

I became interested in velomobiles while using a bicycle to commute through the Canadian winters. Some Californians had only been trying to go fast, and they found success with the recumbent position and streamlining, which then necessitated a third wheel for crosswind stability. Those enclosed, three-wheeded racers were just what I needed in the winter. They even provided an enclosed luggage space, so I saw an opportunity.

The current streamlined bicycle record is 86 mph (138.4 kph), and similar technology is used in the Shell eco-marathon to get more than 10,000 mpge at low speeds. By starting with a velomobile and adding power, it is not difficult to get 50% payload capacity in a passenger vehicle, just as we do with transport trucks. Small velomobile "pods" might integrate easily into an automated road-train system, providing a private, mobile space with low impact and cost. If we left the pedals in, we'd get healthier exercise on the busiest days instead of less, which is a great combination.

a favorite trick at General Motors (Detroit, MI, US) because it combines the functions of *spring* and *anti-roll bar* into one elegant unit. As one wheel rises, the spring flexes down in the middle, lifting the opposite wheel to any degree you choose, according to relative lengths of spring. In the photo on p. 6, notice that the left front wheel, although it is not impacted by a "bump," lifts to a degree in concert with the right front wheel, to reduce roll (for more on suspension systems, see Learn More).

On my trike, I improved both roll and pitch stiffness by dividing the total travel between the wheels and using a separate suspension for the seat, which still felt stiff for pedal reactions. (The seat shape worked well in the original plan to have the rider shift his weight on corners. The lower arm of a simple parallelogram was split in two, to fit beside the backbone frame tube and blend into lower seat sections used for cornering.)

Even a plank-on-axle soapbox derby car achieves *some* suspension, and it is easy to find elegant ways to get more travel while retaining fine geometry, but we may miss the usual spring towers when it comes time to refine the ride with shock absorbers or load levelers. A composite transverse structure for springs and anti-roll functions can combine well with the steering and shock integration of a MacPherson strut. I used the bodywork to mount my rear shock, and showed that friction can still be used instead of hydraulics for shock absorbers. Parts rubbing together can dampen selected motions and dissipate heat just as well as hydraulic resistance. Two composite springs could work together to support a load, but be angled to rub where they touch, providing the necessary friction with minimal weight and expense.

Traditional stacked leaves can result in a "rising rate" spring with many benefits. It can provide a soft ride yet accommodate variable loads and offer better control on rough roads, but still allow the harmonic frequency to change with amplitude so it does not go wild on washboard even without shock absorbers. For vehicles with wider loading variations, it might be best to use composite leaf springs primarily as locating members, and then use hydrolastic elements to take care of load leveling and bounce control. They can pump themselves up or down, or integrate with digital controls. They could even power small generators, for maximum efficiency.

The flexible frame also needs to have an acoustic barrier or two planned in between the wheels and any large surfaces. We can do things like using a large chunk of engineered foam between a front crossmember and the frame, providing both isolation and hinges. With the steering box mounted on the crossmember, it becomes easy to keep the wheels aligned.

As the English scientist Thomas Young discovered at the dawn of modern engineering, *everything* is a spring. We may as well get used to it, and take advantage of opportunities instead of strictly segregating our almost-rigid and flexible components. Separating frame and spring functions make them easier to design but then those separate components wind up *heavier*. A more crashworthy design might have a rather floppy but tough composite monocoque that provides much of the spring action, with just a light, rigid subframe keeping the wheels aligned. CW

LEARN MORE

Read this article online | short.compositesworld.com/Car-Cycle

Read *CW's* recent case study of a composite suspension system in "Automotive front axle: A glass act" | short.compositesworld.com/FABlade

ABOUT THE AUTHOR

Bob Stuart (Spiritwood, SK, Canada) left home and school at 17 and took up artistic metalwork. Several years as a monk were followed by dedication to a vocation in Human Powered Vehicles. After attending the 3rd annual Human Power races in California, he bike-toured to Victoria, BC and stayed car-less, except to attend competitions. Sidetracked into pedal boat work, his first design won races, but he sold the molds when he realized they were not saving any oil. He remained childless, pending, he says, "an income not dependent upon reducing our natural inheritance." After his prototypes won considerable publicity but a search for a business partner proved unsuccessful, he retired to write tips for the next generation.

In defense of glass fiber

» I just returned from Paris and the annual JEC show, held in a new location and, to my surprise and delight, very well attended given the distance from central Paris. The event's environment was as dynamic as I've ever seen it, a strong reflection on the optimism in the composites industry today. What struck me particularly this year were the endless displays of molded *carbon fiber* parts — on the various exhibition stands *and* throughout the various new "Planets" organized by JEC to feature parts or assemblies. Although one would expect the Aero Planet would be dominated by carbon fiber structures, the Auto Planet was probably greater than 90% carbon fiber parts. On reflection, I wonder how many of these floor pans, side frames, hoods and roofs are simply technology demonstrators or proofs of concept? How many of them are truly headed for serial production? I suspect most are the former, because there have not been that many capacity expansions announced recently by carbon fiber manufacturers, and large automotive programs that incorporated parts of this size would certainly drive the need for more capacity. Costs of carbon fiber components still need to come down significantly.

> Given the hype around carbon fiber, it's easy to overlook the importance and future of glass fiber.

At JEC, I also had meetings with several of the fiberglass suppliers, whose business seems fairly brisk in today's environment. Given all the hype around carbon fiber, it's easy to overlook the importance of glass fiber and the future of this very pervasive reinforcement. Admittedly, I write a lot about carbon and its potential future, but I think we should also give fiberglass its rightful place in the spotlight. Without it, the composites industry as we know it would be dramatically smaller in size.

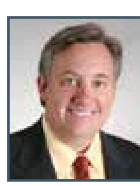
To put things in proportion, the global market for fiberglass used in composites is approximately 5 million MT per annum, while estimates on the high end for carbon fiber put it around 80,000 MT per annum, or *less than 2%* of the market size for glass fiber. This is a substantial difference in scale! Which probably explains why we so easily treat glass as a commodity material. Glass is the predominant fiber in composite materials used in corrosion-resistant pipes and tanks, bridge decks, boats and wind turbine blades. It's also the dominant reinforcement for automotive composites that are actually in production, especially when one considers SMC and thermoplastic injection molding compounds. In aerospace, too, most of the panels that form the interior cabins of commercial aircraft are based on fiberglass.

Glass fiber offers many design advantages, especially considering its relatively modest cost. It is much stronger than steel in tensile strength, and almost as strong as industrial-grade carbon fiber. Its high elongation (roughly 5% strain-to-failure for E-glass, compared to carbon at 1.5-2.0%) enables structures to absorb greater impacts or abrasive forces when paired with high-elongation resins. In fiberglass composites, the coefficient of thermal expansion can be tailored to be closer to that of aluminum and steel, making it a good candidate for metal/composite structures that see fluctuations in temperature. And the molecular structure of the glass itself makes it more amenable to various coupling agents and sizings. This improves glass fiber's adhesion to a broad variety of polymers.

To be fair, at JEC I did see several innovative applications of fiberglass composites in automotive. One was a liftgate inner panel with woven glass inserts in critical impact and stress areas, overmolded via injection molding with glass-filled thermoplastic. I believe the field of structural injection overmolding may be a better fit for fiberglass than for carbon, at least for the next 5-10 years.

Another part that caught my eye was an ultralow-density glass SMC outer panel combined with a thin, carbon fiber inner panel for a hood assembly. This concept of using carbon fiber selectively as stiffening elements in conjunction with glass fiber is not new — wind blade manufacturers often use carbon fiber spar caps in longer blades. Such blades are still 95% fiberglass by reinforcement type. I think we should make more effort to explore glass/carbon hybrid structures to achieve better cost/performance ratios.

Although there are many varieties of carbon fiber, today we mainly use E-glass with a small amount of S-2 glass. Based on my conversations with glass suppliers, there are further opportunities to create glass fibers with targeted properties at a price point between E-glass and S-glass. I, for one, would like to see more development in new glass formulations that can open markets for which carbon fiber composites are clearly too expensive. And if we use the approach of hybridization, we'll open up the market for carbon as well. CW



ABOUT THE AUTHOR

Dale Brosius is the chief commercialization officer for the Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US), a US Department of Energy (DoE)-sponsored public/private partnership targeting high-volume applications of composites in energy-related industries. He is also head of his own consulting company and his career has included positions at US-based firms Dow Chemical Co. (Midland, MI), Fiberite (Tempe, AZ) and successor Cytec Industries Inc. (Woodland Park, NJ), and Bankstown Airport, NSW, Australia-based Quickstep Holdings. He served as chair of the Society of Plastics Engineers Composites and Thermoset Divisions. Brosius has a BS in chemical engineering from Texas A&M University and an MBA.

Testing is inefficient: Material simulation's advantage over the status quo

» Historically, we have screened, characterized and designed new materials with physical testing because simple coupon tests are inexpensive and the results are generally accepted as fact, even when sample sizes are small. The problem is that material science has advanced: New materials are continuously evaluated for their potential, and choices need to be made between types of fibers, matrix materials, composite architectures, use of additional phases and effects of material defects. Further, the options available to support cost- and weight-saving innovations are now almost endless. A simple test matrix for screening alone can add up quickly and does not provide a lot of opportunity to evaluate sensitivities or explore large design spaces (see Fig. 1, at right).

Test matrices are typically determined using engineering experience and internal methods (i.e., rule of mixtures). The time between ordering these tests and getting the results can easily be six months. With results in hand, decisions are made on how best to refine the test matrix for material down-selection. If results are promising, *additional* layups or material combinations are then ordered for a second round of testing. Another six months pass before results are ready for review. This process may be repeated once or twice before sufficient data are collected and a material is fully characterized (see Fig. 2, illustrated in orange). Given today's extraordinary number of possible material combinations, the conventional, multiple-step testing campaign described above, followed by validation and certification, has become extremely time-consuming and expensive.

Simulation tools can be used to accelerate this "test only" approach, addressing test process inefficiencies by quickly predicting the performance of a composite. They can make these predictions long before physical coupons could be ordered, let alone created, tested and analyzed. Simulations can cover several disciplines: mechanical and thermo-mechanical behavior, as well as thermal and electrical conductivity. Users of simulation tools also quickly discover that they can *expand* their design space and simulate *many more combinations* than they could physically test and, therefore, dig deeper into performance drivers. This additional material screening, characterization and design can be done in days or weeks, not months. Then, only the best candidates are selected for a shorter period (and fewer rounds) of physical testing (Fig. 2, illustrated in dark blue).

For example, if we wish to optimize a material for stiffness and weight, material simulation can quickly determine the relationship of the composite's stiffness and density to its fiber volume fraction and concentration of inclusions. Other properties are held constant between models, allowing us to compare and refine the variables we can control.

Rarely does anyone start from zero knowledge of their materials, so the inputs are either known or can be reasonably estimated.

	Fiber A	Fiber B	Fiber C
Volume Fractions	3	3	3
Layups	5	5	5
Matrix A or B	2	2	2
Coupons per Fiber	30	30	30
			90

Fig. 1 "Simple" test matrix = many coupons and much loss of time

A simple text matrix for screening a few laminate variations can quickly add up to production of numerous coupons and a lengthy testing time.

Source | e-Xstream engineering

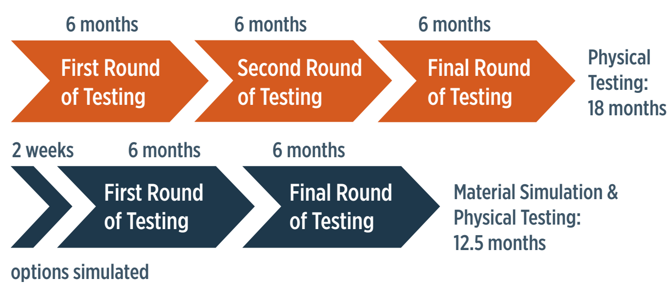


Fig. 2 Simulation = reduced physical testing time and elimination of outliers

Simulation evaluates many material combinations so that the first round of testing can focus on a more targeted group of *likely* candidates. Source | e-Xstream engineering

The simulation results help to identify the material configurations for which we should invest in physical testing, thus eliminating a substantial portion of the original design space. Physical tests now can be focused on a more targeted group of candidates that feature combinations with a much greater probability of meeting design goals. The benefits here are two-fold: We can avoid testing combinations that clearly would have been outliers. Or, conversely, because it is now possible to conduct inexpensive virtual testing on additional candidates we might not otherwise consider, we can open doors that lead to greater materials innovation and a better understanding of the critical performance drivers.

Those who object to material simulation say users don't have all of the constituent properties, and warn that fiber surface effects on composite performance and fiber/matrix interactions are difficult to predict. Others hesitate to use models that are not 100% predictive and insist on having a high degree of accuracy before using models in their material efforts. However, all of the challenges cited are analogous to the structural analysis of parts, where we have used finite element analysis (FEA) for more than 50 years. The only difference is that we are *familiar* with the assumptions that we need to make at the part level. With a little knowledge about our materials, simulation results can provide the same guidance and similar assistance with decisions that FEA does in structural parts analysis. That said, "garbage in" will be "garbage out"; therefore, when setting »

up our material models, we use caution to select input properties from known or trusted sources (e.g., NCAMP or CAMPUS databases) and, where possible, we crosscheck with hand calculations. Testing then can focus on validation and acceptance, not answering "what-if" questions that are easily addressed through simulation.

Anyone who remains uncomfortable with the original modeling assumptions can now reverse engineer properties from the test results. Tests are used to calibrate the models and then validate the predictions. There are cases where the macro response of the material demonstrates a behavior that is caused by microstructural effects which are independent of the constituents' physical properties. A simple rule of mixtures cannot account for these effects, nor does it give us the ability to modify orientations, include resin-rich areas or evaluate a filler's dimensional effects on the macro performance. But physics-based models can include all of these effects and provide diagnostics at the micro-level, which would otherwise require complex test methods.

Calibrated models provide even more opportunity, either for further design or to augment the test results. Predictions of intermediate combinations give us more confidence going into the final round of testing. Certification is still done with physical tests, but now has the additional benefits of insight and optimization provided by simulation early in the process. At the end of the test campaign, the use of simulation has shortened the path to final acceptance.

A former professor of mine once said, "All models are wrong, but some are useful." If we accept that simulation is a useful *guide* for designing complex engineered systems, then we open up tools that can greatly accelerate new material design, development and insertion. Because we have well-established acceptance criteria for the products we manufacture and sell, we are ultimately interested in the final result and not the path we took to get there.

In summary, simulation doesn't replace validation and certification testing, but offers a path to greater testing efficiency. Benefits include

- answers in hours vs. months.
- ability to inexpensively evaluate a much larger design space
- simple and inexpensive sensitivity studies.
- a deeper dive into what drives performance, which helps to focus test efforts.

Many companies hesitate to change the status quo, but those who do are using simulation to support material initiatives that are saving considerable time and achieving more optimal results than before. CW

ABOUT THE AUTHOR

Bob Schmitz is senior business development manager for e-Xstream engineering (Newport Beach, CA, US). He is responsible for e-Xstream's Aero and Industrial accounts in the US, has been in the simulation industry for more than 13 years, has experience evaluating structures using linear and nonlinear finite element methods and currently works to expand the use of advanced simulation tools to accelerate the adoption of composites and replace traditional materials. Schmitz earned his BS and MS in engineering mechanics from the University of Wisconsin-Madison and an MBA from the University of Denver.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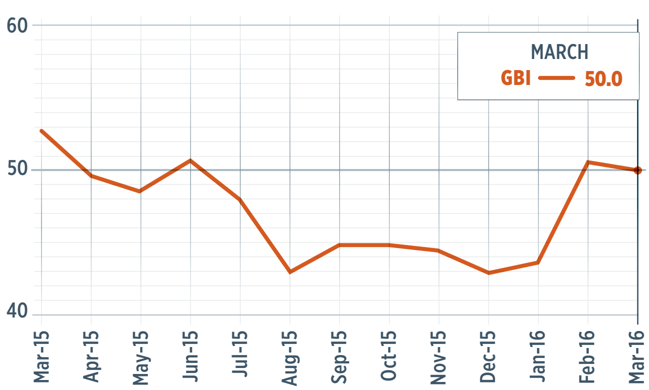
March 2016 — 50.0

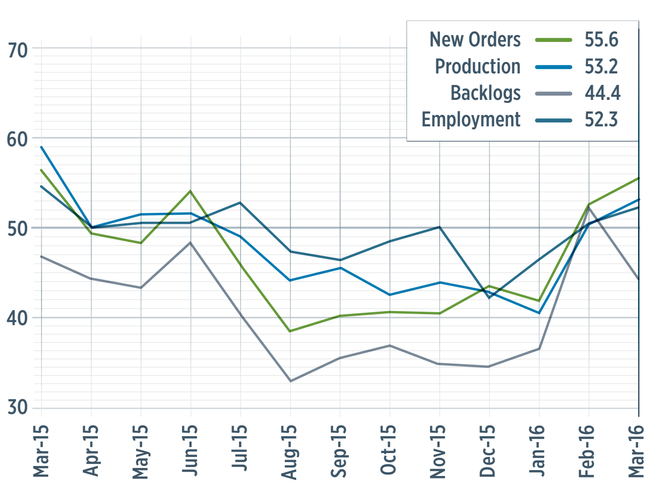
New orders and production are up. Capital spending plans foreshadow equipment investments.

» With a reading of 50.0, the Gardner Business Index showed that conditions in the composites industry were largely unchanged in March from February. Prior to February, the industry had seen a period of contraction from July 2015 through January 2016.

New orders and production increased in March for the second month in a row. And both subindices grew at a faster rate in March than they had in February. As March closed out, new orders, generally, had increased more than production in recent months. Although the backlog subindex expanded for the first time since December 2014 in February, it fell back into contraction in March. But the rate of contraction was significantly slower than that seen in the second half of 2015. The employment subindex, in March, increased for the second month in a row and the third time in five months. Exports continued to contract because of the strength of the US dollar. However, the rate of contraction, when March survey results were in, had slowed steadily in recent months. Supplier deliveries shortened at the fastest rate since the Index began in December 2011. This indicated increasing slack in the supply chain.

A GBI reading of >50.0 indicates expansion; values <50.0 indicate contraction.





Materials prices increased for the second month in a row in March. Although this subindex rebounded sharply, it was still relatively low compared with the levels seen during the course of the past three years. Prices received decreased in March for the sixth month in a row, but the rate of decrease decelerated for the second month in a row. The future business expectations subindex improved modestly after a significant increase in February.

Larger composites manufacturing facilities struggled for the second month in a row in March. Plants with more than 250 employees contracted for the fourth straight month, although the rate of contraction had slowed each of the previous three months. Facilities with 100-249 employees contracted for the first time since November 2015. Companies with 50-99 employees grew for the second month in a row. Conditions at these companies, in March, had improved notably since November. Companies with 20-49 employees expanded at a very strong rate for the second month in a row. In fact, February and March were the strongest months of growth for this fabricator category since March 2015. Composites fabricators, generally, fell back into contraction after expanding the previous month.

By the end of March, the aerospace industry had expanded four of the previous six months. The growth in February and March was very strong, with the industry growing at its fastest rate in March since May 2012. Although the aerospace industry had performed well for composites fabricators recently, the automotive industry showed signs that it was struggling. In March, the automotive subindex contracted for the fifth month in a row.

Future capital spending plans in March increased 37% compared with one year ago. This was the first month-over-month increase in spending plans since August 2015. The annual rate of change continued to contract at a significant rate, but the rate of contraction did slow from the figure logged in February. This could indicate the early stages of a recovery in capital equipment spending. CW

ABOUT THE AUTHOR

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JEC's Paris show (March 8-10) sported a new name and new venue, and topped previous exhibitor and attendance figures. Here's what *CW* found on the show floor.

AUTOMOTIVE

BMW cars again a composites showcase at JEC World 2016

Source | BMW


Source | *CW* / Photo | Jeff Sloan

BMW AG (Wolfsburg, Germany), already notable for its progressive use of composite materials in its *i3* and *i8* automobiles, provided the Parisian canvas for a palate of composites innovations.

A novel all-carbon fiber composite hood developed by Cytec Solvay (Heanor, UK) in cooperation with fabricator C-CON GmbH (Munich, Germany) and automotive metals specialist Läpple AG (Heilbronn, Germany) made its debut on the BMW *M4 GTS* (see photo, top right). Prototyped in just nine months, it represents a substantial step-change in auto parts fabrication and shows how composites molding can be adapted to fit within an established automotive manufacturing supply chain.

BMW approached C-CON with the idea of converting the *M4 GTS* hood from aluminum to carbon fiber composites. C-CON turned to Cytec (at the time, not yet acquired by Solvay) for help developing the required materials and processes. Alex Aucken, Cytec Solvay's global automotive director, Industrial Materials, says the tight development window put tremendous pressure on all involved, but in the end, the material/process not only produced a hood 40% lighter than its aluminum predecessor, but also could be viable and cost-effective in other applications. The 8-kg hood consists of a 1.2-mm thick, Class-A outer panel bonded to a 1.2-mm thick inner structure, with additional carbon fiber composite hinge reinforcements near two corners. Aucken and Tim Wybrow, application research and engineering manager at Cytec Solvay, say that the process involves in-situ application of novel MTR 760 epoxy, developed by Cytec for the application, on a 24K tow carbon fiber just prior to filament winding around a 1m diameter mandrel, in an optimized but atypical angle and layer configuration. After winding, this prepregged layup is removed from the mandrel and then slit to create a flat blank, which is large enough to provide material for as many as three tailored inner- or outer-panel blanks.

