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JUNE 2015

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VOL 1 № 6

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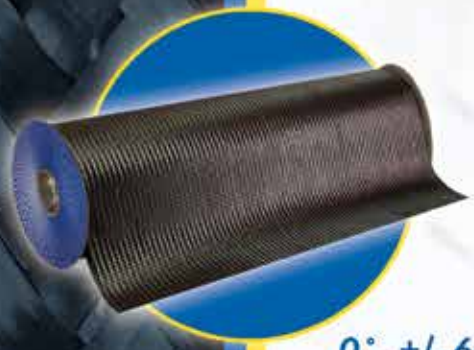

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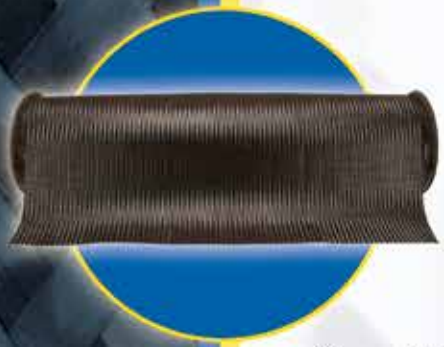

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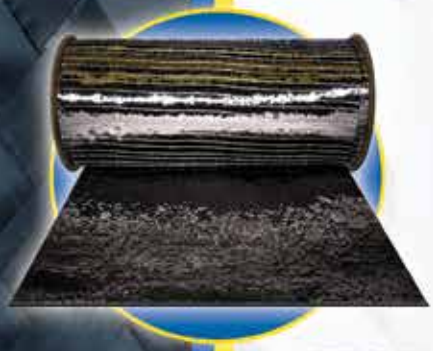

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COLUMNS

FEATURES

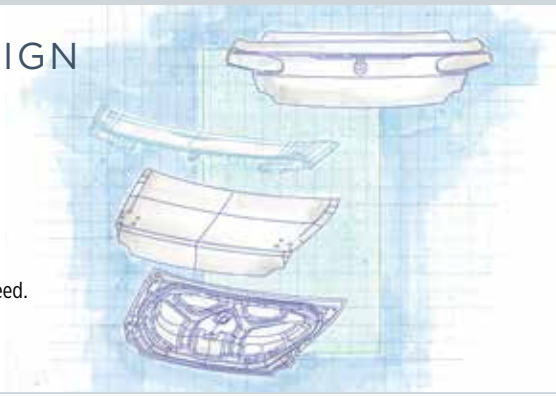
» DEPARTMENTS

» ON THE COVER

The San Francisco Museum of Modern Art expansion's exterior is the largest use of fiber-reinforced plastic in a US architectural building project to date. More than 700 contoured panels were molded to face the 7804m^2 addition's 10-story structure. Architectural composites specialist Kreysler and Associates (American Canyon, CA, US) reveals how it was done on p. 44.

Source / Kreysler and Associates

FOCUS ON DESIGN



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» There is one question I have consistently fielded throughout my 25 years of magazine editing and publishing, and it goes something like this: "Don't you worry about running out of things to write about?" The short answer is, "No." The composites industry (and every industry, for that matter) is too active and dynamic to allow the editorial well to run dry.

> The end product will increasingly be justified by the means.

The real measure of editorial evolution is *what* is covered and *how*, not *how much*. If you look back at what we published in these pages 10, 15 or 20 years ago, you will find stories that reflect, for the most part, the technology and thinking of the time. It is instructive, therefore, to assess what we are covering today to see what it tells us.

This month's issue is particularly telling because it reflects what I argue is a tipping point for the composites industry. This tipping point represents the intersection of two governing principles of composites fabrication, one representing the past, and the other, the future. In the past, during the early decades of composites manufacturing, manual work prevailed, quality varied widely, and relatively high costs were tolerated because of the substantial mechanical and weight-saving benefits composites offered. In short, the ends justified the means.

Meanwhile (and this represents the environment into which we're "tipping"), manufacturers of legacy materials, such as aluminum and steel, went back to the lab and did a great job of developing lighter alloys that have, in the past few years, eroded the cost/benefit advantage of composites. We're seeing this play out vividly in the aerospace and automotive markets. Thus, the pressure is now on composites fabricators to optimize material selection and part design and develop mass-production strategies that demonstrate not only an end-product performance advantage, but a manufacturing cost/efficiency edge as well. In short, the end product increasingly will be justified by the means.

We have several stories this month that reflect the industry's effort not only to be more cost-effective and efficient but to tackle applications that just a few years ago would have been impossible to consider. You'll find the impossibility in our story (p. 44) about the composite façade realized and fabricated by Kreysler & Associates for the San Francisco Museum of Modern Art (SFMOMA). This project represents not only an unprecedented use of composites in a daunting construction scenario, but also a composites-enabled consolidation of structures and installation activities that enabled the SFMOMA contractor to actually save money compared to conventional materials and methods.

On p. 34, you will find Sara Black's report on thermoplastic composites R&D in European aerospace applications, based on visits she and I paid to several thermoplastics specialists in The Netherlands and France earlier this year. Boeing and Airbus are investing substantial time and money in an effort to prove the viability of composites in aerostructures, and companies such as Fokker Aerostructures are not only proving such viability but also earning production contracts in the process.

Our two Works in Progress stories this month (p. 26 and p. 30) address, respectively, chopped carbon fiber mechanical strength and bubble behavior in out-of-autoclave (OOA) fabrication. The appeal of chopped carbon fiber is substantial, as Donna Dawson's report shows — at the right length and orientation, it could offer mechanical properties approaching continuous carbon fiber. Understanding and managing bubble behavior in OOA processing has real potential to help fabricators more efficiently produce composite structures, out of the autoclave, that are comparable with autoclave-cured structures.

Finally, on p. 62, you'll find Peggy Malnati's report on the design and development of the composite decklid for the Nissan *GT-R*. This is a relatively high-end vehicle, but the application proves the efficiency and affordability of composites in automotive, thanks in the main to a compression molding-based process can achieve production volumes of up to 50,000 units per year.

So, no, we'll not run out of editorial fodder anytime soon, and we have you to thank for that. And here's hoping that we continue to tip toward ends that are justified by the means.

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JEFF SLOAN — Editor-In-Chief

Wind turbine blades: Back to the future?

» In 1987, a 3.2-MW prototype wind turbine was installed in Hawaii. At the time, it was the largest wind turbine in the world. Manufactured by the Boeing Co. (Chicago, IL, US) under a NASA/US Department of Energy (DoE) development program, the MOD-5B had a rotor diameter of 97.5m and *two* blades, which featured *partial*-span, variable-pitch control, that is, the outermost portion of the blade could be rotated to adjust its aerodynamics.

This NASA program exposed the challenges for the design, manufacture and operation of MW-scale wind turbines. During the 1990s, mainstream commercial wind turbines were kW-scale and gradually growing in turbine power rating and rotor size. The prevailing rotor configuration was the "Danish" type: three blades with full-span, that is, entire-blade, pitch control.

> Blade length has increased in proportion to turbine rated power *and* as rotor size expanded at a given rating.

Fast-forward to 2012. The Chinese company Envision Energy Co. Ltd. (Beijing) and its Danish subsidiary's design team installed a 3.6-MW prototype with a two-bladed, partial-span pitch rotor. Currently, the U.S.-based company Zimitar Inc. (Benicia, CA US) is developing a similar rotor.

Are wind turbine rotor designs going "back to the future"? Not necessarily. First, the Danish configuration still prevails. More importantly, the MOD-5B rotor was *all-steel* and weighed 144 MT. The Envision prototype uses FRP materials for the blade structure, and incorporates a carbon fiber-reinforced polymer (CFRP) main rotor driveshaft — a first for a commercial, MW-scale turbine. In addition to reducing component weight, Envision reports the CFRP shaft has flexibility characteristics that mitigate loading compared with the steel alternative. Similarly, the Zimitar rotor design employs FRP blades and aerodynamic control devices. It has a 64% larger diameter than the MOD-5B and nearly twice the rated power at approximately 68% of the weight.

That points to another difference. Over the past two decades, blade length has increased in proportion to turbine rated power, *and* as rotor size expanded at a given rating. A decade ago, a typical 2-MW rotor had an 80m diameter. Today, to capture more energy, some 2-MW rotors have diameters of 110m and greater.

As blade length increased, it was increasingly critical to mitigate weight growth yet ensure adequate stiffness. These objectives were realized by using FRP materials with increased stiffness-/strength-to-weight. Current strategies fall into three categories: 1) increasing the fiber weight fraction (W_f) for glass fiber-reinforced plastic (GFRP), using standard E-glass, 2) using intermediate or high-modulus glass fibers, and/or 3) using alternatives with increased stiffness-/strength-to-weight, such as carbon fibers.

Historically, wind blades have benefited from a shift to manufacturing by vacuum-assisted resin transfer molding (VARTM) or by using prepreg materials, with increased compaction and W_f compared to the earlier wet-layup process. Although this resulted in weight and stiffness improvements, there are practical limitations for compaction of the thick laminates typical of MW-scale blades. Also, the fatigue strength of blade laminate tends to decrease with increased W_f. For GFRP materials, ongoing developments in fiber sizing and fabric architecture are improving fatigue strength and infusibility of heavy fabrics in thick laminates.

Another trend is the increased use of pre-consolidated elements in blade construction. These can include sub-elements that are fabricated and cured, using the same basic processes as the rest of the blade, or other processes, e.g., pultruded "rods" or "slats." Sub-elements are integrated into the structure during layup and infusion of the blade shells and can enable increased W_f, improve fatigue resistance and ease manufacture.

CFRP has been used for load-carrying blade structure, most notably by turbine manufacturers Vestas Wind Systems A/S (Aarhus, Denmark) and Gamesa (Zamudio, Spain), and, in some recent models, by GE Wind Energy (Fairfleld, CT, US). CFRP has known strength and stiffness benefits, but disadvantages include cost, sensitivity to manufacturing variations and electrical conductivity, which can complicate lightning protection.

A "middle ground" approach between use of standard E-glass and CFRP is intermediate- and high-modulus glass fibers. Owens Corning (Toledo, OH, US) is an industry leader in this technology, with several fiber and fabric products developed for wind blades. Today, the use of these glass fibers appears to be growing somewhat faster than the use of CFRP.

Longer blades complicate not only manufacturing but transportation as well. Therefore, modular designs are of increasing interest. Gamesa was the first to commercialize a mid-span joint at the MW-scale on its G128 4.5-MW turbine blades. Wetzel Engineering Inc. (Lawrence, KS, US) also is developing a modular blade concept, using "spaceframe" technology.

As the trend toward increased blade size continues, the challenges of weight mitigation, stiffness optimization, manufacturability and transportability will motivate further developments in materials, processes and design. Not "back to the future," but a promising future, nonetheless. CW

ABOUT THE AUTHOR

Dayton Griffin, MSc, is a senior principal engineer at DNV GL (Seattle, WA, US), with 20 years of wind energy experience. He is an internationally recognized expert in the area of wind turbine blades, including rotor blade aerodynamics, structure, materials and manufacturing technologies.

Revisiting some past perspectives

» My first "Perspectives and Provocations" column appeared two years ago, in the June 2013 issue of *CW* predecessor *Composites Technology*. Twenty-four episodes later, it is useful to look back on several of those columns and offer some updates, based on my personal experience.

That initial column looked at the large commitment BMW (Munich, Germany) and SGL (Wiesbaden, Germany) are still making to put carbon fiber into automotive primary structure, via the *i3* and *i8* platforms, and it questioned whether any other OEM would follow suit. Two years later, *none* have done so, although several have announced closer ties to fiber suppliers as they continue to evaluate the potential. Recently, I had the pleasure of visiting BMW engineers and managers in Munich, and had substantial discussions about the path they have traveled, lessons learned and the road forward. In March this year, I noted here that I believed they eventually would like to see carbon fiber used on their mainstream *3*- and *5*-Series platforms — a fact they did confirm — but it is going to take significant steps beyond today's costs and cycle time to get there.

> "I have officially joined the Institute as its chief commercialization officer."

I also was able to see, up close and personal, the preforming and molding processes used on the *i3* and *i8* structures. One can grasp immediately areas for improvement, but at the same time, one cannot help but be impressed by what is already being done. Simply put, BMW is well ahead of the rest of the industry in understanding what can be done with carbon fiber, and the new *7*-Series platform, a true multi-material vehicle of steel, aluminum and carbon fiber (including *recycled* fiber), is evidence of what they've learned (see p. 16 in "CW Trends"). Most of all, I came away impressed with BMW's openness and willingness to share these experiences with others, because it knows that getting to true cost reduction requires more OEMs and suppliers to get on board and grow the market.

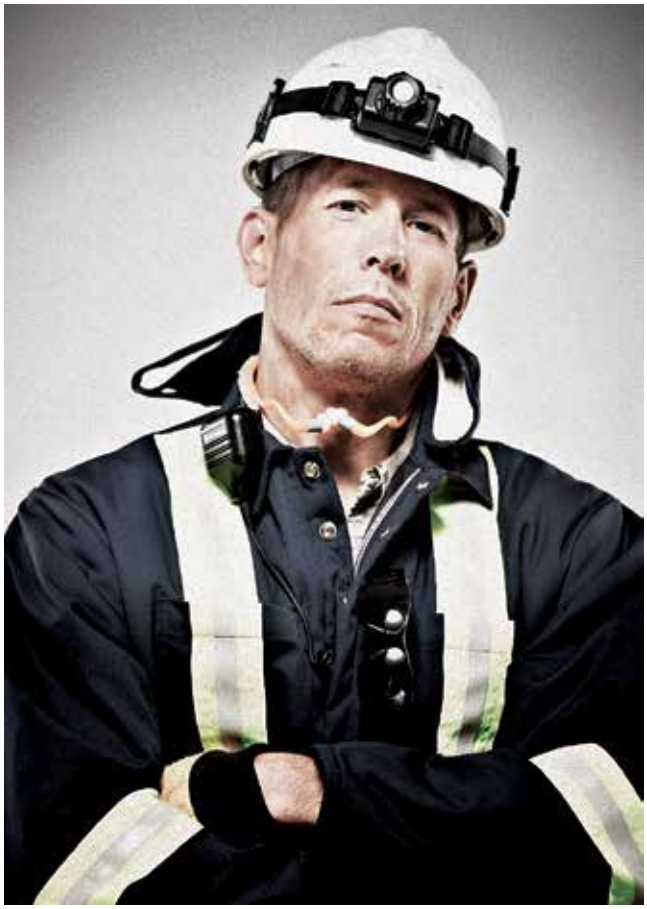
In January of this year, I attributed slowing growth of carbon fiber sales into sporting goods to lack of innovation, combined with the industry's becoming a victim of its own success. I did mention I was in the market for a new tennis racquet, and after trialing several, I did buy the latest Wilson ProStaff model, which features braided carbon and aramid fibers in the throat area to improve torsional stiffness. Shortly after, I was contacted by Oxeon AB, which offered to let me try one of the new line of Prince racquets, which use Oxeon's TeXtreme Spread Tow thin fabric in the handle and throat areas, also to reduce twisting upon ball strike. I selected a model that matched very closely my Wilson racquet specifications in terms of overall weight, balance and head size, and have been testing it. While I'm far from having professional talent, the Prince racquet has a different "feel," even though it's very close to the Wilson racquet in specifications. I'm impressed with the control it offers on volleys and overheads, and I am now playing with it as much as I play with my Wilson. The Prince also has a very "cool" look to it, and the pattern of the TeXtreme fabric is, deliberately, visible. Both racquets are improvements upon my previous equipment … so maybe there is a bit more engineering and innovation in this market than I initially postulated.

My column in *High Performance Composites* from March 2014 was very bullish on the prospect of a US Department of Energy (DoE)-sponsored composites manufacturing institute, noting that such investments in the non-defense side of advanced composites was greatly needed to boost innovation for vehicle and wind energy applications, among others. Following a lengthy proposal process over the course of 2014, President Obama announced that the DoE had selected a team for the new institute, led by the University of Tennessee (Knoxville, TN, US). Staked with an initial investment of US$70 million from the DoE and more than that in matching state and industry cost-share, the Institute for Advanced Composites Manufacturing Innovation (IACMI) seeks to greatly reduce the costs of advanced carbon fiber and fiberglass parts and improve the predictive reliability of simulation and design tools to make such parts compelling options for lightweighting and more efficient energy applications.

IACMI operations should officially commence soon (see the IACMI update on p. 20, in "CW Trends"). And I have officially joined the Institute as its chief commercialization officer. I am looking forward to helping industry work with the IACMI to make this dream a reality. And, of course, to stimulate subject matter for future columns. CW

ABOUT THE AUTHOR

Dale Brosius is the head of his own consulting company, which serves clients in the composites industry worldwide. Services include strategic planning, market analysis, assistance in mergers and acquisitions activities and technical support. 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. For three years he also served as the general chair of the Society of Plastics Engineers' annual Automotive Composites Conference and Exhibition. Brosius has a BS in chemical engineering from Texas A&M University and an MBA.



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Understanding the influence of fiber orientation on structural analysis of fiber-filled parts

» Adding fiber reinforcement to plastic parts creates unique challenges for structural analysis. Variations in material properties and fiber orientations during injection molding processes can be significant but often are overlooked. The result is an over-simplification of the model that neglects key influences, such as weak areas due to weld lines, residual strains that cause warpage, and property variations due to fiber alignment. Therefore, parts are often overdesigned or must be optimized through trial and error. In a market where molders are looking to increase performance while reducing cost, those approaches are just not acceptable.

The effect of fiber orientation on material properties is a key way the injection molding process impacts mechanical performance. The following illustrates just two ways fiber orientation influences the structural behavior of fiber-filled parts and discusses the need for a bi-directional approach to design and analysis.

As the injected material flows through the mold, fiber alignment is affected by the direction of flow and the mold cavity geometry and can vary greatly throughout the part. The resulting fiber orientation has a direct correlation with mechanical properties. In Fig. 1, Example A illustrates how areas with highly oriented fibers have a high modulus in the direction of orientation and a much lower one (one-third as high) in the cross-flow. In comparison, Example B illustrates that if fibers are largely 45° to the flow direction, the moduli are equal.

Fig. 2 shows how variation in fiber alignment results in significant variation in mechanical properties in even simple part geometry. With the gate location at the left point, the first area experiences expanding flow, and fiber orientation is largely perpendicular to the flow. This is followed by an area with more random alignment and, finally, areas where flow is predominantly in the flow direction. The result is a complex distribution of anisotropic mechanical properties, as shown in Views A and B.

Under mechanical loading, plastic parts typically exhibit a significant plasticity prior to rupture. When fibers are added, both plasticity and rupture loads are influenced by fiber orientation and loading direction. This is illustrated in the tensile test results shown in Fig. 3, where all three load directions show significant plastic response prior to rupture, but the stiffness and strength of the material show high dependence on the relative fiber direction. The plasticity of the specimen loaded in the fiber flow direction is clearly different than that of the fibers loaded at 45° or perpendicularly (90°). The strain-to-rupture loads are also different, with the specimen loaded in the cross-flow direction rupturing 33% sooner.

These examples demonstrate the need for structural simulation with insight into the after-molding or as-manufactured condition of the part and an ability to model the nonlinear material response. Simulation solutions are making great strides in providing these capabilities. For example, Autodesk Moldflow »

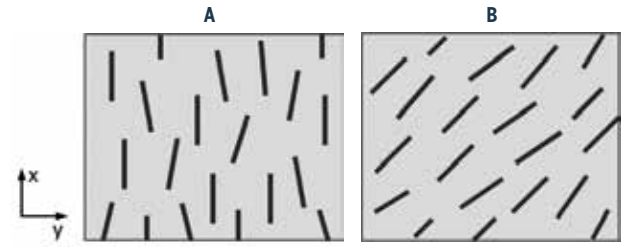

FIG. 1

	Fibers in x direction	Fibers under 45°
E_x(MPa)	12,000	6,000
E_y(MPa)	4,000	6,000

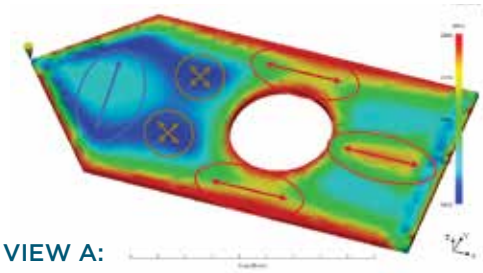

FIG. 2 VIEW A:

This shows the variation in the modulus in the dominant, or x, direction. It is shown to measure high (indicated by yellow/red regions) in the aligned flow and low (blue regions) in crossflow and randomly aligned regions.