For consolidation and cure, a blank is placed flat between two thermoplastic films, which are clamped in place, under tension, by a metallic frame. This *double-diaphragm* forming process, says Aucken, obviates the need for preforming and allows the carbon fiber blank to take the sometimes very complex shapes required, with minimal wrinkling. The frame is then placed in a metal mold in a compression press and cured in less than 5 minutes. C-CON handles filament winding and blank preparation. Läpple does the molding, trimming, cutting and assembly.

Notably, the team set out to develop a composites fabrication process that would enable Läpple to convert to composites without the capital equipment investment for a press, so the hood is molded on a *metal-forming* press. "We have to fit into the existing infrastructure," says Wybrow.

The hood meets BMW's cost, strength, stiffness and pedestrian-safety requirements, has a void content of 1.2%, and its Class A surface is easily paintable.

On the Hexion (Columbus, OH, US), stand, Dr. Francis Defoor, global market segment leader, transportation, discussed the carbon fiber roof arc for the BMW *7-Series*, made via HP-RTM with Hexion's Epikote Resin TRAC 06000 epoxy. It uses a proprietary core technology and offers a cure time of about 60 seconds, Defoor said. The build rate right now is 80,000 units/year, with a target of 100,000-200,000 units per year. Hexion, like many other material suppliers, also is establishing a research technical center, in Germany, to develop HP-RTM, liquid compression and compression molding. Thinking more broadly, Defoor argued that composites fabricators for automotive are still grappling with efficiency and cost requirements imposed by OEMs, but he believes that composites cycle time challenges have largely been solved. What remains, he said, is to solve material handling challenges, which will require more intense application of automation and robotics.

Hexcel (Stamford, UK) also emphasized at JEC its BMW connection, discussing the use of its HexPly M77 UD carbon fiber prepreg in the BMW *7-Series* car's B-pillar (left photo), manufactured in a 90-second-cure process, with automated cutting and in-situ inspection, to produce 500 units/day.

AUTOMOTIVE

Teijin goes public with long-awaited Sereebo molding process

Source | *CW* / Photo | Jeff Sloan

Teijin (Tokyo, Japan) revealed in Paris for the first time many details about its Sereebo high-volume composites manufacturing process. First announced in December 2011 and designed specifically to meet the auto industry's need to fabricate carbon fiber composite parts and structures at high volumes with short cycle times, it was developed in Tokyo and, in cooperation with General Motors (GM, Detroit, MI, US), at Teijin's technology center in Auburn Hills, MI, US.

Eric Haiss, vice president of Auburn Hills-based Teijin Advanced Composites America Inc., told *CW* that the process combines a nylon 6 resin matrix with a mat of chopped carbon fibers (length ~20 mm). The mat is preheated and then molded/formed in a standard compression molding machine in cycle times of 60-80 seconds. Haiss says Teijin cannot reveal the form the nylon 6 takes, except that it is integrated into the carbon fiber mat. In addition, the carbon fiber is sized for the nylon 6 resin.

Parts on display at Teijin's JEC stand indicated the Sereebo process is capable of producing structures with relatively deep draws and large curvatures, with no wrinkling (see image at top right). In addition, changes in mat thickness allow for tailored fiber reinforcement to meet specific mechanical load requirements. Further, says Haiss, the way the fiber is oriented in the mat, isotropic properties can be moderately controlled. Available data indicate that parts made with Sereebo exhibit significant energy-absorption properties: 70 J/g, compared to 59 J/g for continuous carbon fiber composites and 20 J/g for aluminum.

Haiss says the Sereebo process will be used by Teijin to fabricate structural parts for an undisclosed OEM automotive program and model year, but Teijin's history of cooperation with GM makes that carmaker the most likely customer. Fabrication will be done in the US. A firm location has not yet been determined, but it won't be Auburn Hills.

Teijin will discuss Sereebo on June 16 (8:00 a.m.), at *CompositesWorld's* Thermoplastic Composites Conference for Automotive (TCCA), in Novi, MI, US: **www.tccauto.com**

A&P, TenCate test database compares slit-braid and woven fabric

A&P Technology (Cincinnati, OH, US) introduced at JEC World 2016 a new database of test data, developed with Tencate Advanced Composites (Morgan Hill, CA, US) to compare laminates composed of its trademarked QISO quasi-isotropic (0°, ±60°) fabric, a slit braid material, with laminates composed of conventional woven fabric, both prepregged with TenCate's highly toughened TC275-1 epoxy resin. Coupon and panel testing reportedly proved QISO superior in mechanical properties and impact performance, says A&P.

Barry Meyers, VP of technical services at TenCate Advanced Composites, comments, "Based on early discussions with A&P, we had a hunch that the combination of TC275-1 and QISO would result in improved performance, but we did not expect to see such a dramatic improvement in mechanical properties, compared to typical woven laminates. We have seen particularly high improvements in compressive strength and open-hole compression."

QISO's quasi-isotropic architecture has the same properties in every direction, so the orientation of the fabric is not a concern, allowing for simple layup and a reduction in scrap. QISO is offered in a variety of widths and weights.

AEROSPACE

Embraer forecasts 20-year Latin American aircraft demand

Embraer Commercial Aviation (Santiago, Chile) released in April its market outlook for Latin America, which forecasts that the region will take delivery of 720 new jets in the 70- to 130-seat segment over 20 years (11% of the segment's worldwide demand). The fleet in service is estimated to grow from today's 310 units to 740 by 2034. Annual growth in demand for air transport there has been above the world average (~5%), hovering at 7% for 5 years, a trend expected to continue, at 6%, for two decades.

The region's growing middle class will account for much of the increase, because many Latin Americans have yet to take their first flight — the region has 0.4 airline passengers per capita, *one-sixth* of the US number. Currently, says Embraer, more than 200 Embraer *E-Jets* are in service in the region, where Embraer holds a 70% share of the segment. The *E-Jet* family has logged more than 1,700 orders and 1,200 deliveries to some 70 customers in 50 countries. To meet future demand, Embraer is bringing its *E-Jets E2* models to market, which feature composites in flight controls (flaps, ailerons, elevators, rudder, spoilers), landing gear doors, wing-fuselage fairings and radomes. It recently rolled out the first *E190-E2*, which will enter service in the first half of 2018.

SAMPE Europe Summit 2016

SAMPE Europe held its one-day Summit Paris 2016 event at the Hotel Pullman Paris Eiffel Tower on March 7. *CW's* technical editor Sara Black was in attendance and noted the following standout presentations.

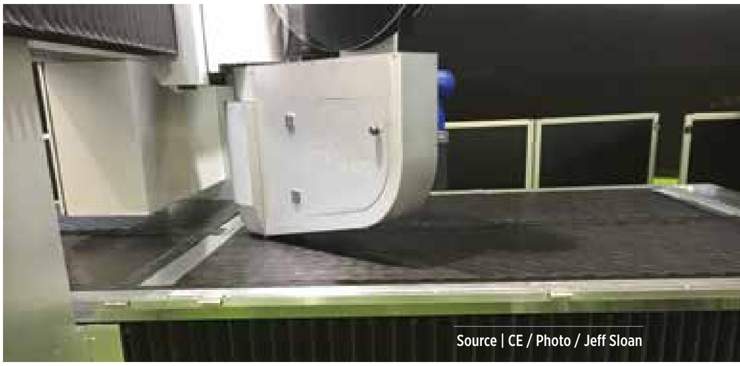
Formerly a director of Audi's Lightweight Center (Ingolstadt, Germany) and currently a board member of Carbon Composites eV, Heinrich Timm described Audi's study of the impact of mass, and how high-strength steels, aluminum and composites all played a part in creating sufficient stiffness for the automaker's car bodies. He emphasized that trial and error does not lead to the best solution, that carbon is not a replacement for metal, and that virtual simulation is a must for a multi-material concept, to take advantage of carbon fiber's anisotropy. He described a Carbon Composites eV project that aims to reduce the processing cost of carbon composites by 90%, and material cost by 50%: "If we don't reach these numbers, carbon fiber won't be going into mainstream automotive." Nevertheless, he cited the Audi *7-Series'* "patchwork" hybrid approach with carbon in selected areas, and the benefits of system integration. He concluded with the prediction that about 15% of a car body in carbon composite would make sense.

Valentin Koslowski (University of Stuttgart, Germany) gave a fascinating paper on a bio-based architectural concept: replicating spider cocoons with carbon and glass fiber to form novel architectural spaces. The process starts with an inflated polymer bag, with its shape maintained with positive pressure. An articulated robot inside the bag places individual tows of carbon or glass against the plastic; the end effector developed by the university is able to stick the tow to the plastic without applying so much pressure that the bag breaks. The composite tows cure ambiently to form arching, random fiber strands that are programmed based on the natural spider cocoon elements. When cured, the bag is removed, and the resulting graceful and interesting "room" or space is left. The group has also robotically formed "trees" and other biotic elements; one of its designs will be installed this year at the Albert and Victoria Museum in London, as a sun canopy.

Roeland Coumans of CeraCarbon (Stein, The Netherlands) described new (pat. pend.) CeraCarbon, consisting of carbon fiber laminate tubes coated with a ceramic material. Coumans said his product already has been adopted by Moto GP motorcycle racing teams for suspension elements that typically see wear and abrasion. CeraCarbon elements are 75% lighter, saving 1.5 kg in unsprung weight. Aircraft landing gear elements and helicopter blades could be promising applications.

Jan Peeters (FiberCore Europe, Rotterdam, The Netherlands) described his company's composite bridge building method. Using a reconfigurable mold, automated methods and serial production, FiberCore has installed more than 450 durable structures in Europe at costs that are often lower than conventional materials. His Infracore concept of stacked, z-style composite beams eliminates the Achilles heel of composites in bridges: interlaminar shear and subsequent delamination.

JEC World 2016: Aerospace highlights


Source | CE / Photo / Jeff Sloan

Fokker Aerostructures (Hoogeveen, The Netherlands), a GKN Aerospace company, demonstrated at its stand a thermoplastic composite aircraft demonstrator spoiler, fully functional and consisting of only three parts: top skin, bottom skin and a single spar. Material is carbon fiber/polyetherketoneketone (PEKK) AS4D/PEKK unidirectional tape, supplied by Cytec Solvay (Woodland Park, NJ, US). Arnt Offringa, director of Fokker Aerostructures research and development, says that skins have additional plies at load introduction areas, and vary in thickness from slightly more than 1 mm to 4 mm (about 10-30 plies). Additionally, skins are stiffened with simple hat sections, co-melted with the skin during short-duration autoclave processing, used to heat and consolidate the parts to prevent porosity. The flap's trailing edge has an integral edge stiffener formed by simply folding the top skin over the lower skin. Fokker also announced that it has licensed its Fokker-developed end-effector that features 35,000-Hz ultrasonic heating capability to a partner machine builder and automation company, Boikon (Leek, The Netherlands), which displayed automated thermoplastic blank production in the demonstration area of the show (see photo). The Falko automated layup head is, according to Boikon, the world's first layup system based on continuous ultrasonic tacking technology; more information on the automated thermoplastic layup machine is available here: **www.fiberplacement.com/#/automated-lay-up**

Visitors were plentiful at automated equipment manufacturer MTorres' (Torres de Elorz, Spain) stand in the wake of its recently announced new-generation hybrid automated tape laying (ATL)/automated fiber placement (AFP) solution. Specifically for wingskin fabrication, the system reportedly triples productivity and reduces scrap significantly. Its 24-course ATL head can be interchanged with its AFP head in less than two minutes. Reportedly, fiber placement of wingskins is faster and more efficient than tape laying, because tows are cut on the fly without stopping by MTorres' patented rotary cutting system. Further, the machine gantry has been redesigned to handle the extreme accelerations possible with AFP. The ATL heads can be used for additional tasks, such as laying fiberglass or copper mesh plies, in the same manufacturing cell, improving productivity and logistics, says the company. (*continued on p. 28*)

(*continued from p. 27*)

MTorres also is a key equipment supplier to the Fundacion para la Investigacion, Desarrollo y Aplicacaion de Materiales Compuestos (FIDAMC) located near Getafe, Spain, a collaborative aerocomposites R&D center supported by Airbus and local Spanish government agencies. *CW* will be following an ongoing FIDAMC investigation into the feasibility of an all-thermoplastic wing with integral welded stiffeners. MTorres will supply the automated fiber placement (AFP) head with laser heating for the demonstrator project.

Hexcel (Stamford, UK) held its annual press conference at JEC and reported financial and other news. Nick Stanage, chairman, president and CEO of Hexcel, reported the company had $1.861 billion in 2015 revenue, with 45% of that coming from the US, 39% from Europe and 16% from ROW. Stanage says Hexcel is the largest aerospace weaver in the world and "virtually" the largest honeycomb manufacturer in the world. Hexcel places US$5 million worth of material on every A350 XWB that Airbus manufactures. In April, Hexcel opened a new R&T Innovation Center in Duxford, UK, for the development of fast deposition, infusion, fast-curing and advanced modeling technologies, plus low-temperature cure systems for thick prepregs. The industrial market is the company's fastest growing segment, led by Tim Swords, VP and GM industrial. He commented on Hexcel's recent acquisition of Formax (now branded Hexcel Reinforcements UK), emphasizing the lineup of multiaxials and NCFs that the business brings.

CW MONTH IN REVIEW

Notes on newsworthy events recently covered on the *CW* Web site. For more information about an item, key its link into your browser. Up-to-the-minute news | www.compositesworld.com/news/list

Albany International finalizes acquisition of Harris aerostructures business
The Harris division supplies advanced composite products primarily for airframe applications.
04/11/16 | short.compositesworld.com/AlbanyHarr

New bridge deck in Ohio made with fiber-reinforced polymer
Composite Advantage wins bid to replace the structure with its FiberSPAN bridge deck system.
04/11/16 | short.compositesworld.com/OHbridge

IAC debuts FiberFrame on 2017 Mercedes-Benz
Germany-based International Automotive Components (IAC) has launched its ultra lightweight natural-fiber sun roof frame on the 2017 Mercedes-Benz *E-Class*.
04/11/16 | short.compositesworld.com/IACsunroof

CCDI Composites reveals carbon fiber torque tube assembly
California-based CCDI's carbon fiber driveline for an American sports car manufacturer saved 30 lb compared to its steel predecessor.
04/11/16 | short.compositesworld.com/CCDItorque

SpaceX nails Falcon 9 launch and sea landing
If the rocket is qualified for reuse, the Hawthorne, CA, US-based company plans to relaunch the same vehicle on an orbital mission in June.
04/11/15 | short.compositesworld.com/Falcon9sea

FACC Solutions completes 1,000th split scimitar winglet
FACC's Wichita, KS, US, operation is upgrading Boeing 737NG blended winglets to new split scimitar winglets.
04/11/16 | short.compositesworld.com/FACC1000

Quickstep enters South Korean automotive market with composites contract
The company will deliver composites manufacturing equipment to the Korea Institute of Science and Technology (KIST) by the end of 2016.
04/07/16 | short.compositesworld.com/QuickKorea

DARPA awards Phase 1 contracts for its Gremlins program
The contracts have been awarded to four teams led by Composite Engineering Inc., Dynetics Inc., General Atomics Aeronautical Systems Inc. and Lockheed Martin.
04/07/16 | short.compositesworld.com/DARPAGrems

Fokker, Airbus partnership to focus on glass fiber/metal laminate
The strategic partnership will research and develop automation of Fibre Metal Laminate (FML) production.
04/04/16 | short.compositesworld.com/GlassFML

2017 Toyota *Prius* features carbon fiber rear hatch
The carbon fiber composite rear hatch on the latest plugin hybrid from Toyota helps the car achieve an estimated 120 mpge.
03/28/15 | short.compositesworld.com/PriusHatch

JEC World 2016: Automotive highlights

On the automotive side, Henkel (Düsseldorf, Germany) emphasized on its JEC stand a glass fiber-reinforced composite leaf spring, based on Henkel's polyurethane matrix resin Loctite MAX 2, used in the chassis of the new Volvo (Gothenberg, Sweden) *XC90*, a premium crossover SUV; the platform of this vehicle is expected to be applied to other Volvo cars in the coming years. Frank Kerstan, global program manager, automotive composites, says BENTELER-SGL (Ried im Innkreis Austria) is making the leaf springs via resin transfer molding (RTM) in 30-second cycle times. Able to produce 8-10 leaf springs in each mold, BENTELER-SGL plans to manufacture up to 500,000 leaf springs per year by 2018. On the developmental side, Kerstan says Henkel is working on several intriguing technologies, including a urethane-based adhesive for multi-material automotive bonding applications that have a CTE mismatch. Also in the works is an RTM-based molding system using urethane resin that allows for the fast production of Class A surface body panels. This is done, says Kerstan, by use of a double-injection process in which the second injection creates the high-quality part surface that Class A requires.


Source | CW / Photo | Jeff Sloan

Meanwhile, at its JEC World stand, Huntsman Advanced Materials (The Woodlands, TX, US) announced that it has developed a new epoxy resin system and a novel, cost-efficient compression molding process, to facilitate the simple production of structural composite parts, and enable cycle times as low as 1 minute without any further post-curing for high-volume applications such as automotive. Currently, a trademarked ARALDITE is used to manufacture BMW's (Munich, Germany) *i-Series* cars. With a cure time of 2 minutes at 130°C, this system gives a total cycle time of around 2,5 minutes. However, the latest rapid-cure.

ARALDITE epoxy system reportedly provides a cure time of only 30 seconds and displays a higher T_g, thus enabling robust processing up to 150°C and a press cycle time of only 1 minute, without further post-curing of the part. Following cure, the epoxy system displays a tensile elongation in excess of 5% with a T_g of 120°C.

To complement this new epoxy system, an innovative and simple Dynamic Fluid Compression Molding (DFCM) process also has been developed by Huntsman, which eliminates high-pressure injection and, in many cases, even the need for a preform. Resin impregnation occurs through the thickness, greatly reducing the potential for fiber displacement, a common problem with resin transfer molding (RTM). Company tests show reduced void content of laminates in comparison to conventional wet-compression molding (WCM) processing, and porosity of less than 1%, making it comparable to high-pressure RTM (HP-RTM) or autoclave, even in deep-draw parts. Fiber volume content of 66% can be easily achieved with no special processing conditions. The new DFCM process means lower mold pressures and a lighter press, plus no need for a high-pressure injection machine. Plus, DFCM eliminates resin waste because no surplus of resin or fiber is required to remove air from the part. The new process enables fast processing of thermoset parts, without the expense of prepreg and higher-priced thermoplastics.

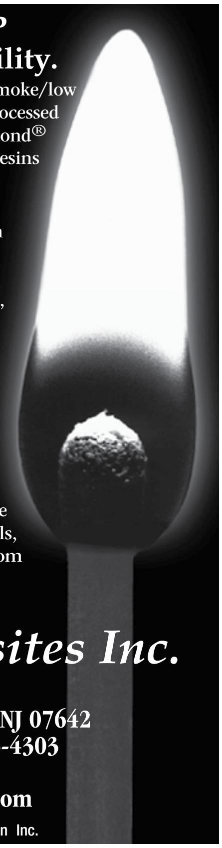
JEC World 2016: Fully recyclable sailboat hull demonstrator

Source | *CW* / Photo | Jeff Sloan

Arkema (Colombes, France), in addition to news of its collaboration with Polystrand (Englewood, CO, US), had as the centerpiece of its stand a complete carbon fiber sailboat hull made with the company's trademarked Elium liquid thermoplastic resin. The vessel, dubbed *Mini 6.50 Arkema 3 Innovation*, served as a prototype or demonstrator, to showcase not only the infused hull but other Arkema products as well. Boatbuilder Lalou Multi, known for its ocean racing endeavors, built the hull using the easily-processed Elium acrylic, which is liquid at room temperature and suitable for infusion and resin transfer molding (RTM), but reportedly has the strength and stiffness of epoxy with 50% higher toughness, says the company. The fact that Elium is a thermoplastic makes the hull recyclable at end of life, a huge benefit according to Lalou Roucayrol, head of the Lalou Multi organization. Watch a video about the boat hull and Elium here: www.sailingscuttlebutt.com/2016/03/09/video-boat-building-recyclable-composite/.

BIZ BRIEF

Frazer Barnes, managing director of **ELG Carbon Fibre Ltd.** (Coseley, UK), emphasized his company's pyrolysis-based composites recycling technology and the need for the development of material characteristics for fibers derived from recycling processes. "We need to give engineers the confidence to use the material," Barnes says. "The best way to do that is to show applications." ELG produced 1,080 MT of recycled carbon fiber in 2015, mostly short, chopped fibers up to 6 mm long. Applications include injection molding processes for automotive and electrical/electronics. ELG also makes a line of 90-600-g/m^2 nonwovens that comprise carbon fiber or a carbon fiber/polypropylene mix. ELG hopes, in the coming 5 years, to establish a larger production facility in Germany to help it achieve a total production capacity of 6,500 MT per year.