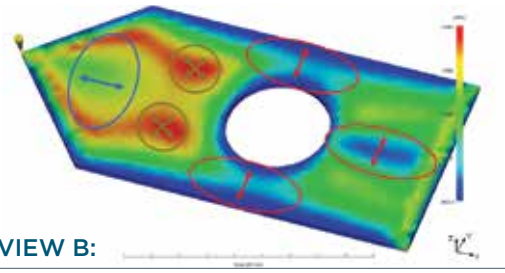

FIG. 2 VIEW B:

This shows the variation in the modulus perpendicular to the dominant (y) direction. It is shown to measure low (indicated by blue regions) in the aligned flow and high (yellow/red) in crossflow and randomly aligned regions.

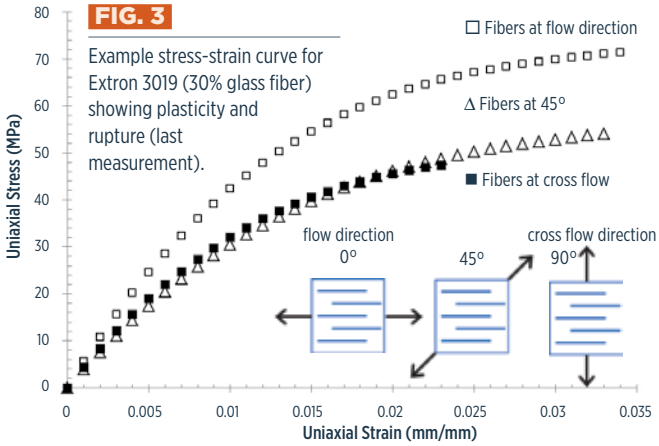

FIG. 3

Example stress-strain curve for Extron 3019 (30% glass fiber) showing plasticity and rupture (last measurement).

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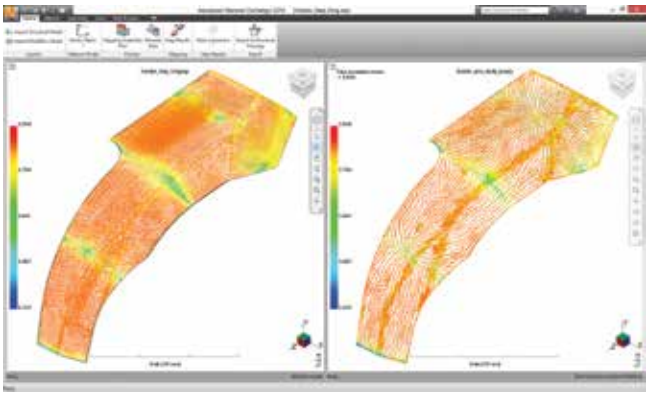


FIG. 4

A screen shot from Autodesk's Advanced Material Exchange showing fiber orientation being mapped from manufacturing (right) to structural simulation (left).

(Waltham, MA, US) software can determine weld-line locations, fiber orientations from injection or compression molding and warpage due to cooling of a discontinuous-fiber-reinforced composite part. Siemens PLM Software (Plano, TX, US), Dassault Systèmes (Vélizy-Villacoublay, France), and ESI Group (Rungis, France) are able to inform users about ply orientations from a portion of the manufacturing process for continuous fiber-reinforced composites as well. There is work yet to be done on simulating the molding process in areas such as identifying a potential delamination from hand or tape layup and linking this information to curing to determine warpage and residual stresses.

The next critical step is transferring this as-manufactured information to the structural analysis. Many solutions for continuous-fiber composites only pass fiber orientation one way, from design to structural or to manufacturing simulations, but the as-manufactured information is not yet easily incorporated into the analysis. Solutions for discontinuous-fiber composites are further developed by the likes of e-Xstream engineering (Newport Beach, CA, US) and Autodesk, which offer software able to bring as-manufactured fiber orientations (Fig. 4), fiber volume fractions and warpage results from molding simulation to the structural simulation, providing more realistic results and valuable insight. CW

ABOUT THE AUTHORS

Doug Kenik and Angie Schrader work with the Design, Lifecycle & Simulation product group at Autodesk. Kenik is the product line manager for Autodesk's composite simulation products and has been involved in both research and development of the technology within those products. Schrader works across simulation products on validation and special projects.

CW Business Index at 49.7 – Industry largely unchanged

» With a reading of 49.7, the CompositesWorld Business Index for April 2015 showed that the U.S. composites industry contracted at a very modest rate in the month of April. Prior to that, the industry had registered either modest growth or been flat since July 2014. This is not all bad, considering the industry had fairly strong growth in the first half of 2014. Compared with one year earlier, the index contracted 4.2% in April. This was the fourth straight month of month-over-month contraction. The industry was still growing on an annual basis, but the rate of growth was very low.

In April, new orders in the US contracted for the first time since November 2013. The subindex fell quite sharply compared to the previous three months. Production was flat in April, the first time it had not expanded since December 2013. Backlogs had contracted every month but one, since May 2014. Compared with one year ago, the backlog subindex had contracted for four straight months. The trend in backlogs indicated that capacity utilization at composite fabricators had seen its peak rate of growth this cycle. However, the rate of contraction in backlogs had started to slow on a month-over-month basis. Employment was unchanged in April. The subindex had been bouncing back and forth between growth and no change since August 2014. Exports continued to contract due to the relatively strong dollar. However, the export subindex had improved since reaching a low point in September 2014. Supplier deliveries lengthened at their fastest rate since April 2012.

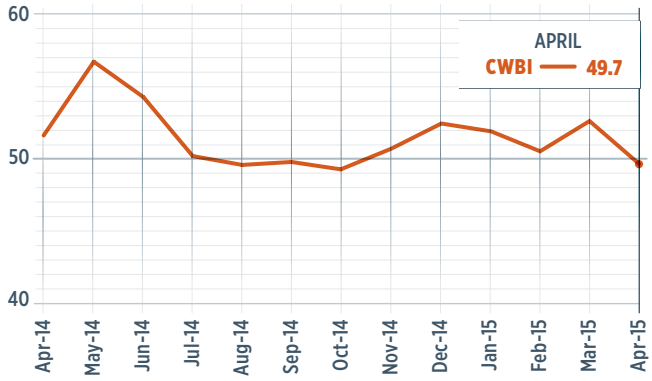
US material prices increased at their fastest rate in April since November 2014. However, the rate of increase was still relatively low. Prices received increased for the fifth straight month. The rate of increase in prices received generally had accelerated during the five previous months. Future business expectations improved in April. Since August 2014, they have been on a significant upward trend. In fact, expectations were noticeably above their historical average.

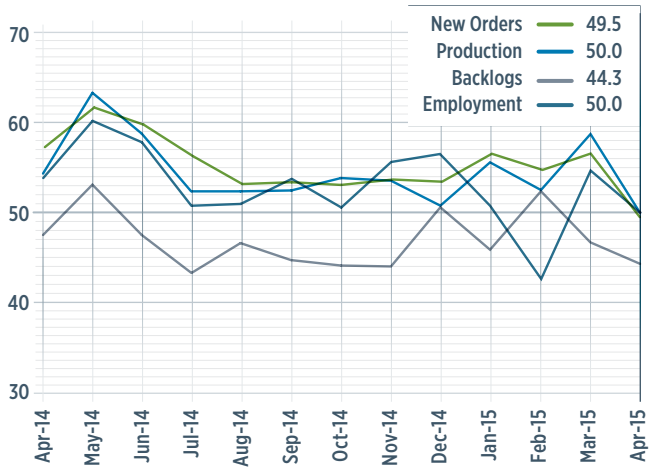
In April, US composite manufacturing plants with 100-249 employees had expanded every month since June 2014. In four of the previous five months, the subindex for this subgroup of plants had been above 63.0. However, in April, all other plant sizes contracted. Facilities with more than 250 employees contracted at their fastest rate since the Index was first recorded in December 2011. Companies with 20-99 employees contracted in April after expanding in March. Companies with 1-19 employees contracted for the second month in a row. In fact, these companies had, in April, contracted every month but one since June 2014.

Regionally in the US, the West was the only one to see any significant growth in April. It had grown every month but one since August 2013. The North Central – East region also expanded in April, but the rate of growth was quite slow. Both the North Central – West and the Northeast contracted after growing in March. The decline in the Northeast was particularly sharp. The Southeast was flat.

In April, it was evident that future capital spending plans had been hit quite hard in recent months. The previous two months had seen spending plans contract more than 40% compared with the same period, one year earlier. And, spending plans also had contracted four of the preceding five months. On an annual basis, spending plans had contracted for five consecutive months. CW

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





ABOUT THE AUTHOR

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***"What's coming?"* is the theme: in CFRP automotive mass production, US wind energy, NASA and IACMI composites research, and more.**

AUTOMOTIVE

CFRP in mass-production cars: Hyundai Intrado, BMW 7 Series

Source | Hyundai


Source | BMW


Source | BMW

"What's next?"

Since the introduction of the carbon fiber-intensive BMW *i3* and *i8*, that's been the big question. There are signs that carbon fiber composites will soon find use in two additional production cars, one a concept and the other in production.

The concept car is Hyundai's (Seoul, South Korea) hydrogen-powered *Intrado* crossover (top photo), introduced in 2014. It wasn't until this year, however, that *CW* learned that the vehicle's passenger cell is fabricated, in part, by Axon Automotive (Wollaston, UK), well-known for its space-frame composite structures, made using the company's Axontex system. The process employs braided carbon fiber tubes, which are infused to the desired cross-section over a low-density polyethylene foam core, which expands during infusion to provide compression against the mold.

The Axontex system for the *Intrado* uses Hyosung (Seoul, South Korea) Tansome H2550-12K high-strength carbon fiber, vacuum-infused with Scott Bader's (Wollaston, UK) Crestapol 1250LV acrylic thermoset resin. The passenger cell also uses Scott Bader's Crestabond adhesive to bond composite, aluminum and steel parts.

For vehicles, says Axon, its Axontex system enables structural optimization by placing material where it is most needed. Further, the hollow components help save weight. Axon says it has developed and patented a high-volume manufacturing process for the production of Axontex parts and has been manufacturing passenger cells for Hyundai as the carmaker considers production plans. What's unknown is when Hyundai might put the *Intrado* into production.

The second vehicle is in production and will enter the market: BMW's 2016 *7 Series* (middle and bottom photos), like the *i3* and *i8*, uses carbon fiber supplied by SGL Automotive Carbon Fibers (SGL ACF, Moses Lake, WA, US) in a manufacturing process SGL calls Carbon Core. This appears to be a multi-material design (see closeup at left) that combines carbon fiber composites, steel and aluminum. The new *7 Series* is as much as 130 kg lighter than the 2015 version. The *7 Series* car will be on display at the 2015 International Motor Show in Frankfurt, Germany, Sept. 17-37.

MARINE

Carbon fiber rowboat to enable solo Pacific Ocean crossing

In this unique one-off carbon and Kevlar rowboat, Sonya Baumstein will attempt to become the first woman to row from Japan to the US.

The idea of crossing the Pacific alone in a 7m-long, carbon fiber-intensive rowboat is daunting, to say the least. Although the 6,000-mile journey from Choshi, Japan to San Francisco, CA, US, is arguably the most difficult open-ocean crossing in the world, Sonya Baumstein says she is more than ready for the challenge.

"I've never done it, so there is nothing to be afraid of," she quips. Baumstein isn't entirely unprepared, however. In 2011, she rowed from Spain across the Atlantic to the Caribbean. After that, she kayaked from Washington State to Alaska. And In 2013, she *paddle-boarded* across the Bering Strait.

Baumstein worked with America's Cup naval architects Paul Bieker and Eric Jolley to help design a boat to fit her needs. The craft in final form features a cockpit that gives Baumstein enough space to sit and row and the boat has enough room for her to lie down in its cabin to sleep, but it weighs only 350 kg *fully loaded,* and is without a motor or back-up sail option.

The boat's low mass is credited to the use of Divinycell foam as the hull core material. Boatbuilder Carbon Craft (Tampa, FL, US) donated the mold and the boat was infused, assembled and outfitted by SpinDrift Rowing (Port Townsend, WA, US).

Source | SpinDrift Rowing

The journey will take as long as 180 days. If she finishes, she will be the first woman and the first American to row across the Pacific. Onboard the boat are 900 dehydrated meals, 180 drink supplements, an electric desalinator that can produce 30L of water per hour, 60L of backup freshwater and 75 kg of scientific equipment. The latter will enable Baumstein to collect oceanographic data that will help scientists understand *El Nino* weather patterns and climate change. "The incredible cost associated with sending research vessels is prohibitive and the size of the vessels are far too big to collect accurate data at the surface level, or stay out for the duration I can." Baumstein says.

IACMI Update: US Consortium reports much progress

Source | IACMI

Born on Jan. 9, based on a US Department of Energy (DoE) award of US$70 million, the Institute for Advanced Composites Manufacturing Innovation (IACMI) will soon commit those federal funds and US$189 million more committed by industry partners to the development of composite materials and high-volume composites manufacturing processes for applications in what IACMI CEO Craig Blue (see photo) calls "technology areas": wind, automotive and compressed gas storage. Overarching research will key on composites recycling and carbon fiber precursor alternatives. Blue previously reported that IACMI's efforts will be organized primarily through five US states: Michigan, Kentucky, Tennessee, Ohio, Indiana and Colorado. Blue notes, in fact, that "states are critical to commercialization," adding that they can provide the business environment and incentives to help accelerate advanced composite innovations to market.

When CW caught up with Blue for an update, the big question was *how IACMI will manage its 123 partners and their myriad projects?* Blue says all research proposals will be evaluated by a Technical Advisory Board. "It's really a lot like a company," he explains. "The Board of Directors will have final say on the larger investments."

Such investments will pull together a variety of IACMI resources, including university research centers, suppliers of composite materials and equipment, and OEMs, with the larger OEMs, says Blue, exerting much "pull" through the program. One of the tasks IACMI will undertake will be to protect partner intellectual property (IP), yet nonetheless, ensure that innovative solutions get to market quickly. "We're weaving together capabilities, equipment, expertise to a variety of technical readiness levels [TRL]. The whole goal here will be commercialization," he points out. Indeed, Blue says the consortium's overall goal is a TRL of 4-7 for its "industry-proven projects."

The degree to which IACMI succeeds should be readily apparent because, says Blue, the Institute will report progress and show off innovations at two large member meetings each year and at the industry's major trade events.

IACMI's hub will be the University of Tennessee, Knoxville, which led the effort to form the Institute. The federal commitment to IACMI, based on the funding plan, will be about five years. However, Blue hopes that with state help and continued strong support from industry, the effort will be sustained even further. The ingredients certainly are there: partners hail from 36 US states, providing great breadth of resources and expertise.

Read more about the IACMI's inception and find a list of consortium members at **short.compositesworld.com/IACMIlsit.**

AEROSPACE

NASA's Advanced Composites Consortium targets future aircraft

NASA announced in early April that it had established a public/private partnership with five organizations to advance knowledge about composite materials that could improve the performance of future aircraft by enhancing the strength of lightweight components without increasing their mass.

The agency selected the National Institute of Aerospace (NIA, Hampton, VA, US) to manage what will be known as NASA's Advanced Composites Consortium. Rounding out the Consortium's US-based membership are NASA's Advanced Composites Project, managed from the agency's Langley Research Center in Hampton; the Federal Aviation Admin. (FAA, Washington, DC); General Electric Aviation (Cincinnati, OH); Lockheed Martin Aeronautics Co. (Palmdale, CA), Boeing Research & Technology (St. Louis, MO) and a team from United Technologies Corp. led by subsidiary Pratt & Whitney, Hartford, CT.

The NIA will handle internal communications and help manage the programmatic and financial aspects of members' research projects. The NIA also will serve as a "tier two" member with a representative on the consortium's technical oversight committee.

"NASA is committed to transforming aviation through cutting-edge research and development," says Jaiwon Shin, associate administrator for NASA's Aeronautics Research Mission Directorate in Washington. "This partnership will help bring better composite materials into use more quickly, and help maintain American leadership in aviation manufacturing."

NASA formed the consortium in support of the Advanced Composites Project, which is part of the Advanced Air Vehicles Program in the agency's Aeronautics Research Mission Directorate. The project's goal is to reduce product development and certification timelines by 30% for composites used in aeronautics applications.

A panel of NASA, FAA and Air Force Research Laboratory experts reviewed 20 submissions and chose members based on technical expertise, willingness and ability to share in costs, certification experience with government agencies, and their technology emphases and partnership histories.

Representatives from each consortium member participated in technology goal-planning discussions, assembled research teams, and developed draft project plans in three areas: prediction of life and strength of composite structures, rapid inspection of composites and manufacturing process and simulation.

For more on NASA aeronautics R&D | **www.aeronautics.nasa.gov**

For more on the NIA | **www.nianet.org**

CW MONTH IN REVIEW

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

Airbus A400M test flight crashes in Spain
Several countries have grounded their active-service A400Ms until the crash cause can be determined.
05/11/15 | short.compositesworld.com/A400crash

Virgin Galactic making progress on the second SpaceShipTwo
This announcement comes six months after the fatal crash of the first SpaceShipTwo rocket plane.
05/11/15 | short.compositesworld.com/SS2two

NASA successfully tests morphing wing for next-gen aircraft
Shape-changing FlexFoils made from composite materials offer fuel and weight savings plus noise reduction.
05/11/15 | short.compositesworld.com/MorphWing

Airbus A350 XWB aircraft has more than 1,000 3D-printed parts
The parts were used in place of conventionally manufactured parts to ensure the plane's timely delivery to Qatar Airlines in December 2014.
05/08/15 | short.compositesworld.com/A3503Dpart

CFM LEAP-1B engine begins flight test program
The engine structure features extensive use of carbon fiber and ceramic matrix composites.
05/07/15 | short.compositesworld.com/LEAP1B

Zoltek to increase carbon fiber capacity in Mexico
The industrial-grade carbon fiber manufacturer will double production capacity at its Mexico facility to 5,000 tons per year.
05/07/15 | short.compositesworld.com/ZoltekMex

Two-bladed wind turbine powers Texas desalination plant
New mid-size, lightweight turbine model aimed at cost-effective, commercial power generation.
05/07/15 | short.compositesworld.com/2BladeinTX

North America is fastest-growing market for automotive lightweight materials
The market for these materials is projected to grow a healthy CAGR of 14.4% to reach US$206.8 billion by 2019.
05/04/15 | short.compositesworld.com/NAutolight

Vestas receives 400-MW order for Nebraska wind farm
In megawatt terms, the project will be Vestas' largest single-phase project ever in the United States.
05/04/15 | short.compositesworld.com/VestasNB

Construction begins for first U.S. offshore wind farm
The Block Island Wind Farm, off the coast of Rhode Island, is on track to start spinning in 2016.
05/01/15 | short.compositesworld.com/USOffshore

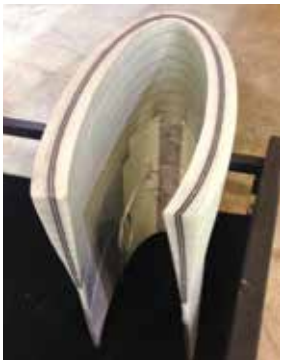
Epsilon Composite's K1 concept: Filament winding + pultrusion

What if it were possible to combine the best features of pultrusion *and* filament winding? Epsilon Composite (Gaillan en Médoc, France) is doing just that and, declares Matthieu Landais, business development manager for Epsilon in the Americas, "It's a revolution for extra-large structures!"

Already a specialist in pultrusion of carbon fiber and high-performance resin systems, active in industrial, energy and offshore markets and an Airbus-qualified aerospace part supplier (see, for example, short.compositesworld.com/ECBigBridg), Epsilon intends its K1 concept for long shapes that can have variable cross sections. K1 involves filament winding of glass or carbon with the addition of carbon fiber/epoxy axial stiffening elements that are pultruded separately and then incorporated into the part during the winding process. The pultruded stiffeners add strength and stiffness, and their number, size and location in the part and the type of carbon fiber used (options range from large-tow, industrial-grade to ultra-high-modulus fiber) is dependent on the application and part design, says Epsilon Composite sales director Romain Coullette.