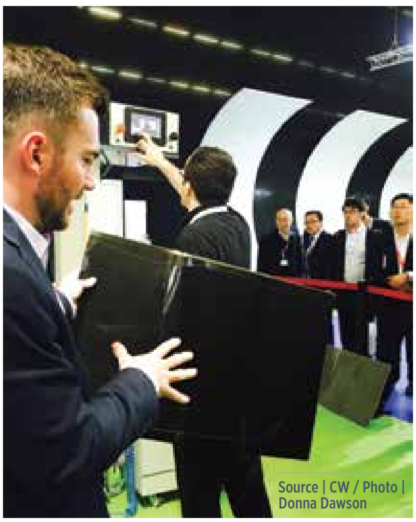
CONSTRUCTION

Acell premiers Smart Panel fire-supression system

Acell Industries Ltd. (Dublin, Ireland), developer of a cost-effective architectural panel technology covered previously in *CW* (short.compositesworld.com/AcellArch), has announced Smart Panel, an innovative building fire-suppression system. Smart Panel, a cored architectural panel, contains a proprietary fire suppressant paste that is connected via electrical wires to a conventional smoke alarm. The panel can be situated in walls or the ceiling of an interior space. When triggered by the smoke alarm, the paste undergoes an exothermic reaction and effectively blasts the resulting powder material onto the fire through a Venturi effect, extinguishing it within seconds. The safe, instantly deployable, rapid-response fire suppression system tackles virtually all types of fire, yet reportedly leaves zero residue and does no property damage in domestic applications. The chemical mixture requires no oxygen, which means that even after the powder has deployed, people can still safely exit. The company is bringing Smart Panel to market in part because, as of April of this year, all homes in the UK will be required to have fire-suppressant systems, either water sprinklers or a powder-based system like Acell's. View a video of the panel in action during a fire test | vimeo.com/96663280

RocTool demos "startup" molding systems at JEC Paris

Calling it "ideal" for startup composites molders who don't want to invest in ovens, autoclaves or time-consuming heated-tooling options, RocTool (Le Bourget du Lac, France) demonstrated its trademarked LIT out-of-autoclave/out-of-press process at JEC. LIT uses a rigid bottom



Source | CW / Photo | Donna Dawson

tooling mold (made from nickel, steel or Invar), with a top "tool" that is actually a flexible bladder. When the flexible top mold is closed over the rigid bottom, the top forms itself to the rigid mold and applies pressure. The tool is heated very quickly by RocTool's proprietary automated inductive heating system. When the mold is opened, the part lifts with the flexible top mold and is removed from it, rather than from the bottom tool. With current technology, LIT can mold parts up to 6m². The part heated up for about 1.5 minutes (up to 190°C) and then cooled for a half minute or so. It also applied pressure up to 10 bar on the part demonstrated, but RocTool claims pressure up to 20 bar are possible. Total cycle time was 2-3 minutes. The cured part was cool enough to remove and handle without gloves. The matrix demonstrated was an epoxy slightly modified with a thermoplastic, reinforced with carbon fiber. The process will work with standard epoxy or other thermosets in even less time, RocTool claims.

BIZ BRIEFS

Continental Structural Plastics (CSP, Auburn Hills, MI, US) and **Mitsubishi Rayon Co. Ltd.** (MRC, Tokyo, Japan) have established a memorandum of understanding (MOU) regarding the development and manufacturing of innovative carbon fiber components for the auto industry in North America. Under the MOU, CSP and MRC have agreed to commence detailed studies through which they intend to pursue an equity-based joint venture that will produce compression molded components made from carbon fiber-reinforced plastics, which could include compression molded SMC as well as prepreg compression molding (PCM). Components will include Class A body panels as well as non-class A parts, including pillars, engine cradles or supports, bumper beams, underbody shields,and more.

OSG USA Inc. (Glendale Heights, IL, US), a manufacturer of taps, drills, end mills, dies and indexable cutting tools, reports that it has acquired **AMAMCO Tool & Supply Co.**, an ISO 9001:2008- and AS9100C-registered manufacturer of high-quality, custom, carbide machine tools used in the aerospace, automotive and medical industries. Founded in 1972, AMAMCO will continue to operate in Duncan, SC, US, as an independent company, led by newly appointed president and former VP at AMAMCO, Jon Salem.

Plataine (Waltham, MA, US and Tel Aviv, Israel) and **Argosy International** (New York, NY, US) will partner to increase manufacturing efficiencies for composites manufacturers in the Asia-Pacific region. The deal is expected to help Argosy customers streamline their manufacturing processes by leveraging the "Industrial Internet of Things (IoT), and allowing them real-time context-aware optimized decisions to facilitate every aspect of their business." Plataine's Total Production Optimization solution combines IoT technology to collect manufacturing and quality-related data on the production floor and make actionable, optimized decisions and recommendations in real time.

Oxeon spotlights composite protective headgear

At JEC World 2016, spread-tow reinforcements specialist Oxeon AB (Borås, Sweden) had on hand the recently announced Avance MIPS, an innovative ski racing helmet made by protective headwear manufacturer Giro Sport Design (Santa Cruz, CA, US). "TeXtreme has enabled us to create an ultralight shell that's tougher, stiffer and stronger than anything Giro has previously offered. Most importantly, TeXtreme provides impressive high-energy impact management," says Mattia Berardi, Giro Ski's product manager. According to Berardi, "The Avance MIPS outer shell is constructed from TeXtreme carbon fiber fabrics. TeXtreme's wide, flat tapes fit tighter together and remain straighter than the round tows found in conventional carbon fiber materials, and thus require less resin needed to bind the fibers together."

Source | CW / Photo | Jeff Sloan]

Also on display at the booth was a new Pro Star motorcycle helmet from Bell Helmets (Scotts Valley, CA, US). Chris Sackett, vice president of Bell Powersports, says: "For the new Pro Star, we wanted to take shell technology to the next level and by using the ultra-thin TeXtreme carbon fiber material we managed to engineer our best shell ever. The unique characteristics of the TeXtreme material enabled us to take out 20% of the weight and still have the same high level of performance."

EPTA's World Pultrusion Conference spotlights innovation

Source | Thomas Technik & Innovation KG

The European Pultrusion Technology Assn. (EPTA) held its bi-annual World Pultrusion Conference, March 3-4, in Prague, Czech Republic. EPTA president Luigi Giamundo, owner/CEO of Atp Srl Avanzate Tecnologie Plastiche (Barletta, Italy), welcomed 124 registrants from 24 countries — the largest EPTA delegation to date — to 23 presentations that covered market trends, machine and process innovations, new applications, sustainability and environment issues and raw material development.

Elmar Witten, managing director of conference organizer AVK – Federation of Reinforced Plastics eV (Frankfurt, Germany), discussed pultrusion's relative position in the broader composites marketplace. Of the 8.8 million MT of worldwide composites production volume, he reported, the European share was about 2.3 million MT, based on a 2014 survey by JEC (Paris, France). Chopped fiber-reinforced thermoplastics accounted for 1.25 million MT and continuous fiber-reinforced thermoset — including pultruded products — made up about 1.04 million MT. Germany is the largest producer, followed by Scandinavia (Finland, Norway, Sweden, Denmark). One hundred companies in Europe produce ~98% of the composite products made in Europe, Witten added, primarily in glass fiber-reinforced applications for automotive, construction and electrical/electronic sectors. Pultrusion production is growing slowly but steadily in that context, but at this time, the composites market is still dominated by processes that employ sheet molding and bulk molding compounds, followed by hand layup and sprayup. Carbon fiber composites show similar gradual growth in automotive and aerospace markets.

Jaap van der Woude of the European Composite Industry Assn. (EuCIA, Brussels, Belgium) had news of EuCIA's Life Cycle Aspects tool, a web-based eco-calculator that determines the expected service life of composite parts and their impact on the environment. A work in progress, it currently considers orthophthalic resins and glass fibers, and various processes that convert fiber and resin to a product. The Web-based calculator leads the user step-by-step through the procedure and will be available at no charge through 2016. It is privacy-protected, and EuCIA does not have access to data input by a user.

André Weber, R&D director, Schoeck Bauteile GmbH (Baden-Baden, Germany), reported on the status of a EuCIA-backed composite rebar standards development effort in Europe. At this time, test procedures for material properties are in progress, as established by the European Technical Assessment (ETA) for regulation of construction projects. Weber said most composite rebar is unidirectional pultruded fiberglass. He noted that the problem with pultruded rebar is not achieving desired strength but, instead, bonding: The ribs on the rebar must be designed for it, and Weber recommended a wedge-type angle on the rebar. Fire/heat resistance also is critical. He noted, further, that the rebar must be bent to round corners, and said that this technology is available.

Klaus Jansen, general manager for Thomas Technik & Innovation KG, part of Thomas GmbH (Bremerverde, Germany) reported on the company's efforts in the area of *non-linear* pultrusion. Jansen says Thomas can produce a constantly curved profile by moving the *heated die mold* instead of moving the profile through a stationary mold. Curved parts have been produced using polyester, vinyl ester and epoxy thermoset matrices, Jansen says. Thomas also has developed methods for pultruding variable radii for *linear* pultrusion, using moving, segmented guide rails and a moving mold. Jansen claimed that the company can modify *any* pultrusion machine to perform variable radii/linear pultrusion. Future goals include a circular design for a coil spring using a torque drive with curvature control, on either a horizontal or vertical axis, with a rotating or moving guide rail (see photos, p. 38).

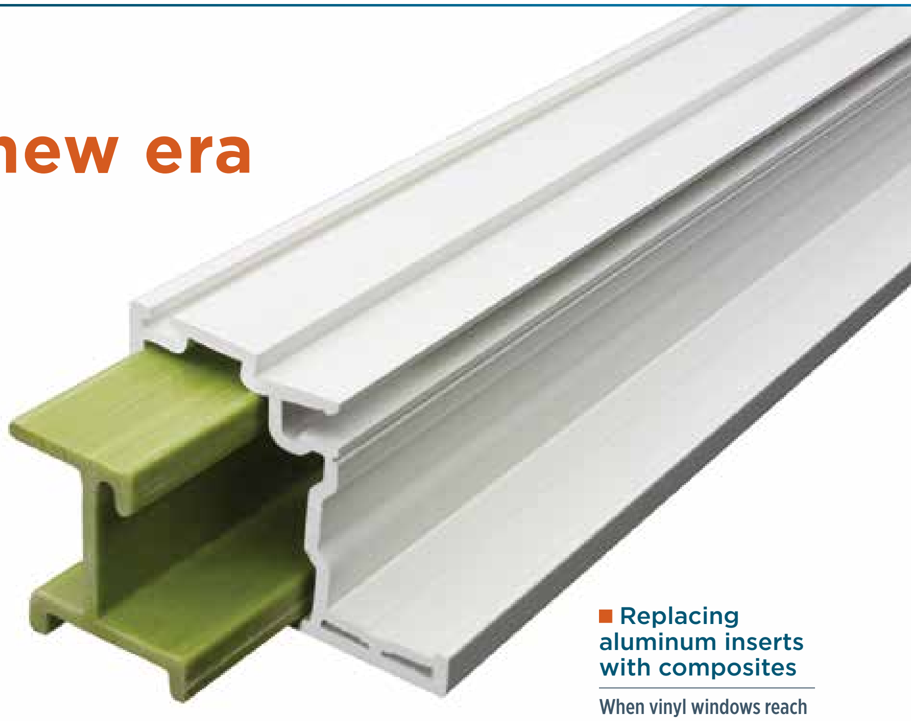
Read much more news from the EPTA and coverage of technical innovations in both thermoset and thermoplastic pultrusion in *CW's* extended online coverage of the 2016 World Pultrusion Conference | **short.compositesworld.com/EPTA2016**

BIZ BRIEF

Günter Wolfsberger, product manager composite fiber technology at **Magna Steyr** (Graz, Austria), and Carlos Garza, operations manager at automotive parts manufacturer **Katcon Advanced Materials** (Santa Catarina, Mexico), announced plans to work together to develop a manufacturing line to fabricate automotive body panels, using glass fiber/polyurethane skins around a paper honeycomb crushed core. The system conceived would use **Hennecke** (Sankt Augustin, Germany) sprayup technology and could produce up to 100,000 units per year. Wolfsberger and Steyr discussed a specific demonstration to make a 14-kg BMW *M3* car hood on a fully automated line that could produce one paint-ready, Class A hood every 280 seconds. Such a hood would be 66% lighter and 9% less expensive than its steel predecessor. This system is notional at this point, but Wolfsberger and Katcon say they have attracted the interest of several automotive OEMs.

Ushering in a new era for windows … and more

Superlative stiffness and thermal efficiency could make this highly glass-filled pultruded polyurethane insert a construction industry go-to material of choice.



Replacing aluminum inserts with composites

When vinyl windows reach a certain size threshold, vinyl frame and sash profiles require reinforcement in order to meet wind-load deflection requirements. Deceuninck's (Monroe, OH, US) INNERGY line replaces the traditional aluminum insert with pultruded polyurethane inserts comprising 80% glass fiber and 20% Baydur 3500 polyurethane.

Source | Deceuninck

By Michael LeGault / Contributing Writer

» Despite recent groundbreaking applications — the high-profile, 12-story FRP rain-screen façade included in an expansion of the San Francisco Museum of Modern Art (SFMOMA, San Francisco, CA, US), for one (see Learn More, p. 42) — the use of composites in the construction industry remains the exception, not the rule. In most building substructures, vinyl, wood, concrete, steel and aluminum predominate. Not so, however, in windows.

Here, an initial composites beachhead has been established in the residential construction market, primarily in the form of pultruded, glass-reinforced polyurethane components, and composites appear to have gained enough of a foothold there to spur plans and developmental activities aimed at wider commercialization of entirely new composite building/architectural applications, such as doors, skylights and even curtain walls (windowed façades) for high-rise buildings.

> An uptick in sales of the pultruded window inserts is seen as a harbinger of new applications to come.

This assault has been spearheaded by the ongoing development work of a handful of materials suppliers and window manufacturers, which are capitalizing on a convergence of new window technology, changes in the *International Building Code* and the introduction of the US EPA's Energy Star 6.0 rating system, a federal energy performance standard for window systems (see Learn More).

That new technology features glass-filled polyurethane, a key benefit of which is its *1,000* times greater effectiveness as a thermal insulator compared to aluminum, which translates to much less thermal loss. Paul Platte, market manager at Covestro (formerly Bayer MaterialScience, Pittsburgh, PA. US), says the impact of the EnergyStar rating system is just beginning to impact the window market. "We're living in a time of generally higher energy costs," Platte says. "Both window manufacturers and contractors can tout the EnergyStar certification as a competitive advantage, compared to windows without it."

During the past five years, Covestro has been working with a number of window and door manufacturers and suppliers on development projects aimed at achieving new commercial composite applications, using its pultrusion-grade polyurethane resins. The materials, which are part of the company's Baydur family of resins, are specially formulated to enable to use of glass loadings higher than what normally can be achieved with conventional pultrusion resins.

These efforts are now coming to fruition. In 2012, Deceuninck North America (Monroe, OH, US) launched a new window reinforcement system, INNERGY, incorporating pultruded glass-fiber-reinforced polyurethane window stiffeners for insertion into customer's hollow, extruded vinyl window sashes and frame profiles. The stiffeners comprise 80% glass fiber and 20% polyurethane and replace conventional aluminum inserts. After the customary sluggish reception to a product launch, Deceuninck, a supplier of window component systems to window manufacturers, reports a robust pick-up in sales and interest in INNERGY inserts.

"Growth has been tremendous," says Philip Morton, director of business development. In 2015, shipments of the window inserts increased 40-50% over 2014 volumes," and the company expects similar growth rates during the next several years. Morton also says the company is involved in development work to broaden its product range, beyond its role as a reinforcement, into primary shapes for a variety of building components.

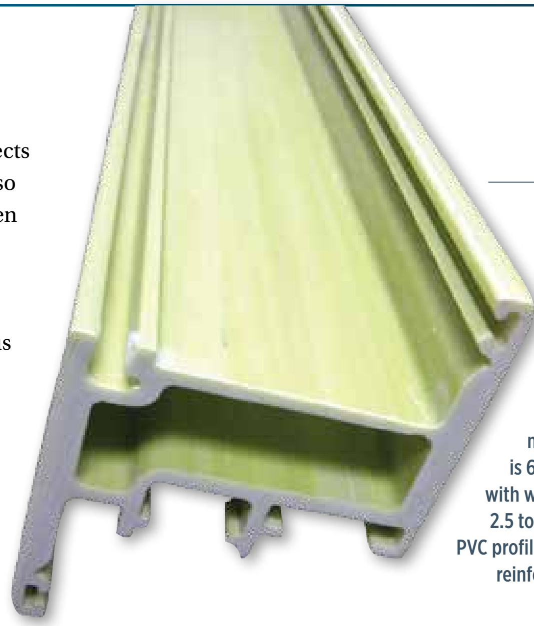
The high glass content is the critical element in the structural properties of the stiffeners, imparting a flexural modulus of about 7.9 million psi (54,468 MPa) compared to about 10 million psi (68,947 MPa) for aluminum. Deceuninck designs for windows in a variety of sizes. When a residential window reaches a critical size, roughly 1,120 mm to 1,220 mm and wider, vinyl profiles require reinforcement to achieve the necessary resistance to wind load and deflection. That size threshold is even smaller for windows in commercial buildings, which have more stringent load requirements.

Morton says there are a number of compelling reasons to believe the uptick in sales of the company's polyurethane materials technology is both real and a harbinger of new applications to come. To achieve, for example, the voluntary EnergyStar certification, a residential window must have a measured U-value rating of 0.27 or less, independently certified according to test procedures established by the National Fenestration Rating Council (NFRC, Greenbelt, MD, US). U-value is the overall heat transfer coefficient, measuring the heat transfer (in watts) through 1m^2 of a structure divided by the difference in measured temperature across the structure. Innovations have advanced glass to increasingly higher levels of U-value performance. However, the ongoing use of aluminum and steel reinforcements has become a "thermal short circuit within the entire window system," according to Morton.

Another factor favoring the selection of polyurethane — in this specific case, as window frame and sash inserts — is the compatibility of polyurethane with vinyl. At one time, window manufacturers had no other choice but aluminum or steel as reinforcing materials. Cutting and processing these materials requires different types of machinery than that used to process softer vinyl, Morton says. Polyurethane, however, can be processed with the same machinery used to cut vinyl, which saves capital costs. Additionally, aluminum/steel chips from cutting are a contaminant that abrade and mar the surface of vinyl, resulting in scrap. Polyurethane eliminates this scenario and the burdensome QA procedures now in place to avoid it.

New apps, present and future

The addition of a new section to the *International Building Code* in 2009 officially opened the door to FRP materials in buildings taller than four stories in interior finish applications, such as walls and ceilings, and in nonstructural exterior applications such as curtain walls, cladding and rain screens, provided they meet the fire propagation acceptance criteria of the National Fire Protection Assn.'s (Quincy, MA, US) NFPA 285 test method. Covestro's Platte notes, however, that more than 60% of commercial buildings in the US are three stories or shorter, »



From windows to doors

Deceuninck has a number of initiatives underway to expand its glass-filled pultruded polyurethane technology beyond window applications. Pictured here (left) is a test profile for a balcony door sash under development in Europe. The profile is 60 mm wide by 75 mm tall, with wall thickness ranging from 2.5 to 5 mm. The part replaces a PVC profile that has an internal steel reinforcement. Source | Deceuninck

Demo patio door

Deceuninck displayed this demonstrator patio door with a sash comprising glass-reinforced polyurethane at the 2014 GlassBuild show. The company is partnering with a US-based door manufacturer in the development of a multi-panel polyurethane door system to replace an existing door made of vinyl and steel reinforcements. Source | Deceuninck

Polyurethane pultrusion

INNERGY glass-fiber-reinforced polyurethane window stiffeners begin, as pictured here (at left), as glass rovings and polyurethane meet and are combined (right) as they are fed into the pultrusion die.

Source | Deceuninck

according to data published by the US Department of Energy. Performance requirements (load, deflection, fire and smoke) for high-rise applications also are more stringent and costly. Accordingly, Platte says, the company expects that the next phase in the market extension of polyurethane pultrusion technology will come in residential and low-rise commercial door and window applications during the next two to three years. Large-scale high-rise applications are envisioned as three to five years down the road.

Development work at Deceuninck is targeting all of these areas. The main thrust of this new effort, however, is using polyurethane pultrusion to produce composite primary shapes, not just reinforcement inserts. The company has developed a prototype door sash to replace a sash made from vinyl with a conventional heavy-duty *steel* reinforcement (see the photo at top of p. 41). “We’ve done a wide range of testing, and we’re very pleased with its performance,” Morton says, reporting the polyurethane sash actually outperforms the vinyl/steel sash. Morton adds that the company is developing a multi-panel, glass-reinforced door system for a door manufacturer and just completed a primary structural component for a Canadian commercially rated ribbon window system for which the customer is conducting load tests.

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Read this article online |
short.compositesworld.com/INNERGY

Read about SFMOMA’s composite rain-screen façade online |
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Read about changes in the IBC online |
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Read more about NFPA 285 testing online in “Better, cheaper screening of FRP building materials” |
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Further, Morton says the company has been in discussion with numerous companies about using the polyurethane technology in commercial skylights, as well as “the whole field of commercial windows and doors.”

One of the key dynamics shaping this budding transformation is the step-change improvement of the thermal performance of modern glass. Insulated glass technology has taken a couple of leaps forward in recent years, Morton reiterates, “to the point where the thermal performance of glass is outperforming the thermal performance of its aluminum window inserts and frames, regardless of how many thermal breaks are added.” This is especially critical in commercial buildings with many windows: “Now, in order to optimize the overall benefits of insulated glass systems, you need a framing material that is low thermally conductive as well,” he says.

Whether or not these new applications and opportunities materialize into a full-scale building materials revolution, of course, depends on an array of factors in an admittedly complex industry. Composite materials suppliers and manufacturers, however, have to like their chances in this market, given that one constant, material *performance*, is innately superior to the alternatives. CW

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Tough foam-filled honeycomb core for fracking tanks

Rhinokore's fiberglass skinned, closed-cell-foam-filled thermoplastic-cored sandwich panels form these massive water tanks used in hydraulic fracturing operations. The thermal insulation provided by the core saves oil and gas companies much of the time, money and energy typically required to heat water in uninsulated metal tanks — a real bonus during winter cold. Shown here are two 2.4 million-liter tanks (left and middle) and one 1.2 million-liter tank (top right) on a lease site near Watford City, ND, US. Tanks are fitted with black liners, to prevent leaks, and lids (not yet installed, here) to reduce heat loss from the top.