Epsilon has more than 20 fully automated pultrusion lines at its Gaillan en Médoc facility, of which two are dedicated to K1 projects. Last year, those two lines turned out pultrusions totaling more than 3 million m in length.

The company's large-part focus includes wind blades, high-voltage power-transmission towers, infrastructure elements, such as support columns, and more. Landais says one recent, massive K1 project for a client in the Middle East involved architecture: fabrication of 70 large pillars, 14m high, which consumed nearly 100 MT of carbon fiber. Epsilon Composite formulated a custom, high-temperature-capable epoxy for the project. Three layers of pultruded elements gave the pillars the required buckling stiffness. K1 also has been used to produce large, stiffened carbon fiber rollers for Epsilon's industrial clients.



Source (both photos) | Epsilon Composites

More recently, at JEC Europe 2015, the company showcased a one-third scale, but still massive, 12m demonstrator vertical-axis wind turbine blade (top right photo). A cutaway view (photo at left) showed the pultruded stiffeners (black).

Wind blades and struts are a promising market for Epsilon. "The K1 process is very fast and repeatable and offers part weight savings up to 30%," claims Coullette, adding, "We produced the demonstrator blade in one day." He notes that Epsilon Composite plans to license the K1 technology for specific business cases.

For more information | **www.epsilon-composite.com**

CORRECTION

CW's March 2015 feature, "Autocomposites Update: Engine oil pans" (p. 66), incorrectly identified the source of a proprietary steel/plastic/steel sandwich material used in a commercial automotive engine oil pan. The material, known as Quiet Steel, is produced by Material Sciences Corp., based in Elk Grove Village, IL, US. *CW* incorrectly credited its genesis to Materials Sciences Corp. (Horsham, PA, US). *CW* regrets the error.

MARINE

IBEX, *CompositesWorld* to co-present Future Materials exhibit at IBEX 2015

One of the new feature areas being planned for the 25th International BoatBuilders' Exhibition & Conference (IBEX, Sept. 15-17, 2015) will focus on Future Materials, a new hands-on exhibit at the center of the show's Composites Pavilion.

The Future Materials exhibit will be curated by editors from *Professional BoatBuilder* and *CompositesWorld* magazines. Described as a collection of new composite materials, processes and technologies, the exhibits on display will be gathered from a wide variety of sources, including not only the marine sector but also the aerospace and automotive industries, plus some applied academic R&D.

"The goal for the Future Materials exhibit is to present a mix of innovative, near-term practical applications for boatbuilders as well as ideas to inspire novel solutions to present and future challenges in composites design, fabrication, end-use marketing, recycling and repair," says *Professional BoatBuilder's* editor Aaron Porter. "It has been eye-opening and inspiring to focus *CompositesWorld's* broad knowledge of a full range of new composites technologies and trends on the unique needs of boat designers and builders at IBEX," he notes, adding, "I think the potential in some of these advancements will surprise even experienced marine composites techs."

CW's senior editor Ginger Gardiner points out that composites materials manufacturers with cutting-edge ideas and approaches that have not yet made it to the mainstream of composite boatbuilding were welcomed to submit samples and descriptions in advance of the show for consideration. Final selections for the exhibit space will be made by *Professional BoatBuilder* and *CompositesWorld* magazine editors.

"We look forward to working with the editors of these two industry leading publications to bring the most innovative products to the IBEX show floor," says Anne Dunbar, IBEX show director. "The Future Materials exhibit will be featured in the Composites Pavilion, which has become the center of marine industry composite technology."

At *CW* press time, more than 70 exhibitors had already reserved space in the Composites Pavilion and will offer composite industry demos in more than 1,300m^2 of exhibit space. And in 2015, the Composite Challenge & Cocktail Competition returns. This exclusive networking event will take place in the Pavilion on the opening day of the show and is an opportunity for attendees to engage directly with composites pavilion exhibitors to see and discuss the latest marine composites technology.

For more information about IBEX 2015 | **www.ibexshow.com**

ENERGY

Despite PTC doubt, AWEA sees US "wind rush" in progress

According to the American Wind Energy Assn. (AWEA, Washington, DC, US) a modern-day "wind rush" akin to the gold rushes of the 1800s is in progress in the US, particularly in the Great Lakes region and the Southeast.

"Wind turbine technology has advanced in just a few decades ...." says AWEA CEO Tom Kiernan. "Taller towers, longer blades and improved electronics ... are all part of this revolution." As a result of these changes, today's most advanced turbines require a wind speed of only 5 m/sec to begin generating utility-scale quantities of electricity. That means sites with comparatively lower average wind speeds now can be considered for commercial wind farms.

"The Great Lakes region is an early beneficiary of this," points out Emily Williams, AWEA's deputy director of industry data and analysis. "In states like Michigan, we're absolutely seeing a wind rush." With continued technology advancements, AWEA predicts that US states that currently have no commercial wind turbines at all, primarily in the Southeast, will see development in the coming years.

Longer blades are making high-wind areas even more productive as the average annual "capacity factor" or percentage of the maximum rated capacity that a turbine generates year-round now tops 50% in some cases. Further, some older sites are being *re*powered by new turbines, and others are receiving a variety of refinements to existing turbines, such as blade tip extensions, making the sites more productive. The wind energy industry started 2015 with near-record levels of construction activity, with more than 12,700 MW of wind in the pipeline. As a result, when recently added US wind projects have had a full year of production, total wind output will power the equivalent of 18 million homes.

"Every year, our industry makes wind turbines that are better, smarter, safer and more powerful. Those innovations are bringing down the levelized cost of wind energy for American consumers," claims Chris Brown, president of Vestas-American Wind Technology (Portland, OR, US). The levelized cost of wind energy (LCOE = net cost to install/operate a turbine ÷ expected lifetime energy output) has dropped 58% in just five years, according to the most recent study by Wall Street financial advisory firm Lazard (Hamilton, Bermuda). All this without benefit of the Production Tax Credit, a point ably elucidated by *CW* Columnist and composites consultant Dale Brosius in *CW's* recent May issue, on p. 8 | short.compositesworld.com/WindParity

Carbon fiber as a replacement for glass fiber in D-LFT auto parts

Research progresses toward attainment of 80-90% of continuous carbon fiber tensile modulus in lighter parts molded from direct long fiber thermoplastic compounds.

By Donna Dawson / Senior Writer Emeritus

Research Epicenter

The D-LFT line used for the trials was located at the Fraunhofer Project Centre for Composites Research University of Western Ontario (London, ON, Canada).

Source | Fraunhofer Project Center

» The automotive industry has used glass fibers in direct, long-fiber thermoplastic (D-LFT) manufacturing for many years to produce a variety of parts, among them battery trays, load floors and spare-wheel wells. Long-fiber thermoplastics are a type of composite material wherein thermoplastic polymers are mixed with chopped fiber reinforcements of nominal 6 mm length.

Recently, high-modulus, lightweight carbon fibers were studied as a *drop-in replacement* for chopped glass fibers in D-LFT, as a means to help automakers simultaneously improve part performance and reduce vehicle weight, fuel consumption and CO_2 emissions in anticipation of US government Corporate Average Fuel Economy (CAFE) mandates. CAFE currently calls for an average of about 29 mpge (mile-per-gallon equivalent; that is, either mpg for internal combustion engines, or an equivalent degree of energy efficiency in an alternative mode of propulsion), with gradual increases to 35.5 mpge, by 2016.

> High-modulus carbon fibers were studied as a *drop-in replacement* for glass fibers in D-LFT manufacturing.

The study and its results were first presented at SAMPE Tech Seattle (June 2-5, 2014), by George Husman, the now retired chief technology officer for Zoltek Corp. (St. Louis, MO, US), and, subsequently, at the SPE Automotive Composites Conference & Exposition Sept 9-11, 2014, (Novi, MI, US). Husman summarized study findings recorded in a paper titled "Mechanical Study of Direct Long Fiber Thermoplastic Carbon/Polyamide 6 and Its Relations to Processing Parameters," by Kyle Rohan and T.J. McDonough of Zoltek with Vanja Ugresic, Eva Potyra and Frank Henning from the Fraunhofer Project Centre for Composites Research University of Western Ontario (London, ON, Canada).

Materials and process

Although the D-LFT process can be used with a variety of thermoplastic resins and reinforcing fiber combinations, the automotive industry commonly uses polypropylene (PP) and glass fibers in LFT and D-LFT processing. For that reason, PP was considered for

this study, due to its good processability, resistance to organic solvents and its hydrophobic quality. But David Purcell, Zoltek's executive VP, says that ultimately, "we opted for carbon fiber and polyamide 6 [PA6] as that combination is a common request from the automotive industry."

PP, he explains, typically exhibits relatively lower mechanical properties and service temperatures when compared to an engineered thermoplastic, such as PA6. So, despite PA processing drawbacks, such as higher processing temperatures (see Tables 1 & 2, this page) and greater water absorption, it was judged the better candidate for the intended purpose. Specifically, Zoltek's Panex 35 (50K) carbon fiber and a PA6 thermoplastic matrix from an unspecified source were selected for the experiments conducted in the study.

LFT processing technologies vary, and the type of technology affects the end properties in the part. One type uses glass mat reinforcement commingled with glass thermoplastic sheets. Another, *indirect* LFT processing, uses pellets for injection molding. Relatively new *direct* LFT technology combines the fiber and matrix immediately before the compound enters the mold; the compound can then be processed either by direct injection molding (LFT-D-IMC) or by extruder compression molding (LFT-D-ECM).

LFT-D-ECM was selected for this study because, first, unlike other LFT systems, it uses *two* extruders and, thus, separates the compounding and fiber-mixing steps. Therefore, both extruders can be individually optimized for their specific functions. Second, the material is not subjected to the same high levels of stress typical in injection molding, and, therefore, there is less fiber breakage and, in turn, better mechanical properties in the part.

Immediate improvement

Fifteen experiments were run for the study, each with different processing conditions (Table 3, p. 28), but the parameters for all were constant (See Table 4, p. 28). The study concluded that the selected carbon fiber/polyamide D-LFT material system provided *immediate* improvement in mechanical properties compared with glass fiber D-LFT, especially in stiffness (tensile modulus, or modulus of elasticity, the measure of tensile stress to elongation).