Source | Rhinokore Composites Manufacturing

Thermoplastic honeycomb cores: Tough insulated sandwiches

Foam-filled nylon/polyester fabric yields sandwich panel cores with excellent mechanicals, durability, thermal insulation.

By Peggy Malnati / Contributing Writer

» A thermoplastic honeycomb core that is light and stiff, with above-average compression, shear and tensile strength is offering thermal insulation and reportedly outdoing most other core materials in the category of durability in a variety of sandwich-panel applications. Originally developed by a Canadian company with deep roots in the oil and gas industry as a core for heavy-equipment mats and insulated composite tanks, its use is expanding to transportation and construction applications.

Anatomy & physiology

The patented core, produced since 2007 by Rhinokore Composites Manufacturing (Armstrong, BC, Canada), is made on a custom-built "honeycomb" machine that processes a tough, heavy-duty grade of blended nylon/polyester fabric via high-temperature (427°C) thermoforming into sheets of conjoined hexagonal cells, which are 13 mm in diameter, with 1.1-mm thick walls. (A heater nozzle passes over but doesn't touch the fabric, yet softens the polymeric fibers sufficiently to melt, flow and bond them.)

When pressed into the honeycomb pattern and cooled, sheets of the material are removed and placed into a mold where a two-part thermoset closed-cell polyurethane foam from Leverkusen, Germany-based Covestro LLC (formerly Bayer MaterialScience) is injected into the tool and allowed to cure in a heated press. Machine dimensions limit standard sheet width, length and cross-sectional thickness, respectively, to a maximum 122 cm, 244 cm and 152 mm. Longer sheets are available, and it's reportedly possible to run the process in continuous as well as batch mode, to make one-piece cores large enough for flat-panel sandwich structures in box trucks, commercial-truck trailers, buses, recreational vehicles (RVs) and building/construction.

For applications requiring core cross-sections thinner than 152 mm, the core panel can be rough cut down to a minimum thickness of 6.35 mm, using a high-speed saw. Top and bottom faces of each honeycomb slice are then sanded to achieve the precise thickness and a more consistent finish. The final product is delivered to customers as palletized sheets.

"By adding foam, the performance of our thermoplastic honeycomb is exponentially enhanced," claims Ray Gauthier, Rhinokore's VP of manufacturing. "Empty honeycomb fails in compression because air between cells doesn't reinforce the webbing and, with enough force, it buckles. However, add the low-density urethane foam and these honeycomb columns are reinforced and can take much higher loads. After you inject the foam, you get 12-times higher strength than that of the initial honeycomb by itself." Reportedly, in one application, 76-mm thick cores sandwiched between fiberglass skins can withstand 341,770 kgf/m^2 of compressive force.

The thermoplastic core can be used with faceskins of thermoplastic or thermoset composites, metals, wood and even concrete. At any thickness, the core offers good energy-absorption (impact strength) for greater durability, but lacks the higher stiffness of paper/phenolic cores. In relatively thin cross-sections, the core is flexible (low flexural modulus). Typically, it competes well against cores made of other plastics, balsa and phenolic-impregnated paper at the low and middle price range. Unlike paper and wood core, it's impervious to moisture and will not rot. The material is less breathable than open-cell polymer cores, but, for that reason, it won't trap moisture. It also is said to provide excellent thermal and acoustical insulation.

From part maker to core maker

The core's insulation properties date from its earliest sandwich-panel applications. As a startup in Manitoba, in 2006, Rhinokore produced rig mats, used in the oil drilling industry to cover leased land so heavy equipment doesn't damage soils or get bogged down in mud, and crane stabilizer pads, used to provide a stable base for cranes when lifting heavy loads. After evaluating commercially available paper and plastic cores and realizing that, aside from high-performance aramid, no one made a strong (let alone, reasonably priced) fabric core, the company's owner found, via trial and error, a source of blended nylon/polyester fabric with a favorable balance of toughness, formability and cost. Rhinokore shortly began manufacturing its own cores and sandwich composites to produce its mats and pads, using facesheets of vinyl ester/fiberglass (resin from CCP Composites US LLC, Kansas City, MO, US; glass mat from Vectorply Corp., Phenix City, AL, US) joined to the thermoplastic core via open-mold infusion.

So successful were the mat/pad products that in 2008, Rhinokore moved into a larger production facility in British Columbia. At this point, development work began on horizontally oriented tanks to hold water that is injected (after mixing with chemicals in a separate tank) into deep wells during hydraulic-fracturing (fracking) operations. Rhinokore's same sandwich composites, minus the non-skid surface used for the rig mats/pads, were adapted to form rectangular (rather than the more conventional cylindrical) water tanks for fracking.

After two years of commercial tank production, a Calgary family, "with a desire to take the fracking tank business to a new level," purchased Rhinokore in 2011. The new owners recognized the need for a more advanced tank system and completely »

Fusing and forming the honeycomb cells

After much experimentation in search of a strong but moderately priced fabric-core honeycomb, Rhinokore's original owner found the current nylon/polyester blend provided the best balance of toughness, formability and cost. Sheets of the fabric are put into the company's custom-built honeycomb machine where a heated nozzle passes over the fabric and quickly heats the material to a high temperature, fusing the polymers, and then compresses the material into a series of interconnected honeycomb cells in sheet form.

Source | Rhinokore Composites Manufacturing

Filling the cells for compressive strength

Formed honeycomb sheet is placed in a mold, which is injected with a two-part polyurethane foam that fills all the cells. Sheets are then cut down to required size and thickness, both faces of each sheet are sanded, and then the final products are palletized and shipped to customers or used by Rhinokore in its own part-making operations. Source | Rhinokore Composites Manufacturing

Early applications proved heavy-duty worthiness

An early and ongoing application for Rhinokore's thermoplastic core was for rig mats and crane pads (shown at left and above) for heavy equipment. In this case, the same fiberglass skin/thermoplastic composite cores are used but the faceskins feature a textured surface. Source | Rhinokore Composites Manufacturing

overhauled the original design so that, among other things, the tanks can now be rented and set up by Rhinokore for customers in eight hours instead of the 4-5 days it had required previously. The company's original tanks held 1.2 million liters of fluid. However, given the excellent performance of those tanks in the field, and the high ultimate strength of the sandwich panels used to form them, during the redesign stage Rhinokore researchers eventually decided to double tank capacity (see opening photo, p. 44), and then double it again to 4.8 million liters.

The largest tanks are 61m long by 31m wide. Each sandwich panel used is 15m wide by 3.4m tall and features a 152-mm cross-sectional thickness in a sidewall or a 76-mm cross-section in a tank floor. At sidewall thickness, the cores provide an R40 insulation value. The floor, at half the thickness, achieves an R20 value. This delivers two advantages unavailable in metal tanks. First, it helps prevent water from freezing — a plus given that tanks sit on the ground and fracking often is done in remote northern regions subject to severe winters. Second, it saves oil and gas exploration companies energy, time and costs because less fuel is needed to heat the fluid above the 38ºC temperature required for injection. Moreover, rectangular tanks hold more fluid in a given footprint, and that, in turn, can reduce the total number of tanks required for water storage per exploration site. And because tanks are not pressurized, there's no concern about the potential weakness that corners might otherwise present in a rectangular vs. circular geometry.

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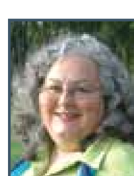
Expanding uses

New applications continue to open up. Bulk-commodity transport company Agri-Transervices Inc. (Armstrong, BC, Canada) uses Rhinokore's sandwich panels for truck-trailer decking. Panels lay flat to carry lumber from British Columbia to Saskatchewan, then are folded into a box to carry grain back to British Columbia. The composite panels replaced rot-prone plywood, which wasn't strong enough to carry the loads. In the RV segment, Bigfoot Industries (2010) Inc. (Armstrong, BC, Canada) uses the cored sandwich panels in place of wood floors in its campers. Larger RV OEMs are evaluating them for wall and roof panels. Truck-trailer producers are considering the cores for decks, walls and roof panels. "Our cores are used in municipal buses in several North American cities, and we're working to expand our reach in that industry," adds Robin Arnold, Rhinokore's VP of business development. "We also see vast opportunities in the construction market, especially for structural insulated panels, where incumbent materials are filled with EPS [expanded polystyrene] foam. Our core is superior to EPS in terms of higher insulation value as well as contribution to structural stiffness." The company is seeking new customers for product development efforts as well as distribution partners for its thermoplastic honeycomb cores. CW



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DEDICATED TO LONG-TERM PARTNERSHIPS WITH OUR CLIENTS, BUILT ON CREATING INNOVATIVE SOLUTIONS TOGETHER. PARTICIPATING IN IMTS DEMONSTRATES OUR COMMITMENT & INVESTMENT IN THIS DYNAMIC INDUSTRY.
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Fig. 1 Non-stop, solar-powered ocean hop

Lausanne, Switzerland-based Solar Impulse co-founders and *Solar Impulse 2* co-pilots Bertrand Piccard and André Borschberg celebrate Borschberg's successful landing in Hawaii (inset shows the *Si2* on its approach) after his five-day flight from Nagoya, Japan.

Source | Solar Impulse

Solar Impulse 2: Pulse on the future

Not yet through their 'round the world flight, this superlight solar plane's airframe-proven materials are already destined for higher callings.

By Donna Dawson / Senior Writer Emeritus

» For anyone fascinated by aircraft, solar power and/or composites, Solar Impulse is a familiar name. It identifies the Lausanne, Switzerland-based company that, in 2010, launched the self-named *Solar Impulse 1*, the world's first piloted aircraft to fly all night on solar power alone. At this writing, its successor, *Solar Impulse 2* (*Si2*), is at the halfway point of the first attempted solar-powered *around-the-world* flight, with Solar Impulse founder and chairman Bertrand Piccard alternating at its controls with CEO André Borschberg.

On March 9, 2015, *Si2* took off from Abu Dhabi in the United Arab Emirates, and, in eight legs, flew to Muscat, Omar, thence across India — stopping at Ahmedabad and Varanassi — on to Mandalay, Myanmar, then to Chongqing and Nanjing, China, and Nagoya, Japan. From Nagoya, Andre Borschberg piloted *Si2 nonstop* for almost five days — 117 hours and 52 minutes — on solar power alone, arriving at Honolulu, Hawaii on July 3 at 5:55 a.m. local time. (The average air speed of the *Si2* is 25 knots, or about 47 kph.)

Difficulties with the plane's batteries (not its composites) forced *Si2* to pause in Hawaii (see Learn More, p. 50). While the Solar Impulse team awaited resolution of this issue, *CW* took the opportunity to inquire into the performance and future implications of the *Si2's* ultralight composite airframe, which could not have been built for its purpose with other materials (no metal could be as light, stiff and strong as needed) and without which, the aircraft's story could not have been written at all.

Halfway around the world on thin air(frame)

For this sun-powered bird, the essential prerequisite was an *extremely light aerostructure*. The raw material that ultimately satisfied this need proved to be very thin composite tapes. The airframe's main and rear wing spars, fuselage and empennage were constructed from thin-ply epoxy prepregs produced by North Thin Ply Technology (NTPT, Penthalaz, Switzerland). The ultra-thin composite tapes, known commercially today as thin-ply or spread-tow tapes, are made by spreading individual carbon fiber *tows*, separating the fibers and flattening them into a wider and thinner unidirectional form. For the *Si2*, NTPT spread M46J 12K ultrahigh-modulus PAN carbon tow from Toray Industries (Tokyo, Japan) to yield very thin 25-g/m² and 100-g/m² unidirectional tape. The UD tapes were resin-impregnated during the process and then converted into ±45° preforms up to 27m long by 1.2m wide, using NTPT's automated tape laying (ATL) machine (for background on spread-tow technology, see Learn More).

Fig. 2 'Round the World repair stop

Si2 rests in a hangar in Hawaii as a crewmember covers the airframe with a protective space blanket. Difficulties with the plane's batteries forced a mission hiatus for repairs. Source | Solar Impulse

Joe Summers, NTPT sales and marketing director, characterizes this project as a big success for all parties involved. "The successful flight of *Si2* validates the choice of products. Thin ply materials have created a strong, lightweight structure capable of circumnavigating the globe with only solar power," he says. He adds that the project further refined NTPT's capability to manufacture, handle and transport large preforms.

All the preforms for construction of *Si2* were shipped to composites manufacturing specialists Decision SA — a member, with Multiplast SAS (Vannes, France), of Groupe Carboman SA, in Ecublens, Switzerland.

When NTPT's prepreg preforms arrived at Decision's facility in Ecublens, they were layed up by hand into custom, precision molds designed and built by Decision for the fuselage, wing sections and tail, including tooling for the complex 27m-long wing spar box. The *total* length of the wingspan, including the spar box, is 72m. (By comparison, Boeing's 787 *Dreamliner* has a wingspan of 60m.) The preforms and ply schedule for all airframe parts were calculated to build up the necessary fiber architecture for handling anticipated loads on the strong and lightweight plane, including spar box torque resistance and bending stiffness specifications.

Decision general manager Bertrand Cardis points out that in terms of the composite airframe structure, including the wing spar box, "We have had no technical issues with the plane. After the half-around the world flight of *Si2*, including spending five days over the Pacific, the behavior of everything we built has been perfect." Cardis stresses that everything was heavily tested to the ultimate flying load on the ground before flight approval, and the flight has proceeded according to plan, verifying the approach to the composite materials and manufacturing process.

Critical cockpit construction

Covestro (formerly Bayer MaterialScience, Leverkusen, Germany) designed and calculated the fairing, or outer shell and pilot access door of the *Si2* cockpit. "The most important thing was to get as lightweight as possible," explains Bernd Rothe, Covestro's plant manager and former Solar Impulse project manager. But that critical concern had to be balanced with the need for protection against thermal dynamics and atmospheric wind currents. Ultimately, the team elected not to use a composite. The shell and door were built to Covestro's specifications by a local prototype manufacturer, using Covestro's then most recently developed low-density 27.5 kg/m^3 rigid polyurethane foam. The 30-mm thick foam has a reduced cell cross section of 180 μm, about 40% less than the standard 300-μm cell. The cockpit windshield and windows are Covestro's transparent polycarbonate — 1.2 g/cm^3 compared to glass at 2.6 g/cm^3. Covestro supplied a different, 28-kg/m^3 lightweight, rigid insulating foam to protect the pilot and instruments from external temperatures that could fall to –50°C. Borschberg reports the insulation worked very well. "We were able to keep the planned temperatures in the cockpit."

The most critical proof of part for the *Si2* cockpit was to be able to eject the door under a high wind, for pilot safety, allowing the pilot to exit and bail out if the plane was at risk. For the critical door *hinges*, then, Covestro reinforced a specially developed polyurethane resin with a standard (but unidentified) carbon fiber, and molded them by resin transfer molding (RTM). »

Fig. 3 Pilot-friendly control pod

Piccard and Covestro (Leverkusen, Germany) plant manager Bernd Rothe check out *Si2's* lightweight, thermally insulated, wind-resistant cockpit. Source | Covestro

"This was the first time we built a carbon-reinforced polyurethane part by RTM, and it worked out very well for *Si2*," says Rothe.

The complete cockpit fairing, door and door hinges weathered testing in a wind tunnel, where to apply the highest probable pressure on the door, it was subject to wind speeds of 100 kph, at various angles of attack and shift, Rothe says. "Under this pressure, the pilot had no problem opening the door or ejecting the door and making a safe exit — the most important thing for us."

Rothe expressed appreciation that "after the first two weeks, we received thanks from Bertrand Piccard and André Borschberg that everything worked well in the cockpit." Testing in Hawaii showed the cockpit is still perfectly climate-controlled. Rothe says, "Yes, we were very proud."

+ LEARN MORE

Read this article online | short.compositesworld.com/Si2pulse

Read about the *Si2's* battery difficulties online in "Solar Impulse 2 grounded in Hawaii until 2016" | short.compositesworld.com/Si2repair

Read more online about NTPT's thin-ply tape technology in "Spread-tow technology takes off" | short.compositesworld.com/IM-NTPTSi2

Foretelling future value

"In terms of structure, if we would do a future version of *Si2* we could certainly make further improvements," says Borschberg, "but in principle, we would keep the same concept and philosophy as it demonstrated that it works very well."

But Borschberg emphasizes that in the long-term, the *Si2's* value is in industrialization: "The objective is to capitalize on the expertise, the know-how and the network that we developed over the past 10 years in the fields of energy efficiency, ultralight material, design of complex systems, solar production and storage [energy cycle] and electric motors."

NTPT's Summers agrees. He imagines that the success of the *Si2's* flight changes the perception of "*what is possible* with flight duration, power sources and construction methods. Low-power, long-duration flight is opening possibilities in such diverse applications as commercial travel, pseudo-satellites, weather prediction and military purposes."

A promising high-performance market for the technology used for *Si2* is, in fact, the so-called High Altitude Pseudo-Satellite (HAPS), or solar-powered drones, which need no launch vehicles and are sustainable and, therefore, less costly alternatives to rocket-launched satellites. Borschberg says part of the Solar Impulse engineering team is already working on a concept solar-powered drone. It will be able to fly higher than *Si2*, into the stratosphere, which extends 50 km above Earth's surface. A drone could be either geostationary or able to move to different locations, Borschberg explains. "It can be used for communications, measurements and observations. The team is currently focused on the predesign phase."

Summers and Cardis both believe their thin-ply materials and manufacturing process are a perfect fit for such applications. Decision sees a rare match in terms of commercial relevance for its *Si2* thin-ply composite construction experience. "We made a big jump into the future by building with this material," Cardis says, "and we hope to apply this proven technology to solar drones."

NTPT is pushing its thin-ply technology even further, targeting UD tapes as thin as 15 g/m^2, to satisfy these and other high-performance markets. "We can already reach 15 g/m^2 with Toray's MR70, though at present, the best we have spread with M46J is 25 g/m^2."

Additionally, Summers says NTPT is constantly pushing the range of high-modulus and ultrahigh-modulus fibers that can be made into thin-ply prepregs. "Higher modulus thin materials are vital for very lightweight and stiffness-critical components for these types of craft." He notes, for example, that NTPT already can manufacture thin-ply prepregs from Toray's M55J (540 GPa) and GRANOC YSH70 (720 GPa) from Nippon Graphite Fiber Corp. (Tokyo, Japan) to weights as low as 50 g/m^2.

Solar-powered drones also are being developed and promoted by Airbus, Google, Facebook and others. Google (Mountain View, CA, US) recently purchased solar-powered drone maker Titan Aerospace (Moriarty, NM, US) with the suggested goal of investigating advanced material design and other aspects of Titan's technology for such future applications as Internet access, disaster relief and environmental damage detection and assessment.

Notably, Covestro's Rothe reports that the composite material used for the *Si2* door hinges is currently undergoing testing by major automotive companies for interior structural body parts. The goal is to produce parts with carbon fiber-reinforced polyurethanes, taking advantage of the short cycle times and high mechanical properties achieved by RTM of the hinges. Polyurethane also is being tested as a resin for wind turbine blades made by resin infusion.

On *Solar Impulse 2*, composites have proven their value in very light aerostructures, have given a big boost to a critical clean energy technology, and promise future value in vehicles that soar to the stratosphere as well as those that take to the streets on *terra firma*.

As CW *went to press, rework on* Si2's *battery systems had been completed and successful maintenance test flights had been conducted Feb. 26 and March 9. Solar Impulse announced April 14 that* Si2 *was mission ready, and would depart Hawaii during the first favorable weather window to complete its remaining five legs, to the West Coast and New York in the US, across the Atlantic to Southern Europe or Northern Africa and, finally, back to Abu Dhabi.* CW

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Lower cost, less waste: Inline prepreg production

New technologies move direct (fabricator-based) prepregging closer to reality.

By Peggy Malnati / Contributing Writer

» That composite laminates made from oriented plies of B-staged pre-impregnated unidirectional (UD) carbon fiber (prepregs) produce finished parts with the lowest mass, among the highest mechanical properties and low void content is undisputable. That they have been, historically, the most expensive, labor- and scrap-intensive, is also well established. Efforts to mitigate the latter continue. Since the early 2000s, movement away from costly autoclave cure to a variety of out-of-autoclave (OOA) processes (see Learn More, p. 58) and the advent of nesting software, automated cutting equipment and laser projection systems has driven cycle times down from hours to 15-25 minutes and reduced scrap rates that ranged as high as 60%. Recently developed "snap-cure" epoxy resin systems maintain the out-life necessary to lay up large and/or complex parts, but offer, at trigger temperatures, cure cycles as short as 90 seconds. On the fiber side, prepreggers have moved to less expensive heavy tow (24-50K) in cost-sensitive industries, such as automotive, and fiber manufacturers are still in search of less costly fiber precursors (e.g., lignin) and less energy-intensive carbonization processes.

The next technology hurdle

What have *not* been addressed, to this point, are the inefficiencies inherent in the production of prepreg as an intermediate, discrete step in the supply chain**.** Two interesting approaches toward this end, both *inline* processes, were introduced at SPE's Automotive Composites Conference & Exhibition 2015 in Detroit, MI, US. They turn composites fabricators into prepreggers in much the same way the direct long-fiber thermoplastic (D-LFT) process shifted the work of compounders to fabricators in the late 1990s/early 2000s. Both new technologies eliminate the previously necessary and expensive steps of freezing and storing prepreg prior to shipping it to the customer, who then must also store it and thaw it before using it in a molding process, the costs of which are borne by the processor and, presumably, the processor's customer.

Automated towpreg vs. hand laid prepreg

A joint effort by Mitsubishi Rayon Co. Ltd. (Tokyo, Japan) and Mitsubishi Rayon Carbon Fiber and Composites (Irvine, CA, US), this new way to make laminate composite prepreg inline involves use of an automated fiber placement (AFP) machine modified to work with towpregs formulated to work in prepreg compression molding (PCM). Replacing hand layup of prepreg with automated layup of towpreg reduces scrap and labor cost, and simplifies preforming and post-mold trimming.