"Tensile strength will be lower than it is in a continuous fiber format, but in automotive parts and consumer electronics applications, *modulus* is actually more critical for meeting specific stiffness design requirements," Purcell explains, "and stiffness »

Table 1

Comparison of strength of carbon fiber/PA6.6 D-LFT vs. glass fiber/PA6.6 D-LFT.

Source (all tables/figures) | "Mechanical Study of Direct Long Fiber Thermoplastic Carbon/Polyamide 6 and Its Relations to Processing Parameters," by K. Rohan, T.J. McDonough (Zoltek); V. Ugresic, E. Potyra and F. Henning (Fraunhofer Project Centre)

Material	Tested Weight %	Specific Strength (E/ρ) (Mpa/(g/cm³))	Comparison vs. Carbon/PA6
Tensile strength: Carbon/PA6	35	104.0	N/A
Tensile strength: E-glass/PA6.6 (Krause, Henning, Troster, Geiger, & Eyerer, 2003)	30	71.7 (83.65)	-19.5%
Tensile strength: E-glass/PP (Ernst, Henning, & Robbins, 2009)	40	54.0 (47.25)	-54.5%
Tensile strength: OEM-approved, 12.5-mm E-glass/PP pellets (Ernst, Henning, & Robbins, 2009)	40	40.0 (35)	-66.3%
Flexural strength: Carbon/PA6	35	174.5	N/A
Flexural strength: E-glass/PP (Ernst, Henning, & Robbins, 2009)	40	92.4 (80.9)	-53.6%
Flexural strength: OEM-approved, 12.5-mm E-glass/PP pellets (Ernst, Henning, & Robbins, 2009)	40	63.3 (55.41)	-68.2%

- Items in parenthesis have been linearly normalized to 35 wt-% for comparison purposes.
- All specimens other than the OEM pellets were manufactured using the D-LFT-ILC or D-LFT-EMC process; tensile E-glass/PA6 was not reported by Krause (Krause, Henning, Troster, Geiger and Eyerer, 2003).
- Densities: PP — 0.946 g/cm³, PA6 — 1.13 g/cm³, PA6.6 — 1.14 g/cm³, carbon — 1.81 g/cm³, E-glass — 2.55 g/cm³.

Table 2

Comparison of modulus of carbon fiber/PA6,6 D-LFT vs. glass fiber/PA6,6 D-LFT.

Material	Tested Weight %	Specific Modulus (E/ρ) (Gpa/(g/cm³))	Comparison vs. Carbon/PA6
Tensile modulus: Carbon/PA6	35	11.3	N/A
Tensile modulus: E-Glass/PP (Ernst, Henning, & Robbins, 2009)	40	4.62 (4.04)	-94.6%
Tensile modulus: OEM-approved, 12.5-mm E-glass/PP pellets (Ernst, Henning, & Robbins, 2009)	40	3.26 (2.85)	-128.1%
Flexural modulus: Carbon/PA6	35	13.0	N/A
Flexural modulus: E-glass/PP (Ernst, Henning, & Robbins, 2009)	40	3.35 (2.93)	-126.4%
Flexural modulus: OEM-approved, 12.5-mm E-glass/PP pellets (Ernst, Henning, & Robbins, 2009)	40	3.50 (3.06)	-123.8%

- Items in parenthesis have been linearly normalized to 35 wt-% for comparison purposes.
- All specimens other than the OEM pellets were manufactured using the D-LFT-ILC or D-LFT-EMC process.
- Densities: PP — 0.946 g/cm³, PA6 — 1.13 g/cm³, PA6.6 — 1.14 g/cm³, carbon 1.81 g/cm³, E-glass — 2.55 g/cm³.

Fig. 1

Isotropic modulus vs. fiber aspect ratios and various fiber weight percentage. Note that the figure shows *fiber weight percent* in the compound to be an important factor in achieving higher modulus.

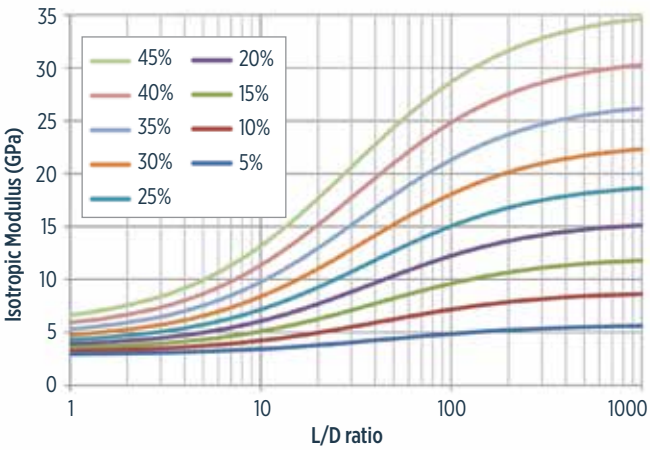


Table 3

Overview of variable processing parameters from 15 experimental trials.

Run Condition	Fiber-Wt (%)	RPM	Charge-Position	Circ	Tested Tensile Panels	Tested Flexural Panels
1	30%	50	Edge	0.16	1	1
2	30%	70	Edge	0.16	2	2
3	30%	100	Edge	0.16	2	2
4	30%	50	Center	0.16	2	2
5	35%	50	Edge	0.16	2	2
6	35%	50	Edge	0.16	1	1
7	35%	50	Edge	0.16	2	2
8	35%	50	Center	0.16	2	2
9	35%	70	Edge	0.16	2	2
10	40%	50	Edge	0.16	2	2
11	40%	50	Center	0.16	2	2
12	40%	70	Edge	0.16	2	2
13	45%	50	Edge	0.16	1	1
14	30%	50	Edge	0.16	1	1
15	30%	50	Edge	0.108	2	2

• RPM = speed of the extruder screw in revolutions per minute.
• Circ. = circumference, in this case, describing the length of one fiber roving drawn into the extruder per screw revolution.

Table 4

Constant processing parameters.

Processing parameters	Set Value
Melt temperature [°C]	270
Mold temperature [°C]	125
Pressing pressure [MPa]	33
Cooling time [seconds]	30

is governed by the modulus and weight of the chosen material." As a bonus for manufacturing economics, the improved properties were shown to be achievable using currently available equipment, with minor modifications.

Another advantage of carbon fiber for this material system is its high modulus, and the relationship of modulus translation to fiber aspect ratio in the final composite, Purcell says.

Modulus translation

It is known that the strength of a composite part is primarily a function of the fiber reinforcement. The greatest strength is provided by continuous fiber, and the use of chopped fibers, rather than continuous fibers, considerably decreases the strength of the final part. However, there is evidence that *longer segments* of chopped fiber in parallel orientation, or distribution, will cause the part to have strength *approaching* the strength provided by the continuous carbon tow. This phenomenon is explicated in the Halpin-Tsai isotropic approximation for longitudinal and transverse moduli, developed by J.C. Halpin at Wright Patterson Air Force Base (WPAFB, Dayton, OH, US) and Stephen W. Tsai, professor emeritus, Structures and Composites Laboratory, Stanford University (Stanford, CA, US).

The Halpin-Tsai equations show that if an aspect ratio (L/D) of 100 — 0.72 mm length/0.0072 mm diameter in the case of carbon fiber — can be reached, then the mechanical strength of the fiber will be about 21.5 GPa in tensile modulus, or 83% of the 26 GPa theoretical maximum modulus for a molded laminate that is 35% by weight of carbon fiber with PA6 polymer.

Purcell notes that in the trials, some fibers retained lengths of as much as 2 mm, but the *average* length was much shorter. "Because we had some fibers that made it through the process at 2 mm, it shows that it's technically possible to make it happen," he notes, but emphasizes that "it's the *average* fiber length that matters more and drives the mechanical performance. A few fibers at 2 mm length did not seem to contribute to the mechanical performance." In any case, the theoretical curve *flattens out* above the L/D ratio of 100, delivering diminishing benefits as fiber length increases. Thus, the theoretical estimated fiber translation (modulus translation) for the same part at a fiber aspect ratio of 278 — that for an average 2 mm fiber length — is ~24.5 GPa, or 94% of the 26 GPa theoretical maximum. While the higher L/D is better, attaining 2 mm length would be a considerable challenge, for only a 10-11% improvement in properties (see Fig. 1, this page).

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In Zoltek's study, the actual properties measured were consistent with the theoretical curves. The majority of the study samples held L/D ratios between 14 and 42; that is 0.1 to 0.3 mm length in the final molded laminate. "More work is needed to drive up the fiber lengths to at least 0.72 mm average and, ideally, 1 to 2 mm average in the final end product," Purcell says.

Findings and future directions

Although the average length of chopped fiber is 6 mm in its raw condition, the fiber breaks down during compounding with the matrix into pellet form — in this case, the thermoplastic polymer — and further breaks down when the pellets are injection or compression molded. Purcell notes that carbon fibers are more prone to fracturing than glass fibers when processed through a twin-screw extruder with a high-viscosity thermoplastic polymer, thus resulting in final fiber lengths in the 0.1-0.3 mm range. The final mechanical strength of the composite part is further compromised by uneven distribution of the fiber during processing. They key to success, then, is striking that balance of uniform fiber distribution while maintaining fiber length, which requires adjustments to the polymer chemistry (for lower viscosity) and twin-screw design (to be gentler on the fibers).

"Based on our findings in the fiber length and, therefore, mechanical performance, there are more adjustments needed to the process — specifically in the screw design and polymer chemistry/viscosity to reduce the fiber breakage," Purcell says.

Although long-fiber chopped carbon was randomly oriented in the compound and, therefore, in the cured test panels, the mechanical performance was consistently better in the flow direction than the cross-flow direction. This directionality became stronger the farther that the material flowed during the pressing operation. However, despite this directionality effect, the fiber weight percentage remained relatively consistent across the panel. It was also observed that the *shorter* fibers appear to influence performance more than the *longer* fibers, possibly due to the tendency of the longer fibers to bundle together.

Results of the study clearly warrant additional R&D of carbon/PA6 D-LFT as a means of improving mechanical performance in parts now made with standard glass LFT in the auto industry — and in other markets that require "high throughput and low cycle times with little to no scrap," Purcell says. Although Zoltek has done no further investigation into this technology to date, he adds, it will in the near future. Goals include extending fiber lengths and improving fiber distribution to achieve greater mechanical strength.