Source (both photos) | Mitsubishi Rayon Carbon Fiber & Composites

Towpreg for PCM

Closest to commercialization is an inline prepregging process developed jointly by Mitsubishi Rayon Co. Ltd. (Tokyo, Japan) and Mitsubishi Rayon Carbon Fiber and Composites (Irvine, CA, US). Otherwise conventional UD prepreg is produced in a hot-melt process by spreading dry fibers and pressing them between resin films to form consolidated sheets. Optionally, these can be slit into tapes, albeit at high cost. In the new process, Mitsubishi scientists reduce costs by directly coating single bundles of carbon tow, calibrating the width and then rewinding the product onto spools. An automated fiber placement (AFP) system — Mitsubishi calls it automated *towpreg* placement — is then used to lay up ply stacks, to eliminate the labor of hand layup. Stacks are subsequently preformed and molded via the company's own prepreg compression molding (PCM) process (more on this shortly).

Towpreg is less costly than the slit tapes typically used on AFP machines (although it lacks the latter's width tolerance); it is also easier to handle than wet (inline-impregnated) fiber systems, so the equipment runs faster with less scrap, again, reducing cost. Similar to Mitsubishi's conventional PCM prepreg, the towpreg uses 24K or 50K carbon fiber tow that is impregnated with a press-ready, rapid-processing, solvent-free epoxy that reportedly cures in 3 minutes at 150°C. The towpregs are dry and rigid at room temperature for easy handling in the AFP machine, but upon heating, quickly tackify and stay viscous at molding temperatures to reduce flow and eliminate dry spots.

Although towpreg can run on any AFP machine, Mitsubishi uses a next-generation STAXX1500 AFP from BA Systems GmbH (Grenzach-Wyhlen, Germany), which is optimized for spooled towpregs instead of the usual slit tapes. Compared to earlier systems, it runs faster (minimum 30 kg/hr with 16 lanes), is less expensive (only two axes, not multiaxial), and has a smaller footprint, making it ideal for automotive applications.

"Replacing hand layup of prepreg with fully automated towpreg layup brings many advantages," explains Max Thouin, technical sales manager, Composites Materials Div., Mitsubishi »

A more flexible, formable, manageable material

Because towpreg moves differently and more independently in the tool than prepreg, it can stretch and shear during preforming to better fill complex contours. Mitsubishi researchers have already molded it into a complex liftgate inner panel on a production automotive tool and found that sections that are difficult to mold in conventional prepreg due to wrinkling or folding (top) can be molded without such flaws in towpreg prepreg (bottom image).

Source (both photos) | Mitsubishi Rayon Carbon Fiber & Composites

Trading "pretty" for performance and practicality

PCM's towpreg's greater flexibility in terms of conforming to complexities of tool surfaces contributes to its aesthetic downside: This finished and trimmed liftgate inner looks good from this angle with this lighting, but as the close-up reveals, the shifting and separation of fiber bundles that takes place during preforming creates a "patchy" visual effect. Cosmetics can be addressed by filling/painting parts or restricting their use to non-visual applications, or by using a facesheet of conventional prepreg before building the rest of the structure with towpreg.

Source (both photos) | Mitsubishi Rayon Carbon Fiber & Composites

Rayon Carbon Fiber & Composites. "Once the layup path is designed and programmed into the machine, AFP provides rapid, repeatable, scalable and fully automated layup of a net-shape 2D laminate stack. This saves both cutting waste and kit production time, as well as ply layup time. Because towpreg is narrow and AFP machines can be programmed to leave holes in layup patterns [for cutouts], it's easier to fill complex contours without extra material that otherwise gets trimmed away." After layup, only a jagged edge is left around a part's external contours, further reducing cost and waste, depending on design complexity. "Unlike conventional prepreg, which requires cold storage until ready for use, towpreg is stable at room temperature for several weeks, although longer storage does require refrigeration," says Thouin. "This makes it easier to stop and start production steps, like when layup gets ahead of preforming and/or preforming gets ahead of molding or finishing."

Notably, Mitsubishi's PCM process uses a low-pressure, heated preforming station immediately adjacent to a conventional

Bringing it all, and they mean all, inhouse

A new inline prepreg (InPreg) production method developed by Fraunhofer Institute for Chemical Technology (Pfinztal, Germany) offers the potential for prepregging, cutting, kitting, preforming and molding in one, continuous inline process. It features this four-zone developmental web-type processing method that already has produced more than 1,000m of material for small-scale lab testing as well as molding of some large parts. After applying resin to the fabric (bottom and top left), the web of material is heated to 90°C for 4 minutes to B-stage the epoxy (middle of top photo), then cooled to room temperature to stop the reaction and make the material manageable to handle (top right). Next the release liners are removed and the prepreg is cut before being stacked and processed via compression molding. Source | Fraunhofer ICT

compression press. This setup reduces voids and improves surface finish, and could enable the many processors who already form sheet molding or bulk molding compound (SMC/BMC) or even D-LFT on compression presses to transition to higher margin carbon composites without a huge capital investment. A molder would only need to invest in an AFP (US$750,000-US$2 million) and a preforming station. Although PCM towpreg's or prepreg's 3.5- to 5.0-minute molding cycle (not counting preforming) can't match SMC/BMC's 2.0-3.5-minute cycles, it's faster than most other OOA methods and *far* faster than vacuum-bag/autoclave processes. Because compression molding uses matched metal dies rather than single-sided tooling, and pressure is distributed evenly across all part surfaces, both A and B sides of parts exit the press with better surface finishes, reducing costly and time-intensive finishing. With a single tool set, Mitsubishi says the current PCM process could mold 84,000 parts/year with an even faster but still developmental 3-minute cure grade. When PCM is combined with less costly towpreg and faster, less wasteful AFP layup, 20-60% costs savings can accrue, largely by reducing waste and hand labor.

An unexpected benefit is that parts that can't be satisfactorily molded in conventional prepreg *can* be molded with towpreg. This is because towpreg rovings aren't locked together (across a single layer or between layers) in the same way as plies of preconsolidated prepregs or tapes. As soon as heat is applied, towpreg fiber bundles can move — stretch and shear — during preforming and molding. Because more movement is possible, towpreg is better able to fill complex tool contours and avoid bridging and resulting voids, overcoming a longstanding disadvantage of laminate composites. Recent work by Mitsubishi using a complex inner-panel liftgate tool showed that with PCM towpreg, researchers could fill challenging sections of the tool without the wrinkling or folding that occurred with PCM prepreg (see photos on p. 53).

> "Automated towpreg placement and PCM show great potential as a high-cycle CFRP molding process." — Koichi Akiyama

Like any material/process combination, there are pros and cons to this development. The biggest disadvantage of towpreg PCM — fiber movement that results in gaps — is aesthetic (see photos and caption on p. 54). Aesthetic shortcomings can be addressed by painting parts or using them in non-visible applications, or by using a facesheet of conventional prepreg before building the rest of the structure with towpreg. The company says it is tweaking resin chemistry to further reduce flow as well as cure time.

"Automated towpreg placement and PCM show great potential as a high-cycle CFRP molding process," notes Koichi Akiyama, group leader, automotive development at Mitsubishi Rayon. "Part cost can be significantly reduced by limiting scrap and integrating automation."

Inline prepreg production

A different approach to reducing prepreg costs is the new InPreg (inline-prepreg) process developed by the Fraunhofer Institute for Chemical Technology (F-ICT, Pfinztal, Germany). F-ICT helped develop the original D-LFT process in the late 1990s, the tailored D-LFT process (with continuous rovings and fabrics) in the mid-2000s, and the direct-SMC (D-SMC) process about five years ago. Knowledge accumulated in these efforts, a unique resin »


Complex prepreg contours via compression press

A fairly large (550 mm by 500 mm by 35 mm) and reasonably complex 2.5D test part (see inset of top profile) has been molded via InPreg/compression molding using a tool developed by Huntsman Advanced Materials (The Woodlands, TX, US).

Source | Fraunhofer ICT

system and machine automation have been brought to bear on the InPreg process to speed downstream prepreg cutting, stacking and molding steps.

Like Mitsubishi's PCM approach, InPreg prepregs are designed to be formed in compression presses rather than more exotic equipment, thus opening up laminate composites to a broader range of processors. Unlike PCM, where preforming and molding are decoupled and completed in separate steps — which needn't occur close together in time or space (prepreg can be preformed, then stored for days before being molded) — the InPreg preforming and molding steps are both accomplished in the compression tool. This eliminates not only the time needed to heat, preform and cool prepreg, but also the cost and space necessary for a preforming station.

Key to the Inpreg process is a four-part, B-stageable epoxy resin system used by industrial prepreggers (Araldite LY1556 resin, Aradur 1571 paste hardener, Accelerator 1573 paste accelerator, and Hardener XB3471 polyamine-based hardener from Huntsman Advanced Materials, Basel, Switzerland). "Due to the unique characteristics of this resin system, which uses a chemical B-staging step, it's well suited for a faster inline process," explains Klaus Ritter, marketing manager and head of Huntsman's Composites Center of Excellence. "Traditional hot-melt systems also allow B-staging to be separated from final cure. However, their higher viscosity compared to chemical B-stage systems means much more exact impregnation equipment is needed to avoid triggering final cure during B-staging."

F-ICT also uses lower cost 24-50K tow carbon fiber, which is formed into a UD, non-crimp fabric (NCF). This dry NCF reinforcement is said to impregnate faster and more easily than conventional UD spread-tow tapes. Because the process impregnates a single NCF layer at a time, voids are minimized and very precise fiber/resin ratios are achieved.

During development, the team built a small production line to prove the concept. To date, it has produced 1,000m of material, which has been used to mold and test small specimens cut from larger flat plaques, as well as some sizeable (550 mm by 500 mm by 35 mm) parts with 2.5D geometry.

The web-based line features four zones: impregnation, pre-cure, cooling and cutting. First, NCF reinforcement is pulled through the system under controlled tension over rollers and impregnated. Pre-cure (to reach B-stage) occurs in the second zone and takes 4 minutes at 90ºC. Next, prepreg is cooled to room temperature for 4 minutes to stop pre-cure and increase resin viscosity for easier handling. In the final zone, newly made material is cut. Then it leaves the line and is laid up in the compression tool, according to the ply schedule, and formed. Molding/full cure is achieved in 10 minutes in the press at 150ºC and 7.5-8 bar.

Because the process isn't overly complex and the line isn't overly long, preimpregnation/pre-cure and cutting/stacking steps can be done in parallel, with both processes feeding the same press. InPreg prepreg remains stable for several days without refrigeration, so molders can build inventory to feed slower forming steps without needing to stop and freeze, then thaw, material before molding.

F-ICT researchers thought carefully about how and where to add automation to speed up downstream production steps. In use, they recommend an automated CNC cutter to cut plies from sheets of freshly made prepreg via preprogrammed patterns. Stacking could be done by hand for low-volume applications — possibly with laser-placement assist — with automation used for higher volumes. Robots equipped with Bernoulli grippers could pick up stacks and load them into the press, then remove completed parts (using vacuum grippers) and send them off to waterjet trimming and final finishing.

The team did a followup study to compare the mechanical performance and economics of InPreg/compression molding with conventional autoclave and vacuum-bag cure methods for making laminate composites (both using single-sided tools) and with fast wet-compression molding, using two-sided, hard tooling. For autoclave/vac-bag processes, the team used classical epoxy/carbon fiber UD prepreg with the same fiber/volume fraction as the prepreg produced via InPreg; a similar material was formulated for wet-compression molding.

The InPreg/compression laminates processed faster and were comparable to autoclave-cured laminates and superior to vac-bag laminates in void content and mechanical performance. Wet-compression molding was faster, but Inpreg/compression had better properties and fewer voids. F-ICT calculates that the cost of parts of comparable mechanical performance from InPreg/compression molding will run 45% more than those from wet-compression molding (with fewer voids and better properties), but only *one-eighth* that of autoclave-cured parts using conventional prepreg.

"InPreg offers many benefits vs. conventional prepreg [produced via hot-melt or solvent-based methods]," notes project leader and F-ICT thermoset technology head, »

Michael Karcher. "Production time and energy are reduced by eliminating freezing [used to stop the cure reaction during B-stage] and subsequent shipping and thawing prior to use. There are fewer process steps, since resin is applied directly to carrier films and fiber. Processing times can be reduced further once two-step (snap-cure) technology is applied to resin systems." F-ICT researchers believe that compression molding is the most cost-effective process for high-volume composites processing because the presses don't need the injection units, venting strategies or tooling action that injection or resin-transfer molding (RTM) require. And because resin is B-staged rather than liquid, the tool can be sealed with a simple gasket.

Further, InPreg/compression provides a lower-cost, faster-processing alternative to high-pressure RTM (HP-RTM) for parts with complex geometry. "Thanks to greater process flexibility, molders can control and adjust properties like draping and tack on the fly," adds Karcher. "They also are better able to experiment with novel hybrid polymer systems that, for example, combine epoxy and urethane and are of great interest in the automotive industry. Further, molders gain greater control of the degree of pre-polymerization/curing after the initial reaction to create a B-stage resin. This combination makes the system attractive as a substitute for material/process combinations used in aerospace and automotive industries, and may open new market opportunities."

The InPreg program is still in an early development stage, but the F-ICT team believes there are many ways to automate downstream process steps that will reduce costs and cycle times. Huntsman researchers believe they can modify the current four-part epoxy system to apply 2-minute-or-faster snap-cure technology, but say this will require new cure technology and additional development time and effort. Both organizations seek industry partners to move the InPreg program forward. In the meantime, Huntsman says it will sell the resin system to any interested party. CW

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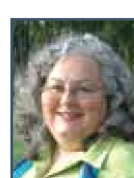
Read this article online | short.compositesworld.com/InlinePreg

Read more about OOA solutions in *CW*'s February 2015 *Out of Autoclave Supplement* | short.compositesworld.com/OOASupp

Read more about snap-cure epoxies in "Automotive composites: Thermosets for the fast zone" | short.compositesworld.com/FastZone

Read about PCM online in "Prepreg compression molding makes its commercial debut" | short.compositesworld.com/PrepregCM



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GE Aviation, Batesville, MS, US

With a supply chain busy making commercial jet engines, including the GE90, GEnx, LEAP and GE9X, GE Aviation has invested heavily in its composites capabilities in Batesville.

By Jeff Sloan / Editor-in-Chief

Aeroengine expansion

GE Aviation's 37,161m² plant in Batesville, MS, US, opened in 2009 and fabricates composite and metallic parts for the GE90, GEnx, LEAP and GE9X commercial jet engines.

Source (all photos) | GE Aviation

» In many advanced manufacturing facilities, there is a great emphasis on managing equipment and technology — much of it automated — with a secondary emphasis on the people who run such machinery. In composites manufacturing, however, especially in the aerocomposites realm, where touch labor is still integral to many fabrication operations, people are as important as equipment to timely, profitable plant operations.

That was certainly the case when *CW* visited Batesville, a small town of about 7,500 inhabitants located in the northern half of the US state of Mississippi, an hour south of Memphis, TN. It was here, in 2008, that GE Aviation (Cincinnati, OH, US) decided to build its latest aerospace manufacturing plant, with facilities for both composites and metals fabrication — primarily for aircraft engine applications.

The 37,161m² plant opened in 2009 and joined the more than 80 other GE Aviation manufacturing facilities in the company's supply chain. Like all the other facilities, Batesville shares the GE Aviation name but also operates independently. All GE Aviation plants are internally responsible for winning and keeping work and, therefore, must compete for it against not only fabricators who compete with GE but fellow GE facilities as well.

Tracking well-coached teams

GE Aviation Batesville's team-oriented part fabrication system relies on this Cell Control Center (above) to help the facility's "coaches" track progress and technical "opportunities." Plant manager Jackie Clark (at center, in photo at left) says GE Aviation Batesville strives to develop a workforce that is highly invested in the composites work it does.

Plant manager Jackie Clark, who led *CW* on the plant tour, says the competitive culture instilled by GE Aviation senior leadership helps make for a robust, demanding work environment in which a premium is placed on employees who are truly vested in the work — those who have, as Clark says, "skin in the game when it comes to performance. We're not looking for clock punchers."

Seeing to flight-critical engine CFRP

What is GE Aviation Batesville making that requires such rigorous attention to detail? Anyone with even a passing interest in aerospace propulsion knows that GE Aviation was the first jet engine manufacturer to use carbon fiber composite fan blades, in its GE90, which entered service 21 years ago on the The Boeing Co.'s (Chicago, IL, US) original 777. It was followed, in 2006, by the even more composites-intensive GEnx, developed to power the Boeing 787 and 747-8. Next came the LEAP engine, developed by CFM International (Cincinnati, OH, US), which is a GE Aviation/Snecma (Safran, Paris, France) joint venture. And, coming soon is the GE9X, which will feature a next-generation carbon/epoxy fan blade design on board the revamped Boeing 777X aircraft (see Learn More on p. 67).

A host of carbon fiber composite parts, big and small, for these engines are made by a well-coached, well-developed, cohesive workforce to fabricate flight-critical parts to tight specifications.

On a very large floor

Our tour starts on the shop floor on the composites side of the Batesville facility, with an introduction to the Cell Control Center. To the unpracticed eye, it is just another bulletin board — but »

Cleanroom cutting and kitting

Ply layup at GE Aviation Batesville is performed in one of several modular cleanrooms located on the factory floor. Many use cutting tables like this one from Gerber Technology (Tolland, CT, US) to prepare kitted material in preparation for layup and subsequent resin transfer molding (RTM).

Resin transfer molding focus

All of the RTM work done at GE Aviation Batesville is performed using equipment supplied by Radius Engineering (Salt Lake City, UT, US), which provides system consistency from platform to platform.

an important one, as on closer inspection, it maps every activity on the shop floor and exemplifies the culture of the Batesville operation. Every part manufactured at Batesville is fabricated in a team (Cell) environment in or near one of 13 modular cleanrooms. The daily performance of each Cell — cycle time, throughput, technical problems, successes — is tracked through the Cell Control Center. At 3:15 p.m. everyday, there is an assessment: All of the "coaches" (there are no "managers" in Batesville) gather at the Cell Control Center to review production opportunities (there are no "problems") and production successes. At the Cell Control Center, and throughout the plant, the rule is simple: If you have a "production opportunity," attempt first to solve it within your team; if that fails, escalate it to higher authorities. "A team," says Clark, "is a good one when it regularly solves its own problems."

Each cleanroom on the shop floor provides the same basic thing: A clean, well-conditioned environment for the hand layup of dry carbon fiber fabric preforms in preparation for resin transfer molding (RTM). The first cleanroom into which we enter is making LEAP 1B fan platforms, the carbon fiber for which is cut on a Gerber Technology (Tolland, CT, US) automated flatbed cutting table and then kitted. The kits are laid up by hand for preforming. Preforms are then loaded into a series of two-cavity tools.

The in-cavity layup for the LEAP 1B fan platform part comprises three preforms, a foam core, and another three layers of preforms. Each tool is then press-loaded, resin is injected via RTM, and the part is cured under pressure for about 5.5 hours. To ensure consistent processing, all of GE Aviation Batesville's RTM equipment is acquired from a single source, Radius Engineering Inc. (Salt Lake City, UT, US). »

There are 18 fan platforms per LEAP 1B engine, and the LEAP is being specified for the Airbus A320neo and the Boeing 737 MAX, which means CFM International will, by 2020, manufacture 1,800 LEAP shipsets per year. That engine program will put a lot of pressure on suppliers, including GE Aviation Batesville, and Clark notes that the facility's biggest challenge will be meeting these full-rate production requirements. Clark says the facility is looking closely at options for automating every production step, from layup to nondestructive evaluation (NDE). In the meantime, she says, "I'm excited by what's happening here. Our employees are 'getting' what we're trying to do and provide a quality product. They understand that they're going to be a part of a major ramp-up on LEAP."

Legacy line

Our next stop is the cleanroom occupied by the team that manufactures GE Aviation Batesville's highest-volume product, the fan platform for the GE90 engine. Attached to the rotating hub of the

From fan blades to OGVs and beyond

GE Aviation has come a long distance since pioneering composite fan blades two decades ago in its GE90 engine. These outlet guide vanes (OGVs) are emblematic of the type of complex carbon fiber composite structures that GE Aviation Batesville now manufactures for a variety of high-performance commercial jet engine platforms.

Critical cure for fan case

A fully bagged fan case is positioned, ready for cure, in one of GE Aviation Batesville's four autoclaves. The facility's largest autoclave (6m by 12m) can hold two fan cases. The cure cycle is 24 hours.

Braiding a big fan case

The largest composite structure made by GE Aviation Batesville is the carbon fiber fan case for the GEnx. It features a dry, braided carbon fiber material from A&P Technology (Cincinnati, OH, US) that is wound onto this mandrel. Tiles of epoxy resin are then placed on the outside edge of the mandrel and the entire structure is overwrapped with a silicone bladder and bagged for autoclave cure.

Assembled and ready to ship

A finished composite fan case (black) is mated with a metallic aft fan case (green). Once this is done, technicians work inside the fan case to cut fan blade grooves, and outside to attach brackets, tubes, tanks and other equipment. Finished fan cases are shipped to another GE Aviation facility in Peebles, OH, US, for testing and final assembly.

GE90, the fan platform acts as a spacer between each of the 22 fan blades. Given a build rate of 230 GE90 engines in 2015, GE Aviation Batesville is currently manufacturing fan platforms at a rate of about 5,060 per year.

Fan platform fabrication begins on one of this cleanroom's three flatbed cutting tables, one from Gerber and two from Eastman Machine Co. (Buffalo, NY, US). These are used to cut dry carbon fiber fabrics that are subsequently kitted for preforming. Each kit is hand-laid in one of two female molds mounted in each of six Radius layup machines (12 molds in all). When layup is complete, a binder is applied, the molds are bagged and the preforms are put through a 20- to 30-minute debulk cycle. When this is complete, the debulked preforms are removed from the cleanroom and taken out to a Radius machine for RTM.

Curt Curtis, technical leader at the Batesville Composites Operation, manages the fan platform fabrication line and says each fan platform comprises five to seven preforms, depending on size and configuration. The molding process is monitored and controlled via a GE informatics system that captures and analyzes the RTM profile on the fly, helping make sure that parts are neither under- nor over-cured. The rules, says Curtis, are pretty basic: "Get the best possible vacuum and the most possible pressure, and you'll get a good part."

After RTM, a fan platform is sent to be trimmed and cut on one of three Mazak Corp. (Florence, KY, US) machining centers. Following this, GE Aviation Batesville employees add wear strips, linings and silicone rubber trim for erosion protection, at which point the fan platform is ready for shipment.

Really big fan cases

In terms of size, no product manufactured at the GE Aviation Batesville facility is larger than the 2.8m diameter fan case for the GEnx engine. It's also the first carbon fiber composite fan case ever developed for a commercial jet engine application. It represents a massive step-change in weight savings, compared to its aluminum predecessor — 159 kg per engine and a total of 363 kg per aircraft as weight savings cascade to other aircraft components. The GEnx engine is exceptional for other reasons as well. With its 2.8m diameter fan, the GEnx on 787 aircraft offers a takeoff bypass ratio of 8.8:1-9.0:1 and takeoff thrust of 69,000-76,100 lb, placing it among the most powerful and efficient aircraft engines on the market. GE is manufacturing about 300 GEnx engines per year, which means GE Aviation Batesville must turn out roughly 6 fan cases per week.

Curtis looks back on the overall effort to convert the fan case from aluminum to composites and says the challenge, historically, always boiled down to cost. In » short, composites were too expensive: "It was a constant battle," he says. However, materials and process advancements gradually nibbled away at the cost difference, and so did the weight savings. "That 350 lb [159 kg] is a game-changer," he contends. Compared to aluminum, CFRP "offers less hanging weight and less rotational weight. Today, cost is now, probably, very competitive."

The layup of the fan cases is substantially automated, consisting of a mandrel fed by a roll of dry braided carbon fiber, supplied by A&P Technology (Cincinnati, OH, US). The mandrel rotates in front of the fixed spool of carbon fiber, allowing the braid to lay over the mandrel's surface. Then, over this braid is placed a series of epoxy resin tiles. These tiles are held in place with a silicone bladder that overwraps the entire exterior of the mandrel. The wrapped mandrel is cured for 24 hours. GE Aviation Batesville has four autoclaves, supplied by Taricco Corp. (Long Beach, CA, US) and ASC Process Systems (Valencia, CA, US), two of which are used to cure GEnx fan cases. The largest, a Taricco autoclave, is 6m in diameter by 12m long and can cure two fan cases, simultaneously.

After a fan case is cured, its inside diameter is lined with a series of eight honeycomb sandwich panels to provide an abradable surface against which the fans will rotate. As with many engines, the fans rotate in a space that must be held to very tight tolerances so as to minimize the space between the tip of the fan blade and the inside of the fan case, without impinging on the rotation of the blades. The abradable panels provide a surface into which a fan blade path will be cut, after case assembly, to allow that final measure of clearance.

> GE Aviation Batesville is well-positioned to absorb a variety of composites work over the next several years.

Also installed are a series of hat stiffeners and metallic inserts for load spreading. In the next step, the composite fan case is mated with the aft fan case, the green structure atop the composite fan case in the bottom right photo on p. 64. The aft fan case, an aluminum/honeycomb structure supplied to GE Aviation Batesville by a third party, eventually will be bonded to the engine core.

After the two fan cases are mated, technicians work on the inside diameter of the fan case to cut the final fan blade path. Other technicians will add to the exterior of the fan cases a variety of brackets, tubes, oil tanks and other equipment. At this point, GE Aviation Batesville's work is done and the entire structure is shipped to another GE Aviation plant, in Peebles, OH, US, for testing and final assembly.

What the future may hold

The big question GE Aviation Batesville faces going forward is how much work it will win on the forthcoming GE9X, which, when it comes to market on the 777X, will be one of the largest and most powerful commercial jet engines in the world. It features an 3.6m diameter fan with 16 carbon fiber composite fan blades. It offers a 10:1 bypass ratio, up to 102,000 lb of thrust and will be 10% more fuel efficient than the GE90-115B that powers the current Boeing 777-300ER. Clark says Batesville is in the running to provide acoustic panels, stator assemblies and OGVs for the GE9X, which was expected to undergo its first tests in March.

Whatever the outcome, with a team-oriented workforce that is clearly invested in the technologies it uses and the products that result, Batesville is well-positioned to absorb a variety of composites work over the next several years. And, with workforce-development partnerships with Northwest Mississippi Community College (Senatobia, MS) and the University of Mississippi (Oxford, MS), there appears to be a strong network in place to ensure that GE Aviation Batesville will continue to attract the type of coachable and invested employees that have made the facility the success that it is.

To be sure, on the technology side, GE Aviation Batesville is not sitting still. Clark says GE Aviation is considering adding multi-cavity RTM capabilities, and there is room for another large autoclave. And entirely new technologies might also be in store. The sheer quantity and quality that will be required of commercial jet engine manufacturers during the next 30 years promises that the Batesville plant will be a busy one.

"We are trying to create an environment and a workforce and facility that is lean, flexible, adaptive, knowledgeable and invested in the work and the product," says Clark. "We think we are in a very good position to do just that." CW

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Natural fiber for a natural challenge

A variety of ski manufacturers offer skis made from Bcomp's (Fribourg, Switzerland) flax/Banova balsa core, ultralight flax/balsa bCore, and ampliTex flax-yarn fabrics. Flax reportedly offers better damping properties than conventional cores and glass or carbon fibers, translating to a smoother ski-run down challenging big-mountain terrain. The skier pictured here is on bCore-cored glass skis designed for extreme deep-powder skiing.

Source | Bcomp / Photo | Oskar Enander

Natural fiber composites: Market share, one part at a time

New suppliers and adventurous composites fabricators put the "feel good" aspect in the rearview mirror, winning customers by competing on price and performance.

By Michael LeGault / Contributing Writer

» With decades of development work behind it, the natural fibers industry is maturing. Indeed, it appears to be on the verge of leveraging the products' numerous cost, performance and environmental benefits for big-time technical and potentially high-volume commercial applications.

In the auto industry, for example, natural fibers — hemp, flax and others — are used in combination with polypropylene and other resins. They are especially well suited for door and trunk liners because of their lower cost *and* lower density. Glass fibers, for example, have densities in the range of 2.6 g/cm^3, but flax fibers have densities of approximately 1.5 g/cm^3, yielding a net weight savings of nearly 40%. The cost discount per kilogram of material is also significant — in the range of 20-100%. Lastly, a paper published by S.V. Joshi, et. al. (2003), at Michigan State

University (East Lansing, MI, US), evaluated the lifecycle impacts of the production of glass vs. flax and found overall energy use, as well as emissions for eight of the 10 chemical compounds, to be substantially less for flax. The only blemish: Production of the natural fiber did result in a significantly greater discharge of nitrates and phosphates into water as a result of fertilizer use and agricultural runoff.

Since *CW's* previous coverage of this subject in 2013 (see Learn More, p. 75), development of a critical mass of natural fiber sources, an expanding materials' knowledge base and wider acceptance of the materials by composite manufacturers have encouraged a number of new biofiber suppliers to spring up, offering products that have significantly advanced the technology.

Stocking raw feedstock for reinforcements

Sunstrand (Louisville, KY, US) claims to be the only US-based supplier of natural fibers and fillers to use and exclusively distribute domestic feedstock. Bales of flax, kenaf, bamboo, cane and other plant materials are delivered directly to its Kentucky facility.

Source | Sunstrand

Flax gets a sporting chance

Founded in 2011, Bcomp (Fribourg, Switzerland) manufactures a trademarked product line that comprises three main families: 1) a line of non-crimp and low-twist, uni- and bidirectional flax-yarn fabrics, called ampliTex; 2) a flax and Banova balsa wood core material called bCore (supplied by 3A Composites, Benton, KY, US), which Bcomp claims is the lightest core material on the market, designed for sandwich composite construction of skis; and 3) a recently launched, high-damping, flax-yarn 0°/90° "grid" fabric, called ampliTex powerRibs. All of the fabrics are compatible with epoxy, vinyl ester and thermoplastic resins, and are available dry and prepregged.

"We are the young guns," claims Patrick Vuagnat, Bcomp's sports manager, noting that the company sources its flax fiber feedstock through an exclusively European supply chain. The company's defined mission is designing and producing natural-material fabrics that can be processed by widely used means, such as resin transfer molding (RTM), vacuum infusion and compression molding, with no compromise in performance compared to conventionally reinforced composites.

The bulk of the company's first commercial applications are sports equipment: new ski and snowboard products in which Bcomp's flax fabrics provide tangible performance benefits. Flax is lighter than glass but, more significantly, compared to carbon/glass (a commonly used layup), flax improves damping properties by as much as 300%. That, says Bcomp, translates to a smoother ride and greater rider control.

> Today, nearly 20 ski manufacturers produce skis using Bcomp's flax fiber-based core materials or fabrics.

Today, nearly 20 ski manufacturers produce skis using Bcomp cores or fabrics, including Black Diamond, Nordica, K and DPS. That said, skis made with some natural fiber reinforcement still represent a small percentage of the total ski market. Further, lightweight carbon fiber prepreg, not glass, is the most common material of choice for high-performance skis, but Vuagnat reports that even here, things are changing: "People realize carbon, despite being light, vibrates too much," he explains. "Therefore, the carbon/flax hybrid construction is the next step in terms of performance."

It is no coincidence that all of the company's first commercial end-use applications are skis. Bcomp's founders are all avid ski enthusiasts. This passion, and serendipity, played roles in the current hybrid-fiber design of high-performance skis manufactured by many of the company's customers.

In 2003, Cyrille Boinay, currently one of the managing directors, was working out of his garage, trying to build a new type of ski that would handle better in powder-snow conditions. His initial plan was to make the ski entirely from carbon fiber composites, but a chance encounter with two engineering friends, who knew about natural-fiber composites, convinced him to try designing a ski that mixed carbon and flax. The two engineers, Julien Rion and Christian Fischer, are now Bcomp's director of new product development and co-managing director, respectively.

A typical ski construction involving Bcomp fabrics comprises a bCore sandwiched between layers of glass or carbon fiber fabric (triaxial 450 g/m^2 is one fabric type often specified) on the bottom with a top layer of ampliTex shear-web, comprising ±45° »

■ Processing variation out, consistency in

A variety of in-house processing technologies are used at Sunstrand to cut, separate and extract the fibers and convert raw plant materials into forms compatible with composites. Fiber variation is minimized by blending and quality-control procedures, yielding a product which, when manufactured into composite parts, provides consistent mechanical properties. Source | Sunstrand

flax fibers. Some ski manufacturers use only the company's core material, with glass or carbon reinforcement in faceskins. The most common method is wet layup by hand followed by compression molding.

Bcomp's flax feedstock is processed by standard methods (retting, scutching, hackling) used to extract fibers for the clothing industry, resulting in a fiber approximately 30 cm in length and 40 microns in diameter. Although the snowboard is its largest market, Bcomp also has commercial products in the surfboard, skateboard and hockey-stick segments, and is engaged in developmental efforts to expand into other markets. Its new powerRib fabric is manufactured using precise fiber placement methods in order to maximize flexural rigidity and buckling resistance. Vuagnat reports it is targeted to applications such as kayaks and bicycle frames *and* auto body panels.

The company has introduced two ampliTex fabrics, combining glass fiber and low-twist flax yarns, especially for surfboards: a 120 g/m^2 unidirectional and a 200 g/m^2 balanced satin weave. Marketed as ampliTex Surf, both are

SIDE STORY

Sizing up natural fibers

A bio-fiber's status as "natural," as opposed to synthetic, has consequences. The two of most concern to composites manufacturers are its hydrophilic nature, and its poor bonding properties with thermoplastic and thermoset polymers. While both are problematic, the solution to potential moisture absorption, and release, by fibers in the matrix is relatively straightforward: Dry the fibers, in pellet, chopped or mat/fabric formats, with heat, a desiccant, or both, and keep them dry until just before use in the molding process.

Solving the problem of natural fibers' inherently poor adhesion to polymers has been a bit more technically challenging. One of the most common, and simplest, approaches is to dose the resin with coupling agents to chemically induce a stronger resin/fiber bond. Sunstrand's (Louisville, KY, US) Dr. Trey Riddle, however, says this approach is quantitatively flawed and minimally effective.

According to Riddle, the concentration of coupling-agent additives is typically in the range of 3%, or 3g per 100g of resin. A coupling-agent additive functions by modifying the polymer with functional groups that enhance its potential to bond with fibers. It does not modify the fiber directly. If the composite has a fiber content of 25%, there is three times more resin than fiber. This means the vast majority of additive-modified polymer is not coming into contact with the fibers, says Riddle, but is simply "floating" in the resin-rich areas between the fibers. "While these additives have proven effective at providing modest improvements in performance, they are not able to migrate to the bond areas and must be mixed uniformly throughout the resin. Thus, significantly more additive must be mixed into the resin to ensure bonding is enhanced, driving up material usage and cost."

A better approach, and the standard process used with glass fiber, Riddle contends, is to put the coupling agent where it is needed by modifying the fibers directly. Improving bonding properties by modifying the fibers is more efficient because all of the fiber surface is in contact with the polymer. The problem is that not a lot of work has been done to develop sizing technology specifically for natural fibers. "Traditional sizing treatments do achieve modest performance improvements," Riddle notes, but contends that "modest" isn't enough. The chemistries simply don't react as well with natural fibers as they do with the glass fiber for which they were specifically formulated.

Riddle says Sunstrand has a program to develop and improve sizing for natural fibers, and says it entails chemical and mechanical methods. He reports some of the methodologies Sunstrand has tried have already yielded improvements in fiber/resin bonding. "It is our hope that in the near future we'll actually be able to commercially supply value-added fibers that perform better as a result of the treatment programs we apply to them."

bleached, yielding a white fabric that makes the boards easier to decorate/finish and less likely to absorb the sun's heat energy and melt board wax. Vuagnat reports that Bcomp also is in the early stages of developing some new fabrics for a US-based skateboard manufacturer.

Designer-friendly fiber reinforcements

In addition to better damping properties than carbon fiber, natural fibers also are more easily and less expensively colored than glass fibers, making them attractive for highly decorated products such as snowboards, surfboards and skis. Pictured here are dyed bamboo fibers. Source | Sundstrand

Engineering nature to need

Although it hasn't captured as much press attention as other natural fibers, bamboo is not only abundantly available but its mechanically extracted, low-density fibers also come with features unique among bio-based reinforcements: Its mechanical properties, particularly modulus and tensile strength, are superior to other biofibers. Further, because bamboo is cultivated in a tropical mono-climate with little seasonal variation, its properties show much greater *consistency* than those of other natural fibers.

A consortium that includes Bangalore, India-based Spectrus, its US partner, Innovium (Dublin, OH), and strongly supportive European and Asian customers, is in the advanced stages of developmental work, intended to capitalize on bamboo's properties.

Developmentally complete, the consortium's fiber-processing method converts bamboo chips into a variety of forms and fiber lengths: powder for resin additive/fillers, short-fiber (2-5 mm) reinforcements for injection molding applications and long fibers (6-12 mm) that are used for long-fiber pellets and semi-finished mats for press moldings. The company says it is very close to using these products to manufacture a variety of automotive and commercial vehicle parts for "leading global firms." Presently, the parts are anticipated mainly for semi-structural interior applications, such as door and seat-back panels, parcel trays and floor panels. In these test and prototype applications, bamboo fibers have significantly reduced weight and damped noise and vibration, and done so better than other natural fibers at a lower part cost.

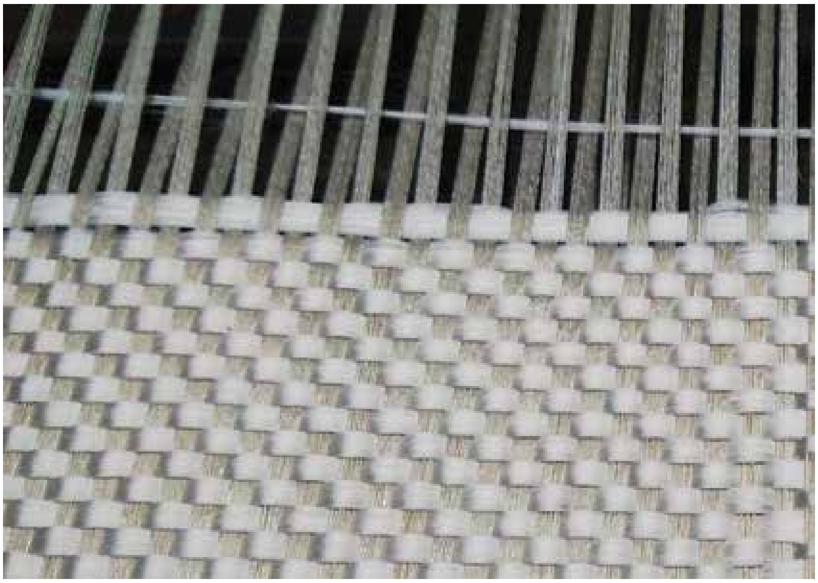
Although natural fibers are usually produced in lengths no greater than 100-120 mm, bamboo can yield *continuous* fiber filaments, which can be processed into yarns, fabrics and preforms similar to those manufactured with glass and carbon fiber. These fiber forms can then be mass produced into thermoset parts via injection molding, resin transfer molding (RTM) and high-pressure compression RTM (HP-C-RTM), also known as gap injection or wet compression molding. Kylee Guenther, owner and operations manager of Innovium, reports, "We are very close to bringing continuous-fiber bamboo composites technology into the automotive industry, as well as mass transportation and other industries."

"It has taken years of intensive development to reach this phase and, we believe, to set another key milestone in the composites industry," says Spectrus CEO Mahadev Chikkanna. He reports that Spectrus is still working on further improving and fully commercializing a complete bamboo product line, ranging from powder to fabrics.

One critical need yet to be addressed in the commercialization effort is optimizing the bond between bamboo fiber and matrix resin (an important area of natural fiber R&D; see the Side Story on p. 70). Mahadev predicts end products with properties somewhere between »

■ Flax/balsa-cored high-performance carbon fiber composite skis

Bcomp's primary customers, ski and snowboard manufacturers, use their materials (flax-yarn fabrics and flax/balsa core materials) to manufacture wet layup, sandwich composite parts with various structures. In 2014, Black Diamond Equipment (Holladay, UT, US) introduced its carbon series of skis, comprising carbon fiber prepreg and Bcore flax/balsa core, a ski line designed for highly technical skiing on steep terrain. Source | Bcomp



Continuous-fiber woven natural fabrics

Unlike other natural fibers, bamboo can yield continuous filaments that can be processed into yarns and fabrics, much like glass and carbon fibers. Pictured here is a woven bamboo mat fabric. Such fabrics can be infused with thermosets or thermoplastics in relatively high-volume processes, such as resin transfer molding (RTM) or HP-C-RTM. Spectrus (Bangalore, India) and US partner Innovium (Dublin, OH) intend to capitalize on this and other properties of bamboo fiber for composite parts targeted to the automotive and transportation industries. Source | Innovium

glass and carbon composites, with lower costs and potential weight savings up to 50%.

Taking a slightly different tack in the natural fibers arena, Sunstrand (Louisville, KY, US) services the nonwovens market with short and long fibers made from a variety of natural fibers, including hemp, flax, kenaf and bamboo. The company also custom manufactures chopped strand mat (CSM), which is made with randomly oriented fibers. The mat fibers are held together with a resin-specific binder (that is, one with a formulation identical to or compatible with the matrix resin, so it won't interfere with resin/fiber bonding) or fiber lignin itself (lignin in liquid form, derived from the same plant as the fiber) used as a binder. Supplied in rolls, the mats can be used as single-reinforcement material, or in combination with multiple layers of woven or unidirectional fabrics in wet layup and infusion processes. Dr. Trey Riddle, Sunstrand CEO, says long fibers, typically 38-115 mm, are also compatible with sheet molding compound (SMC), using either a thermoset or thermoplastic resin, to produce a formable sheet. Riddle reports that the long-fiber mats have an aesthetic, translucent quality that customers find ideal for architectural applications.

In addition to supplying the nonwovens industry, Sunstrand also processes and sells bulk raw fibers to a variety of customers, including materials suppliers (e.g., injection and bulk molding compounders and fabricators), who use or sell the products to manufacture a variety of composite end-use parts. The company also sells fillers and additives made from natural sources — the reason the company bills itself as a bio-*materials* supplier rather than a bio-fibers supplier. Its bio-particulate fillers are made from bamboo and hurd, the inner, woody core of hemp, kenaf and flax plants, and range from 5 up to several hundred microns in length. The fillers are in the same price range as existing conventional products (talc, for example), but offer potential weight-savings opportunities, and in some cases can impart performance enhancements, such as improved impact strength.

Sunstrand produces its natural fibers from exclusively domestic agricultural feedstocks.