Purcell concludes, "What is important to understand are the lessons learned and what must be studied next to improve the process parameters to achieve the goal of 2-mm-long fibers." CW

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Out-of-autoclave processing: <1% void content?

Research sheds light on air and air-bubble behavior in OOA aerospace prepregs.

By **Jeff Sloan** / Editor-in-Chief

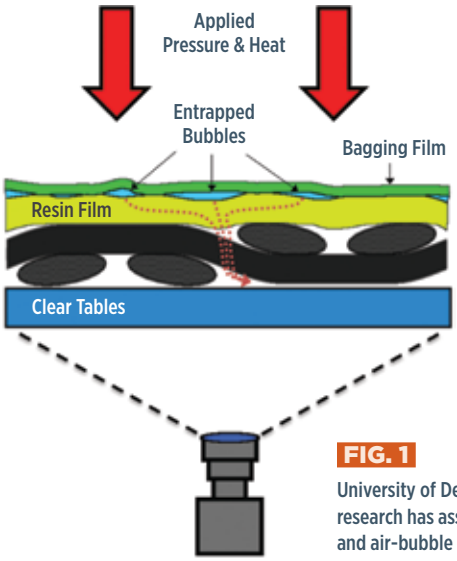


FIG. 1 University of Delaware research has assessed air and air-bubble evacuation in out-of-autoclave (OOA) manufacturing at various levels of impregnation, using film-type resin and a vacuum-based process. A camera under a clear mold (table) enabled documentation of air and bubble behavior.

» The autoclave is, perhaps, the most beloved and most maligned piece of equipment employed in the fabrication of composite aerostructures. It is beloved because, when used properly, it brings to bear on a carbon fiber laminate the brute force required to compress to a very small and harmless size the entrapped air and volatile gases that form voids in cured resin that otherwise would be problematic in a finished composite part. It is maligned, however, because the application of that brute force costs dearly — in capital, energy and time. Composites fabricators in aerospace and other large industries, such as automotive and wind energy, therefore, are in search of out-of-autoclave (OOA) manufacturing processes that can cross the mandated 1% void content threshold with less expensive, more efficient equipment yet achieve autoclave-quality composite parts for critical structural applications. When it comes to the aerospace sector, however, OOA usually means vacuum-bag consolidation of carbon fiber prepregs, followed by oven cure.

The term OOA *implies* that the process is simply a non-autoclave version of the autoclave-based original. Indeed, OOA processing is attractive because it offers a more sustainable manufacturing pathway, based on the cost savings that accrue when foregoing the use of the autoclave, while producing autoclave-quality composites. But OOA processing of aerostructures forces the fabricator to cope with variables that were, for the most part, obviated by the use of the autoclave. And variable numbers one and two are entrapped air and air bubbles, the mismanagement of which can quickly turn a carbon fiber laminate into an expensive, void-filled, out-of-compliance paperweight.

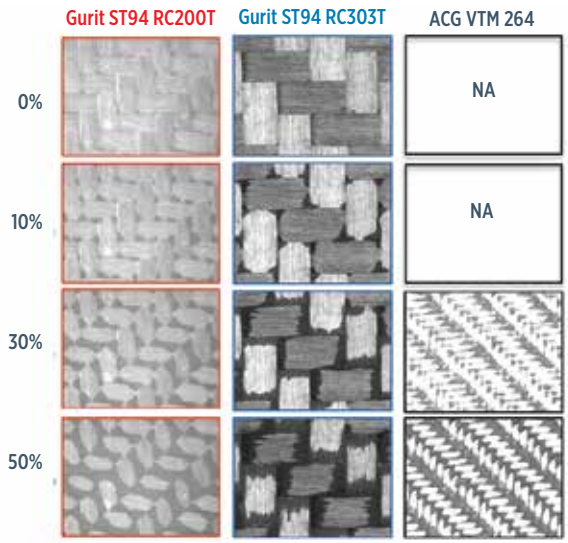
Managing air and bubbles, however, requires some understanding of air and bubble behavior, and such understanding is in limited supply in the composites industry. It is, however, the focus of in-depth experimental work by the University of Delaware (UD, Newark, DE, US), where researchers are trying to shed some light on how air, resin and fibers interact during vacuum-based manufacturing — and the conditions under which air and air bubbles are most likely to escape before resin cure is complete. The work, it is hoped, will help OOA processors more easily achieve <1% void content.

The research team at UD is led by Dr. Suresh Advani, George W. Laird professor and department chair of mechanical engineering and associate director of the university's Center for Composites Materials. He was assisted by Ph.D graduate candidate Tom Cender, Dr. John Gangloff (then a Ph.D. candidate, now a Science and Technology Policy Fellow at the U.S. Department of Energy – Fuel Cell Technologies Office) and Dr. Pavel Simacek, a research scientist at the Center. Assistance regarding bubble behavior was provided by Dr. Volkan Eskizeybek, assistant professor at the Department of Materials Science and Engineering, Çanakkale Onsekiz Mart University (Çanakkale, Turkey). Cender first reported on the group's work in a paper presented at SAMPE 2014 (Seattle, WA, US) titled, "Void reduction during out-of-autoclave thermoset prepreg composite processing."

Full prepreg vs. semipreg

OOA manufacturing using a vacuum-based process is typically done with a fully impregnated fiber reinforcement. However, without the heft of an autoclave, special care must be taken to manage air and void evacuation, and this is typically done with a semi-permeable layer of some sort. Alternatively, a fabricator can choose to use a fiber reinforcement that is partially impregnated (a semipreg) with a resin in film form. The partial impregnation allows air and voids to escape the fabric as vacuum is drawn, before full consolidation is complete.

It's on semipreg technology that the UD team has focused, evaluating the use of resin film with, initially, 2x2 twill fabric. Specifically, the team is evaluating the relationship between various levels of impregnation of the resin film in OOA semipregs and the utility of intra- and inter-fiber pathways for evacuation of gasses that are trapped in the laminate before consolidation and cure (see Fig. 1).



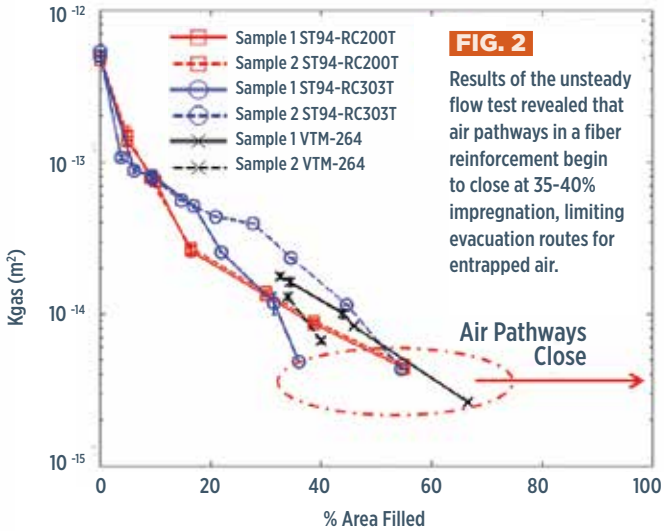


FIG. 2 Results of the unsteady flow test revealed that air pathways in a fiber reinforcement begin to close at 35-40% impregnation, limiting evacuation routes for entrapped air.

"One difficulty in qualifying new OOA prepregs is the wide range of available choices. The distribution of resin — with respect to the dry areas of the prepreg — can be configured in different ways, depending on the supplier," says the report. In short, there is not yet a defined level of OOA prepreg impregnation that is considered optimum for effective gas evacuation. "The goal of this work is to characterize and model the flow processes associated with partially impregnated prepregs."

The experiments used three prepreg types:

- Gurit ST94 RC200T, 200 g/m², 3K tow, 2x2 twill, 42% resin, by weight.
- Gurit ST94 RC303T, 303 g/m², 12K tow, 2x2 twill, 42% resin, by weight.
- Cytec (formerly ACG) VTM264 CF0100, 283 g/m², 3K tow, 4x4 twill, 43% resin, by weight.

Resin is distributed as a film on each twill type and compressed with a consolidation block at 55°C onto and into the fabric to a variety of impregnation percentages: 0%, 5%, 10%, 20%, 30%, 40%, 50%, 70% and 90%. To halt resin flow at the desired impregnation state, the laminate is immediately cooled with ice water over the vacuum bag. With the resin immobilized, the prepreg's permeability is assessed, using what is called the unsteady flow test, which measures pressure drop in a laminate over a given time period.

Fig. 2 shows the results of this test, which indicate that air pathways in the fiber reinforcement begin to close at >75% impregnation (as measured by surface area of impregnated fibers). As pathways close, it becomes much more difficult to evacuate gases and, thus, increases the likelihood of trapped gases becoming bubbles and hardening, during cure, into voids. "Once the inter-tow regions are saturated, any further resin impregnation into the fiber tows results in a linear decrease in the laminate's permeability to air," says the paper.

Gangloff notes, "In traditional composites processes, such as resin transfer molding [RTM], a dry fiber bed is impregnated with liquid resin. The goal is to direct the incompressible resin into all the dry fiber areas for complete saturation. In OOA processes, the prepreg is, typically, partially saturated and is complicated by air trapped between prepreg laminates. This air must be evacuated for full resin saturation. Lack of process understanding has made the edge and through-thickness breathing dominated by trial-and-error and very expensive."

If vacuum is not suffiently achieved inside the laminate's air pathways, gases will inevitably become trapped and manifest as voids. By coupling the technique for monitoring resin saturation with the technique for measuring air permeability, the required vacuum dwell time can be reliably predicted for a given prepreg and part geometry.

Gangloff notes, "When probing the multiphase flow of bubbles and resin together through the tortuous flow pathways in OOA fabrics, more detailed fluid flow modeling is necessary to determine if moving bubbles in moving resin can navigate and escape prepregs during processing before resin cure."