Although other US-based companies supply bio-materials that have been grown in and then imported from other countries, Sunstrand uses an exclusively domestic feedstock and, Riddle claims, is currently the only US manufacturer of bio-materials for the composites industry to do so. The company has contracts with farmers to purchase agricultural feedstocks in raw format. Bales of hemp, flax and kenaf and, in the case of bamboo, complete canes, are delivered directly to its processing facility.

"We use our own, in-house processing technologies to extract the natural fibers and convert them to forms compatible with composites," Riddle says. While variability is always a concern with natural materials, Riddle reports they are able to minimize the effects of variation by means of blending and strict quality-control procedures, producing products with properties that can be quantified within statistical limits. With such measures in place, Riddle says, "We have seen minimal variation in the composite response when manufactured from our materials."

Natural is not equal

Lighter than glass, with competitive specific stiffness and strength, natural fibers also are less abrasive than glass, which prolongs tool life, and are easier and less expensive to dye than glass, providing fabricators with an aesthetic perk for end-use customers. Further, all natural fibers are essentially complex linear structures » formed from ligno-cellulose polymers. However, despite the similarity, differences in the chemistries and functional groups that comprise the polymers dictate differences in mechanical, performance and processing properties. “Every natural fiber has differences in the ratio of lignin, cellulose, hemi-cellulose, etc.,” says Riddle. These nuances play a critical role in determining which fiber or fiber system is best for a given application. And knowledge of these differences helps engineers understand and optimize the performance of the fibers in the final composite part.

Within a composite matrix, the natural fiber is not typically a single fiber, but a fiber bundle that comprises multiple fiber chains held together by lignin. Riddle says this structure almost resembles and behaves like “a composite within a composite.” The different fiber extraction processes used by fiber suppliers also can contribute to variation. For example, hemp, flax, jute and kenaf, a group collectively termed *bast* fibers, all have similar fiber structures and, therefore, process similarly; but bamboo and agave fibers have unique fiber-bundle morphologies that require the use of dramatically different extraction processes. A typical hemp fiber bundle has a diameter of 70 to 80 microns. A bamboo fiber bundle can be up to 180 microns in diameter, or larger. These structural differences, in turn, determine mechanical properties. Riddle notes that kenaf might have a tensile strength of around 200 MPa vs. 500 MPa for bamboo. “In general, bast fibers do really well in nonwovens, but bamboo can outperform them in short-fiber compounding applications,” Riddle contends.

Composites Evolution’s carbon/flax hybrid materials offer all-carbon modulus plus NVH damping.

All of this fiber chemistry has some practical consequences. Although natural fibers, for the most part, are less expensive than glass fibers, when they are used to replace glass reinforcement, Riddle cautions, the replacement *ratio* might not be one-to-one. In other words, raw natural fibers might cost less per kilogram than raw glass fibers, but a composites fabricator might need *more* natural fibers in a particular application to achieve equivalent performance. The potential cost savings against glass, then, is application-dependent. Another limiting factor, he says, is that bio-materials generally have lower processing temperatures limits than glass and may not be suitable as a replacement for glass in matrices that must be processed at very high temperatures.

Expanding the fiber palette

Germany-based FRIMO, a manufacturer of complete production-line machinery and tooling, recently introduced a new forming technology, Organo Sheet Injection (OSI), which combines forming and back injection of resin in a single step, with resulting improved efficiency. In one iteration of the process, parts can be molded from a sheet-reinforcing material called Natural Fiber Polypropylene (NFPP), which is a combination of compacted wood fiber/cellulose combined with polypropylene fibers. The material can be back injected with either polyurethane or epoxy. The company's equipment is employed to make a variety of automotive interior parts from NFPP/polyurethane, such as door liners, which are approximately 50% lighter than the same parts made from glass fiber-reinforced ABS.

Composites Evolution Ltd. (Chesterfield, UK) has developed a line of carbon/flax fiber hybrid materials primarily for the automotive and sporting goods industries. The fabrics, which include hybrid woven yarns and hybrid spread-tow fabrics, are suitable for creating micro-sandwich laminates, which, according to the company, offer modulus equal to all-carbon laminates, but at reduced cost, lower weight and with increased damping properties. The hybrid yarns, targeted to automotive noise/vibration/harshness (NVH) applications, can be used to create one- or two-layer laminates in which the carbon and flax are "tuned" to work synergistically to damp vibration. The hybrid spread-tow fabrics are manufactured with a high degree of fiber alignment and low crimp. Brendon Weager, technical director, says a number of sports equipment companies are considering the tow fabrics in the design of new skis, snowboards and hockey sticks.

A natural progression

The performance and cost benefits of natural fibers are proving to be a powerful combination. Given the successes that have accumulated over the past decade, it's a combination almost certain to attract wider attention and new development work aimed at better quantifying properties and qualifying the reinforcements for a wider range of composites applications. CW

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Read *CW*'s previous coverage of developments in the bio-fiber reinforcements sector in "Bio-composites update: Beyond eco-branding" | short.compositesworld.com/DMmfIDZP

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The Thermoplastic Composites Conference for Automotive 2016 (TCC Auto 2016) program consists of presentations from materials, equipment and software suppliers, including new innovations in composites molding, such as injection overmolding and compression molding. Speakers will emphasize advanced composites technologies that offer carmakers more opportunities to lightweight vehicles while maintaining, if not improving, performance.

TCC Auto 2016 offers technical presentations on Materials and Applications, Machinery Systems, Processes, and Continuous and Long-Fiber Thermoplastic Composites.

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Brian Gardner / Sigmatex

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Lionel Schaal / RocTool

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Andrew Rypkema / PEI, Pinette USA

Weld-Line Strength Prediction Through Combined Manufacturing and Structural Simulations
Doug Kenik / Autodesk

Methodology Development for Experimental and Numerical Rheology Studies on the Plasticizing Effect of Gas in Microcellular Processing and Injection Molding Using Long Glass Fiber Reinforced Polymers
Vanja Ugrešić / Fraunhofer Project Centre for Composites Research

Teijin's Thermoplastic Composite Material Technology (Sereebo)
Yutaka Yagi / Teijin Advanced Composites America Inc.

Process Simulation for Injection Molded TP Composites: Predicting Damage and Orientation of Long Glass and Carbon Fibers
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Validating Long-Fiber Reinforced Thermoplastics Using Industrial Computed Tomography (CT) Scanning
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June 15-16, 2016 — Stade, Germany
10th International CFK-Valley Stade Convention
cfk-convention.com

June 20-25, 2016 — Stanford, CA, US
Online Composites Design Workshop – Stanford University
web.stanford.edu/group/composites

June 22-23, 2016 — Sheffield, UK
Composites Innovation 2016
compositesinnovation.com

July 11, 2016 — Farnborough, UK
Farnborough International Airshow 2016
farnborough.com

July 17-23, 2016 — Sanya, Hainan, China
ICCE-24: 24th Annual Int'l Conference on Composites and Nano Engineering
icce-nano.org

Aug. 28, 2016 — Gramado, Brazil
Brazilian Conference on Composite Materials (BCCM)
bccm.com.br/bccm3

Aug. 31-Sept. 2, 2016 — Shanghai, China
China International Composites Expo
chinacompositesexpo.com/en/

Sept. 7-9, 2016 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
speautomotive.com

Sept. 13-14, 2016 — Chicago, IL, US
Additive Manufacturing Conference 2016
additiveconference.com

Sept. 21-23, 2016 — Augsburg, Germany
Experience Composites
experience-composites.com/en

Sept. 26-29, 2016 — Anaheim, CA, US
CAMX – Composites and Advanced Materials Expo 2016
thecamx.org

Oct. 4-6, 2016 — Tampa, FL, US
IBEX 2016
ibexshow.com

Nov. 2-3, 2016 — Birmingham, UK
Advanced Engineering UK
advancedengineeringuk.com

CW **Nov. 9-11, 2016 — Scottsdale, AZ, US**
Carbon Fiber 2016
carbonfiberevent.com

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Full steam ahead for composite ship doors and hatches

Resin transfer molded Accedoo composite ship doors and hatches offer a 50% weight reduction vs. convenitional steel counterparts.

Source | VABO Composites

Cost reduction, says Arnold Vaandrager, director of VABO Composites (Emmeloord, The Netherlands), is the most important factor in the commercial shipping world. To meet that need, VABO has added to its wide range of composite products (e.g., architectural structures, shovels/buckets for construction vehicles, 10m-tall radar masts for superyachts and manipulator doors and valves for pallet placement machines) ship doors and hatches that offer a 50% weight reduction vs. conventional steel doors. The composite design not only reduces fuel costs but also improves ergonomics and practically eliminates maintenance costs — repeated painting is no longer required. Another advantage is that vibration isolation, ballistic resistance and flame retardation also can be integrated into the part during manufacture.

The glass fiber/vinyl ester resin ship doors and hatches are produced under the brand name Accedoo — a contraction of *access* and *door*. Formed in high-precision aluminum molds via a resin transfer molding process, Accedoo composite doors and hatches comprise a series of standard dimensions and designs. In addition to these standard models, customer-specific dimensions can be provided using a modular mold system.

Having obtained maritime certification from Bureau Veritas (Paris, France), VABO Composites installed 12 Accedoo doors in May 2015 onboard the innovative, new-build fishing ship *MDV-1 Immanuel* in The Netherlands.

An acronym for Masterplan Sustainable Fishery (Masterplan Duurzame Visserij in Dutch), the *MDV* vessels aim to realize pioneering innovations in Dutch fishing. The 31m-long *MDV-1* features a dynamic-hull shape, designed using computational fluid dynamics and a hybrid diesel/electric propulsion system, reducing fuel burn from the current figure of roughly 4 liters per kilogram of average fish catch.

Due to cost, delivery time, regulations and recyclability issues, steel was chosen for the hull, and a composite superstructure is on the table for future builds. But Accedoo doors offered immediate savings, and research by The Institute for Energy and Environmental Research (IFEU, Heidelberg, Germany) showed that a busy cargo ship can achieve a return on investment (ROI), based on weight and fuel reduction for 12 composite doors and hatches, within the first 5 years of the vessel's service life, and even more quickly for ships operating at speeds higher than the *MDV-1's* average of 9 knots (e.g., ferries, at 20 knots).

Maritime Holland magazine reports that the MDV concept may indeed become the new standard in twin-rig North Sea fishing vessels, and none too soon given that much of the 275-vessel Dutch fleet — not to mention fleets from neighboring Denmark, Belgium, France and the UK — is aging and in need of replacement.

VABO Composites expects significant growth for its Accedoo products; it is now completing installation on two minesweepers in Italy and is pursuing increased market share by further industrializing production, including robotic automation that will enable cost parity with steel and ROI on doors/hatches from day one. CW

JEC World 2016 Product Showcase

CW staff members saw much that was new in Paris. Here's a sampling of what they found. Additional coverage can be found online | compositesworld.com/articles

» THERMOSET RESIN & ADHESIVES

Aerospace-grade epoxy surfacing film

The increased use of composites in aerospace engineering is coupled with a demand for high-quality surface finishes on the associated parts. To meet that need, **Henkel** (Düsseldorf, Germany) launched at JEC World 2016 its Loctite EA 9845 LC Aero epoxy-based surfacing film, developed to improve the surface quality of honeycomb-cored composite parts but also containing a lightweight, expanded conductive foil to offer enhanced protection against lightning strike. Based on Loctite EA 9845 SF Aero modified epoxy film adhesive, the film produces a high-quality finished part while also enabling a weight savings of 30%. Designed to reduce surface imperfections and minimize the pre-paint preparation requirement, the film's chemical resistance to paint stripper reduces the time required for masking, which in turn reduces composite part finishing costs. The surfacing film offers additional flexibility in that it can be cured within a temperature range of 120-176°C. **www.henkel.com**

» GLASS FIBER REINFORCEMENTS

Corrosion-resistant glass fibers

3B Binani (formerly 3B – the fibreglass co., Battice, Belgium) offered its new glass product, DS 1125-10N, made with E-CR (corrosion-resistant) glass and composed of individual glass filaments of low-micron diameter. It comes in a granulated shape, is designed to fit a broad range of polyamides, including PA6, PA6.6, PA6.10, as well as copolymers PA6/6.6 and semi-aromatic polyamides, and exhibits superior dispersion for good part cosmetics. Designed for smooth compounding with excellent feeding properties, it generates extremely low fuzz-and-fly, reducing cleaning and maintenance downtime. As a consequence of its tailored strand's integrity, it can be used in high-throughput compounding lines fed by pneumatic conveying. Neutral in color, it can be used in any natural grade compounds without impacting final part color, and is also compatible with flame retardants and impact modifier additives. It reportedly shows very good resistance to a wide spectrum of mold-release agents, including calcium stearate. The product sizing does not interfere adversely with polymer viscosity, which makes it suitable for low-viscosity polyamide compounds, enhancing productivity in injection molding, says 3B's automotive market manager Eric Debondue, who adds, "The combination of this well-balanced fiber repartition with an efficient adhesion of sizing to polyamides, translates into excellent dry-as-molded mechanical properties of the final parts in both static and impact properties." **www.3b-fibreglass.com**

» THERMOSET RESIN & ADHESIVES

Adhesives for LSE materials

SCIGRIP Smarter Adhesive Solutions (Durham, NC, US) highlighted its SG600 adhesive designed for bonding of plastics, specifically, low surface energy (LSE) materials, such as dicyclopentadiene (DCPD), ABS and PVC. Such materials tend to oxidize after production, and typical bonding requires extensive sanding and surface preparation to remove the oxidation; two-component, 10:1 mix ratio SG600 needs minimal surface preparation to bond well, and controls read-through, for fast automotive assembly. The company also debuted a new white paper entitled "An Introduction to MMA Structural Adhesives." The white paper is available on the *CW* Web site: **short.compositesworld.com/SCIGRIPpdf**

» FIBER REINFORCEMENT FORMS & FABRICS

Woven, thin-ply reinforcements

Chomarat (Le Cheylard, France) offered two products at its stand. The first was new ROVICUT, a stretchable woven reinforcement intended for cured-in-place pipe (CIPP) applications. Developed in collaboration with Reline Europe (Rohrbach, Germany), a well-known CIPP sleeve producer/supplier, ROVICUT reportedly conforms more easily to the shape of worn, corroded and damaged metal pipes than other sleeve materials. Further, its makers say ROVICUT sleeves can be made with less material, saving weight and, therefore making installation easier, as well as reducing thickness, which abbreviates cure when UV-curable resins are used. Chomarat worked with Reline to optimize the material for Reline's Alphaliner 1800 machine line for large-diameter pipes, where sleeves must be as thin as possible to avoid adding too much weight to aged structures.

Also on display was the company's well-known, patented C-PLY non-crimp, multiaxial carbon fiber reinforcements, made with spread tows that reduce areal weight. Chomarat announced that alpine ski manufacturer Dynastar (Park City, UT, US) has reduced the weight of its Mythic 87 skis by 26% yet maintains the same mechanical performance, thanks to incorporation of C-PLY material. According to Dynastar, the Mythic 87 ski is now the company's lightest ski.

www.chomarat.com

» DESIGN & SIMULATION SOFTWARE/HARDWARE

Composites design optimization software

Collier Research Corp. (Newport News, VA, US) showcased at JEC World its HyperSizer Express, the newest version of its HyperSizer optimization software, which is designed to deliver the key capabilities of the company's full professional version of HyperSizer in a user-friendly package aimed at the composites engineer. As explained by Collier's Bertram Stier, a research engineer focused on advanced composites, a customer's finite element analysis (FEA) is first imported (HyperSizer Express is FEA-agnostic and most FEA products are, therefore, compatible). A streamlined, menu-driven "wizard" interface then guides the user through the analysis process, which produces optimum composite laminates that satisfy all analyses to all load cases, fulfilling strength and stiffness requirements, and reportedly does so in as little as 30 minutes. Stier says the automatically updated model will ultimately arrive at the minimum practical weight, with global plies and stacking sequences identified, layer by layer, and with fully manufacturable laminate designs: "HyperSizer Express finds the best location for monolithic laminates vs. cored laminates, for example, plus optimal fiber direction and ply thickness." The software reportedly also can handle designs that incorporate prepreg ply patches.

HyperSizer Express is explained in greater detail here: short.compositesworld.com/HS-PDF

» FIBER REINFORCEMENT FORMS & FABRICS

Technical yarns, tapes

Créafibres SaS (Tourcoing, France), did not exhibit at JEC World, but was present and demonstrated to *CW* its range of technical slivers, felts, yarns, tapes, braids and fabrics that have application in the composites industry. The company's stretch-broken, 12-micron stainless steel fibers are twisted and spun to form yarns, which technical sales engineer Régis Boulanger explained are used by customers to impart electrical conductivity to hybrid textiles for antistatic and electromagnetic shielding applications. With excellent high-temperature resistance, the steel yarns are used alone or blended with other thermostable fibers for demanding applications, including satellite structures. Aramid, polyester and polypropylene fibers are also available. **www.creafibres.fr**

» AUTOMATED LAMINATING MACHINERY

Dry fiber placement technology

Danobat S. Coop. (Elgoibar, Spain), a division of machine tool manufacturer DanobatGroup, featured its ADMP (Automated Dry Material Placement) machine and head. Originally developed several years ago for a wind blade manufacturer to lay down fabrics at speeds up to 110m per minute, the ADMP can lay woven and multiaxial fabrics or dry tape with no distortion or sleaze, thanks to its proprietary pick-and-place capability. The company says 5- or 6-axis configurations are available to handle fabric widths up to 2m or more as well as to cut ply patterns. Cutting is performed simultaneously with head motion, says the company; that is, the head doesn't stop. The machine head automatically aligns, deposits and cuts fabric, can apply spray tack (if required) on curved molds, and is configured for inline inspection and wrinkle detection as well as completely automated roll changeover and resupply. Web tension is programmable to ensure that each material form is placed under optimum conditions. **www.danobatcomposites.com**

» DESIGN & SIMULATION SOFTWARE/HARDWARE

Pattern development software

McClean Anderson (Schofield, WI, US) announced at the show that is has released version 2.0 of its SimWind software product. The updated pattern development software, now available for download, features an enhanced graphical interface, pattern simulation improvements, robust motion editing, increased stability and performance, and multi-platform support. SimWind 2.0 supports a wide range of data formats to export and import mandrel and motion data, giving users the ability to create programs for complicated axis-symmetric structures. Extensive technical support is available from the company. **www.mccleananderson.com**

» GLASS FIBER REINFORCEMENTS

Glass fiber for pipe applications

Owens Corning (OC, Toledo, OH, US) introduced two new glass products for the piping market: Pipestrand M6000, a multi-end roving Advantex glass fiber with a sizing system designed for polyester and vinyl ester resins is for filament-wound, low-pressure water pipes and tanks (a single-end roving version is also available). Pipestrand S2300/2500 are single-end rovings with a sizing designed for epoxies (both amine and anhydride curing systems), for high-pressure pipe applications in long-service-life situations in the oil and gas industry or industrial plants. Bryan Minges, global product manager for OC's Composite Solutions Business, says that the company researched new silane-based sizing/coupling agents, which yield better interfacial bonding and strength: "These products deliver measurably higher mechanical properties, which means the pipes can be used in more demanding applications, or they can deliver the same performance, but with less material, for lighter weight." The sizings and improvements to the glass itself also reduce fuzz issues, which results in lower resin consumption and higher productivity, he says.

Minges notes that OC worked for a year with customers, benchmarking fiberglass products for piping, and testing the products both in-house and in outside laboratories. Testing included a full suite of mechanical properties including burst strength and axial tensile performance: "Piping, along with wind and long fiber-reinforced thermoplastic (LFRT), is a new focus area for us, and we have consolidated all of the many products we offered previously, to make it simpler for our customers."

www.owenscorning.com

» THERMOSET RESIN & ADHESIVE SYSTEMS

Bio-based epoxy systems

Sicomin Epoxy Systems (Châteauneuf les Martigues, France) reported that it continues to expand production of its Greenpoxy 56, a more than 50% bio-content epoxy resin and will, henceforth, stock product in the US state of New Jersey for North American customers, *CW* learned from Marc Denjean, the company's export manager. The Greenpoxy line is available in a range of bio-content percentages, and can be used in a variety of molding processes, from hand layup to high-pressure resin transfer molding. According to Denjean, Greenpoxy now comprises the major part of Sicomin's production, due to strong customer demand: "Greenpoxy has the highest bio-based content in the industry, and it delivers high optical clarity and the same mechanical performance as a traditional petrochemical-based epoxy, at virtually the same price."

Also featured were Sicomin's fire-retardant epoxies, including a new system, SR 1125, which is an advanced, self-extinguishing epoxy with a viscosity compatible with infusion processing. It is targeted to large parts

in architectural, civil engineering, rail applications, and in load-bearing structure where fire resistance is key.
www.sicomin.com

» PREIMPREGNATED FIBER REINFORCEMENTS

Thermoplastic prepregging systems

Prepregging system manufacturer **CAVITEC**, a brand within the Santex Rimar Group srl (Trissino, Italy), is a well-known supplier of thermoset prepreg manufacturing equipment and reported that improvements are being made in handling systems, including full automation, more ergonomic designs, and even non-stop, 24/7 systems. But Rolf Troendle, director of the Santex Rimar technical textiles division, told *CW* that the company also is moving into *thermoplastic* prepregging. A pilot line is already operational in Switzerland, producing polyamide tapes, and equipment for high-temperature PEEK and PPS tapes is under development, using proprietary processing methods. The thermoplastic lines must be capable of processing a range of resins, and both unidirectional and fabric fiber forms, says Troendle. "We had many customer requests for thermoplastic processing equipment, which is being driven by the challenges in automotive part processing," he notes, adding that CAVITEC also is involved in several European composites projects, including one involving recycled fibers.
www.santex-group.com

» PRE-CURED LAMINATES FOR STRUCTURAL REINFORCEMENT

Cured carbon fiber laminates for wind blade spars

Hexcel (Stamford, CT, US) introduced carbon fiber laminates with areal weights of 1,500 g/m^2 in a range of lengths and widths, designed and produced primarily for load-carrying spars in wind turbine blades that are manufactured using resin infusion or prepreg processes. Supplied in pre-cured state, which means there is no risk of generating exothermic heat during blade manufacture, the laminates also store heat for a faster ramp up during the infusion process, leading to potential time savings. Hexcel notes that a carbon laminate can be produced in greater widths than pultruded elements, which are limited by the width of the die. Widths greater than 200 mm are difficult to achieve with pultrusion, which limits its utility for the typically rectangular cross sections seen in spars and load-carrying elements in wind blades. Hexcel says its carbon laminates are thinner than pultruded elements, which means that more plies are required, but the thinness makes it easier to achieve a smooth drop off toward the blade tip. This allows an even transition of stresses at the end of each ply, thus avoiding the chamfering that is required with pultruded sections. The thinner laminate's ply also adapts easily to the twisted or curved geometry that is often found in today's large wind blades.

Hexcel also launched a new prepreg for ski manufacture, HexPly M78.1. The fast-curing hot melt epoxy resin matrix is available with carbon, glass or aramid reinforcements and is designed for prepreg applications where short cycles at about 110°C are required. It cures in 7 minutes at 120°C, yet it has a long storage stability of 2 weeks at room temperature meaning there is no need for freezer storage, saving energy and time. HexPly M78.1 also offers good adhesion to auxiliary and core materials including aluminum, wood, thermoplastics and elastomers. www.hexcel.com

» PREIMPREGNATED FIBER REINFORCEMENTS

Multiaxial tooling prepreg

TenCate (Morgan Hill, CA, US) launched its AmberTool HXR series, a multiaxial format tooling prepreg that is said to significantly reduce layup time while maintaining the easy handling of single-ply tooling prepregs. This product was designed for applications where layup complexity is unavoidable but tool production speed is a priority. These prepregs are said to be intrinsically quasi-isotropic, can be handled at ambient temperatures and offer what TenCate says is an excellent surface finish.
www.tencateadvancedcomposites.com

» ASSEMBLY & TEMPLATING SYSTEMS

Laser-based spatial positioning system

Virtek Vision International (Waterloo, ON, Canada) announced in Paris the availability of its Iris Spatial Positioning System (SPS) with localized language support. Iris SPS combines photogrammetry technology with laser projection for assembly processes, and is said to eliminate rework caused by errors during assembly and reduces the cost of design changes, so assemblers always can work from the most current CAD files. Engineering changes are passed to the shop floor in minutes, so assembly can continue without delays/additional expense. The system allows assemblers to build parts using virtual tooling that is not constrained by the physical limits of templates and measuring tools — locating objects in 3D space and locking on to CAD-specified assembly positions without the need for tooling or optical targets. All functions within Iris SPS operators are now localized, including the application interface, Operator Help Guide, Installation Guide and Laser Safety Guide. Initial localizations include English, French and Italian (additional support in Japanese, German, Chinese and Spanish to follow). Additional languages and specific workplace localization also will be supported.

Also new was the Virtek Projection Data Creator (PDC), which creates projections using the latest CAD formats, saving time and costs in deploying product design changes. Virtek's LaserEdge system is a three-dimensional laser templating and positioning system that projects a laser template onto molds to guide operators through the ply layup process, minimizing errors and improving productivity by as much as 50%. www.virtek.ca

» THERMOSET RESIN & ADHESIVE SYSTEMS

Fast-curing adhesives

Scott Bader (Northamptonshire, UK) promoted several products, including Crestabond PP-04, a new 1:1 adhesive with a working time of 4 minutes, developed for bonding polypropylene (PP), polyethylene (PE) and other low-surface-energy thermoplastics. Also new is an even faster, sub-3-minute curing version of structural adhesive, Crestabond, M1-02, which requires no primer for high-volume assembly of metal, plastic and composite components. Reportedly the fastest curing 10:1 ratio grade now available, it was developed for higher volume assembly of smaller parts that must be ready to handle in under 3 minutes for cost-effective productivity.

The company displayed a prototype for a new British sports car, a two-seater convertible with a very rigid, lightweight carbon fiber (CFRP) composite passenger cell frame fabricated by Axon Automotive (a subsidiary of Far-UK Ltd., Wellingborough, Northamptonshire, UK), using its internationally patented and trademarked Axontex structural

beam technology, which specifies Scott Bader's Crestapol 1250LV infusion resin. According to Axon Automotive, the passenger cell prototype frame design is 43% stiffer and is 15% lighter (by mass) than an equivalent lightweight steel frame.
www.scottbader.com

» THERMOSET RESIN & ADHESIVE SYSTEMS

Toughened epoxy adhesive

Activity was high at the stand of L&L Products (Romeo, MI, US), thanks to the BMW *7-Series* body-in-white on display at the SGL stand nearby. L&L supplies the toughened epoxy adhesive used to bond a carbon fiber/epoxy structural element to the *7-Series'* B-pillar. Developed exclusively for BMW, the product consists of an epoxy film with an embedded glass fiber veil that is preformed with the carbon composite plies; the veil not only provides galvanic isolation between the carbon part and the B-pillar's metal substrate, but also prevents squeeze-out of the adhesive during part forming, thus protecting the forming tool. The adhesive had to pass numerous stringent tests to qualify for the automotive program, says Didier Trau, project manager of advanced development at the company's Molsheim, France facility, including curing within the 2-minute part cycle (the product reportedly can be adapted to 1-minute cycles) as well as standing up to the e-coat temperature and final assembly. L&L can supply this same film or a similarly customized adhesive formulation to any customer.
www.llproducts.com

» FIBER REINFORCEMENT FORMS & FABRICS

Carbon/thermoplastic fiber

Coats (Uxbridge, Middlesex, UK), the world's largest manufacturer of sewing thread and other products, used the show to introduce Synergex, its commingled carbon fiber/thermoplastic fiber material. The hybrid fiber form, developed at the company's North American site in Sevier, NC, US, features spread carbon fiber tows commingled with a number of thermoplastic resins, with or without twist, for manufacture of a variety of composite parts. On display was a flat, embroidered commingled carbon fiber/nylon fiber preform, made using tailored fiber placement (TFP) with Synergex fiber stitched onto a carrier film. The preform is molded by a partner firm, car maker Elemental Group Ltd. (Hambledon, Hampshire, UK), to produce a complex wheel arch fender part demonstrator in a sub-1-minute process. The University of Stuttgart is a partner in the preforming process.
www.coatsindustrial.com

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SHOWCASE

Form + function = classy chassis

Sandwich-composite chassis components double as structural and styling elements, reducing cost of ownership.

By **Peggy Malnati** / Contributing Writer

» The conventional car chassis is engineered to meet mechanical load and crash performance, durability and noise/vibration/harshness (NVH) requirements, but isn't expected to be beautiful. Hidden by "dust covers" (the industry's euphemism for exterior body panels), a chassis is on view only to mechanics and weekend do-it-yourselfers. But startup automaker Zenos Cars Ltd. (Wymondham, Norfolk, UK) recently asked, "Why pay to produce chassis components, then pay *more* to hide them?" The answer? The Zenos *E10*, which demonstrates that you can make a chassis beautiful enough to play a visible role in vehicle styling and make the car more affordable in the process.

Keep it simple, cost-effective

The *E10* chassis is produced by Bright Lite Structures LLC (BLS, Peterborough, Cambridgeshire, UK), based on a design and material developed by Antony Dodworth, now BLS' chief technology and manufacturing officer. An important and early OEM program requirement was to keep component, tooling and assembly costs low to better manage cost of ownership (the *E10's* base sticker price is £26,995/US$39,027) and, because it is a race car, keep weight low to optimize speed and handling. The team knew that one of the best ways to do both was to use composites in structural assemblies, not just body panels.

"Our design philosophy going into this program was to make the chassis as simple, attractive and low cost yet functional as possible by maximizing parts consolidation and integrating assembly features," explains Dodworth. "We literally wanted to be able to 'clip the car together' and then bond it with structural adhesive."

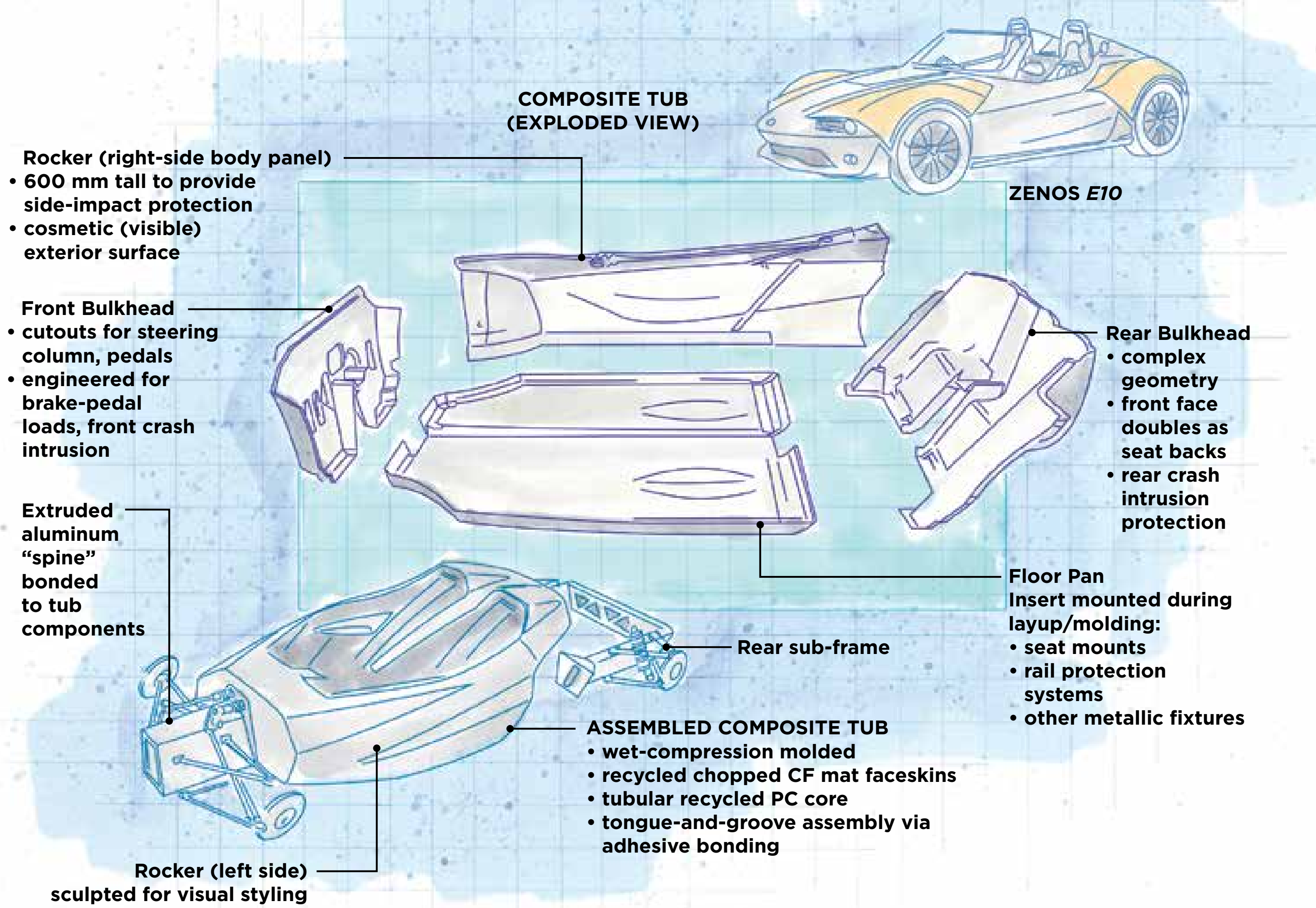
The final chassis assembly design comprised five carbon fiber composite parts — front and rear bulkheads, floor pan and left and right body side panels (rockers) — bonded to a central aluminum spine (see drawing, p. 93). The greatly reduced part count improved vehicle quality — fewer parts equal fewer stack-tolerance issues — and a follow-on benefit was manageable tooling costs (£250,000/US$283,400) for production volumes of 300 sets annually. Assembly time and costs were reduced by molding in bracketry and designing components to slot together tongue-and-groove fashion prior to bonding with Dow Automotive's (Midland, MI, US) BetaMax 2700 series adhesive, which has good flexibility, gap-filling properties and reduces noise transmission.

"Of course, it's very easy to say 'let's make it as simple as possible,' but it's an entirely different thing to accomplish that,"

Chassis handles structural *and* styling duty

A novel street-legal track car from startup automaker Zenos Cars Ltd. in the UK is demonstrating that a chassis structure can be made beautiful enough to play a key role in vehicle styling without needing to hide it under cladding. With this vehicle, body panels, which can be damaged during racing, are designed to bolt on/bolt off as needed and are molded with inexpensive gel-coated, glass-reinforced vinyl ester composite (bright blue, here).

Source | *evo magazine* / Photo | Dean Smith



DESIGN RESULTS | **Bright Light Structures' *Zenos* Composite Chassis**

- Bonded composite chassis reduces weight, cost and tooling investment, yet is attractive enough to play a key role in vehicle's visual aesthetic.
- Sandwich composites with tubular plastic core provide high stiffness and torsional rigidity at low weight for race car speed and responsiveness.
- Fast-cycling wet-compression molding and significant use of recycled materials keeps vehicle cost in affordable range for target customers.

Illustration / **Karl Reque**

Dodworth quips. "Until we started making parts, we didn't realize how brave we'd been."

To meet crash performance challenges, tubular-steel roll bars are bonded to molded features on the rear bulkhead (the front face of which doubles as the seat back) to help transfer loads from the spine to mid-chassis, boosting stiffness and protecting occupants in this open-cockpit sports car, thereby making the rear bulkhead a load-carrying member. Similarly, the door-less car's tall 600-mm rockers/sill plates form a vertical wall that occupants must climb over to enter/exit the racer, but eliminate door cutouts and, therefore, preserve torsional rigidity.

Designing a better sandwich

To realize the *E10* design, however, BLS needed a new sandwich composite. In pursuit of a better sandwich-panel design since his days as R&D director at Bentley Motors (Crewe, Cheshire, UK), Dodworth first looked into Bentley parent company Volkswagen AG's (VW, Wolfsburg, Germany) composite rear package shelf. It's made with BayPreg spray honeycomb composite and features polyurethane (PUR) resin-impregnated chopped glass from Covestro (formerly Bayer MaterialScience, Leverkusen, Germany) with paper cores from SWAP (Sachsen GmbH, Frankenberg, Germany). More than 1 million parcel shelves are produced annually »

Chassis tub production cell

The chassis module is produced by Bright Lite Structures LLC in a wet-compression molding process. Although initial layup is still done by hand, the composite stack is moved via robots to both the impregnation station (right side) and then into the compression molding press (left side). BLS uses 6-bar molding pressures and achieves a 12-minute button-to-button cycle.

Source | Bright Light Structures

using wet compression molding. Inspired by the material/process combo, Dodworth tried it for structural applications, but found it wasn't strong enough even when carbon replaced glass fiber.

To make it tougher and stronger, Dodworth worked with Dr. Michael Connolly, program manager, urethane composites, at Huntsman Polyurethanes (Auburn Hills, MI, US), and after Dodworth left Bentley to form Dodworth Design (which merged into BLS in 2014), the pair settled on a custom grade within Huntsman's VITROX PUR line. VITROX HC 98010 polyol and SUPRASEC 9801 isocyanate offer a good physical-property profile, strong adhesion to the core and good impact strength/toughness at a given resin T_g. The PUR's low and stable viscosity enables rapid, thorough fiber impregnation, and its novel catalyst permits long, yet tunable working times followed by a snap cure, making it suitable for large parts.

Notably, the *E10's* matrix is a *blend* of this PUR and a resin transfer molding (RTM) grade of epoxy. Used alone, the spray and air-exposed urethane would be microporous when cured. The epoxy seals the matrix, prevents vapor/moisture issues, eliminates pinholing and helps tune the composite's energy management for better crash performance. Both polymers are mixed (BLS won't reveal the ratio) just before spraying with an Auto RIM seven-component mixhead from Hennecke Inc. (Lawrence, PA, US).

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Read this article online | short.compositesworld.com/ClassChass

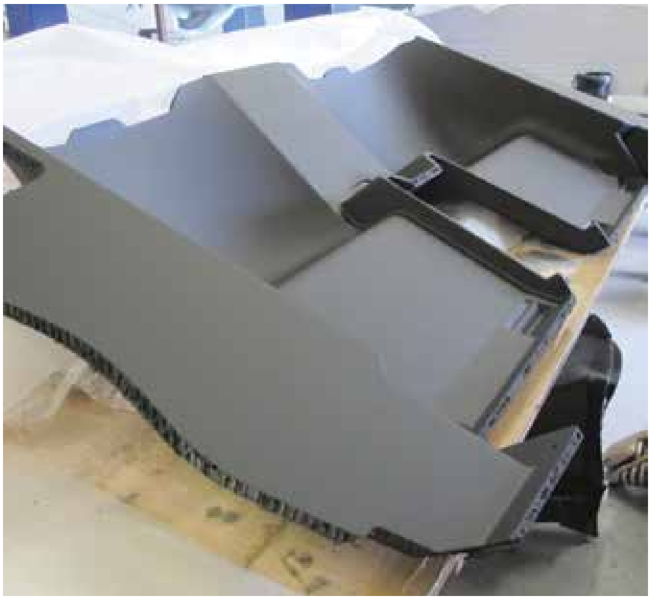
Although "green" wasn't a Zenos design criterion, Dodworth had been developing sandwich composites for a European automaker that prizes "green" technology, so a source of recycled chopped carbon fiber (nominal length 35 mm) was used for both projects. The chopped fibers are formed into a non-crimp fabric (NCF) mat, held in place by nylon stitching and the binder left over from the original reclaimed tricot-patterned carbon weave fabric.

Because Zenos sandwich panels are used in stiffness-, not strength-driven designs, the discontinuous-fiber mat is more than sufficient to meet performance requirements. The mat stretches during molding to accommodate the chassis' deep-draw designs. After impregnation, nominal fiber volume fraction (FVF) for skins ends up in the "high 30s/low 40s" according to Dodworth. The recycled-fiber NCF is "fluffy" and 50% thicker than comparable-weight virgin NCF, so wetout requires a lot of resin. A single ply of NCF is used on either side of the core for all parts except the load floor, where seatbelt pullout requirements necessitate use of two additional plies of continuous-fiber virgin NCF, laid up in a 0/90°/±45° pattern across the top face.

Dodworth also developed a new core from recyclate. He wanted a stiff, light, torsionally rigid material, yet one capable of some flexibility when molding complex parts, which ruled out crushable paper and wood cores. A desire for equivalent properties in all directions suggested a tubular rather than a conventional hexagonal honeycomb structure, an idea Dodworth conceived while playing around with thermoplastic drink straws from the local McDonald's.

Cut and glued together, then molded between fiber-reinforced polymer skins, the tubular core worked in principle. The challenge was to find an industrial source of "straws" to form sheet core. Polycarbonate (PC) was selected because its T_g is similar to that of PUR/epoxy at the 130°C molding temperature. A source of recycled PC was found that was far less costly than virgin. The recycled polymer is extruded through a laser-cut metal plate to form hollow tubes (internal diameter 7 mm). While the tubes are still warm, they're pushed together, and where they touch, they permanently bond as they cool, forming a stiff but light core.

Like the VW package shelves, the *E10* chassis components are wet compression molded. The process can form 3D designs that



Form, function and fine looks, too

The rear bulkhead typifies how the Bright Light design functions: The NCF mat and tubular PC core sandwich possesses the flexibility to adapt successfully to the complexity of the tool surfaces (left) providing a functional surface that also offers, when trimmed and painted, (above) an acceptable aesthetic surface.

Source | Bright Light Structures

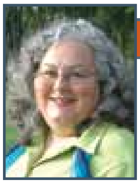
would be difficult to realize in most other composite molding processes without costly preforming, and is equally appropriate for prototyping or high-volume manufacturing, which further reduces component costs and cycle times.

Aluminum matched-metal dies are used (one tool set for each of the five parts), so parts exit the press with two good faces whose texture and aesthetics can be different. Layup is done by hand, but material is shuttled to impregnation and molding stations via robot. Thanks to use of recycled materials, 83% nesting efficiency and the relatively simple exterior geometry of parts, the process reportedly generates far less scrap than conventional composites molding systems, yet testing shows it produces parts of comparable performance at lower cost. BLS uses 6-bar molding pressures and a 12-minute button-to-button cycle. Total cycle time, including kit cutting, layup and post-mold trimming, is 15-20 minutes per part, although that could be reduced further with more automation.

Driving Zen

The chassis meets or exceeds the vehicle's compression, stiffness and torsional rigidity requirements while reducing weight 15-20% vs. aluminum. It also offers greater design flexibility than conventional monolithic composite materials. Although the chassis components do not have Class A surfaces, they receive two coats of primer and one coat of matte-black paint to cover dimpling (core read-through) and create a uniform, non-reflective surface. Depending on model and options purchased, curb weight of the vehicle ranges from 630-700 kg, making it roughly 300 kg lighter than a gracile Lotus *Elise*.

A year into production, the chassis is making significant contributions to safety, as several cars have sustained spectacular real-world crashes on track and road, and vehicle occupants have walked away unharmed. CW



ABOUT THE AUTHOR

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Liquid Shims
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RTM Resins
Potting & Encapsulating Epoxies
Tooling & Casting Resins
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NEW Conductive Adhesives & Coatings
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