Bubble behavior

"The most important aspect of the group's work has been just the documentation of bubble behavior under vacuum," Cender reports. »

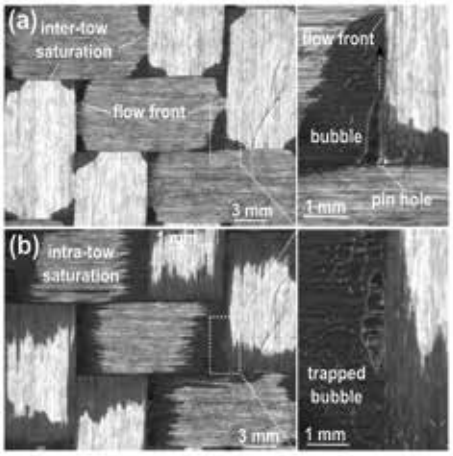


FIG. 3 Inter-tow channels provide the largest escape routes for air bubbles. The team's research showed that bubbles are most effectively evacuated if they move ahead of the resin flow front in the direction of the fiber. Intra-tow resin saturation increases the likelihood of trapping air bubbles, which become voids.

Still images and video of bubble development and movement have proved valuable in understanding what conditions facilitate bubble migration, and what conditions hinder it (Figs. 2 & 3).

"We experimentally observe bubbles moving two to four times faster than the resin flow — in the channels between fiber tows, specifically, the undulations of the fabric," Cender reports. "This makes it possible for bubbles to reach the flow front and be vented from the laminate. We also make note of conditions under which the bubbles will become stuck in the laminate. Bubbles often do not break [free] once the resin fills these inter-tow channels. If a bubble can penetrate the fiber tow, it always moves in the longitudinal direction — with the fibers. Bubbles never penetrate fiber tows in the transverse direction — across the fibers."

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Bubble behavior videos taken by Advani's team are available on the *CW* YouTube page | short.compositesworld.com/Bubbles

Although Cender's work on bubble mobility is ongoing, he says results, thus far, indicate that an OOA semipreg should have an initial resin fraction of not more than 30%. If initial impregnation is more than 30%, says the paper, it "will take longer to de-gas the laminate and does not allow enough space for resin flow inside channels (inter-tow spaces) for voids to reach the resin flow front."

Looking ahead, says Advani, more work needs to be done to understand what variables enhance bubble mobility. Large bubbles move faster than small bubbles, he says, and resin viscosity and surface tension play obvious and important roles. Experiments will further evaluate the roles of tow size, channel size, fabric architecture and rate of vacuum pull in minimizing OOA void content. "One thing we know," says Advani, "is that if we can get the bubble to the front of the flow front, it's much easier to move it."

Ultimately, says Cender, he'd like to develop impregnation data for a variety of fiber forms that prepreg suppliers can use to optimize the products they provide to OOA fabricators. In any case, he says he wants to bring a greater level of understanding and sophistication to OOA molding: "We want to dismiss the misconception that if you apply vacuum to your laminate, that the bubbles will always reach air pathways and be vented from the system. Bubbles can still get stuck if the impregnation is too high, no matter how long the vacuum dwell is held." CW

ABOUT THE AUTHOR

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Thermoplastic composites technology: A view from Europe

For this Dutch consortium, bringing the manufacturability of thermoplastic materials to maturity is the goal in concert with OEMs, materials and equipment supplier members.

By Sara Black / Technical Editor

» *Thermoplastics remain perpetually five years from maturity.* This quote from an industry insider, recorded in a 1994 update on thermoplastic matrices in composites applications published in *CW's* predecessor, *High-Performance Composites* magazine, still rings true more than 20 years later.

There is progress, however. Thermoplastic composites are earning a growing share of structural applications, and their many benefits are a lot closer to maturity today in Europe than anywhere else. One reason is the Thermoplastic Composites Research Center (TPRC, Enschede, The Netherlands), a well-known thermoplastics consortium backed by The Boeing Co. (Chicago, IL, US) and an impressive array of industrial suppliers, together with the University of Twente, Saxion University and The Delft University of Technology, all based in The Netherlands. "There is enormous demand for strong, durable, yet lightweight materials to decrease energy consumption," says TPRC's general manager

Reinforced thermoplastics: Big Euro-business

Currently, thermoplastic materials play a larger role in composites manufacturing in Europe than elsewhere in the world. A Dutch cluster of thermoplastics expertise has pushed the materials into many aerospace applications. TenCate, with one of its thermoplastic prepreg machines shown here, is a key supplier.

Source | TenCate/© TenCate

Harald Heerink. But he points out, "In the past, there have been some huge expectations concerning thermoplastic composites, which were never fully met. One of the root causes for this was a general lack of in-depth knowledge of these materials."

CW had the chance to visit TPRC and several nearby TPRC members' facilities, and learned that the Centre, its partner firms and key thermoplastics-focused groups in other parts of Europe (see "European consortia, *galore!*" on p. 41) aim to change that paradigm. Consortium members are conducting an array of research projects intended, ultimately, to improve the entire thermoplastics value chain, including processing methods, for composite parts.

A knowledge institute

Why is Europe such a hotbed for thermoplastics development? One very strong motivation is that European countries have adopted stringent vehicle end-of-life goals (see "Learn More"), and, therefore, favor thermoplastics for their recyclability. Another, says Arnt Offringa, director of R&D at Fokker Aerostructures (Hoogeveen, The Netherlands), is that his company and others in Europe, including TenCate Advanced Composites BV (Nijverdal, The Netherlands) and DSM (Heerlen, The Netherlands), invested in thermoplastics technology consistently for 25 years and now are reaping the benefits. "This investment was kept up," Offringa points out, "even during the major aerospace downturn of the mid-1990s."

Dutch thermoplastic R&D programs attracted the attention of Boeing in 2007, says Heerink, which led to initial collaboration related to thermoplastic structure among Boeing, TenCate, Fokker Aerostructures and the University of Twente. In 2008, the group undertook two joint research projects on materials, joining and bonding, with assistance on best practices from The University of Sheffield's Advanced Manufacturing Research Centre (AMRC, Sheffield, UK). "The effort found numerous themes that required a decent amount of fundamental research," says Heerink. That led to an agreement to form the TPRC in 2009, which, in essence, created a new member of Boeing's GlobalNet network of research centers, which exists to provide innovation and development of materials and technologies for the aircraft manufacturer.

Three years later, TPRC's facility became operational, adjacent to the University of Twente's campus, says Remko Akkerman, a professor at the University of Twente and the TPRC's technical director: "We were able to create a base, with the right equipment, to conduct research. It's a 'knowledge institute,' based on Boeing's consortium model, where members all along the value chain help shape our roadmap for research activities."

Membership in the consortium can be "full" Tier 1, or Tier 2, which involves a lesser monetary commitment. Tier 1 members are Boeing, Fokker Aerostructures, TenCate, Alcoa Fastening Systems and Rings (Torrance, CA, US), the University of Twente and Saxion University of Applied Sciences, with multiple campuses in The Netherlands, including Enschede. Currently, Tier 2 members are Coriolis Composites (Queven, France), Daher-Socata (Nantes, France), Pinette Emidecau (Chalon Sur Saone, France), Instron (Norwood, MA, US), KVE Composites Group (The Hague, The Netherlands), Aniform (Enschede, The Netherlands), Dutch Thermoplastic Components BV (DTC, Almere, The Netherlands), and the Delft University of Technology (TU Delft). In addition, Heerink explains, there are a dozen "bi-lateral" project members that conduct projects to become familiar with thermoplastic materials for a fee but are not consortium members. Most of the current bi-lateral participants are auto industry OEMs and their Tier suppliers.

TPRC's building houses layup tables, a lab-scale autoclave manufactured by Italmatic (Cassina de' Pecchi, Italy), an »

Focused, but far-reaching

An interior view of the Thermoplastic Composites Research Center (TPRC) facility in Enschede, The Netherlands, adjacent to the University of Twente campus. Although it is compact, the center houses equipment and workcells that enable an array of material research projects backed by The Boeing Co. and other key OEMs and suppliers. Source | CW / Photo | Jeff Sloan

Robotics and automated transport

This Coriolis tape-laying robot (top) places thermoplastic impregnated tapes, while this workcell from Pinette Emidecau (bottom) automatically shuttles materials in and out of a heated compression mold. Source | CW / Photos | Jeff Sloan

automated, high-speed compression molding work cell from Pinette Emidecau and a robotic, automated tape placement (ATP) system with a single-tow head, supplied by Coriolis. A material testing laboratory, offices, conference rooms and material storage finish out the roughly 1,000m^2 floor space within the building. Heerink explains that the consortium receives European-level and regional funding, in addition to fees paid by members, to finance the equipment and research work. Specific projects are selected and guided by the TPRC's consortium board and technical advisory board. New technology developed at the facility is the property of TPRC, through a subsidiary entity. "We own the intellectual property," says Heerink, but emphasizes that "Tier 1 members have automatic usage rights to that IP." Like Tier 1s, Tier 2 members also may participate in all projects, but Tier 2 usage of IP, he says, "must be approved by the Tier 1 members."

"A big focus here is development of more — and better — engineering design tools, both software and material property databases, for thermoplastics, to aid engineers in part designs," adds Akkerman, who was instrumental in starting AniForm, which offers a solver for simulating how composites behave during molding. Other ongoing TPRC research includes investigation into the following:

- Overmolding (where a structural fiber-reinforced composite element becomes part of an injection molded component; see "Learn More").
- Stamp-forming.
- Laser-assisted thermoplastic tape placement.
- Recycling methods.

Heerink adds that the consortium members are also investigating additive manufacturing methods and materials.

Member company advantages

Firms affiliated with TPRC receive the benefits of innovative research, which they can apply to their own operations. *CW* has reported previously on the adoption of a high-rate thermoplastic part production process for the Airbus (Toulouse, France) A350 XWB at Daher-Socata (see "Learn More"), and will publish a Plant Tour later this year to highlight Fokker Aerostructures' successful thermoplastic aerospace part manufacturing.

Tier 1 TPRC member TenCate Advanced Composites, a textile producer since 1704, is a key manufacturer of thermoplastic composite materials for aerospace. Several metric tonnes of TenCate CETEX thermoplastics are used annually on more than 1,500 applications for engines, interiors and primary aerostructure across the Airbus and Boeing fleet families. Its parent company, TenCate, also is a manufacturer of synthetic grass, geosynthetic fabrics and personal protective fabrics, says Rob Boogert, director of operations for TenCate Advanced Composites EMEA: "Our strength is in our diversity and our ability to meet customer demand." While thermoplastics is a major focus, Boogert points out that TenCate's recent acquisition of Amber Composites (Langley Mill, UK) has broadened its thermoset expertise in Europe, and complements TenCate's US prepreg operations as well. The company is involved in supplying composite materials for virtually all the major aerospace programs. »

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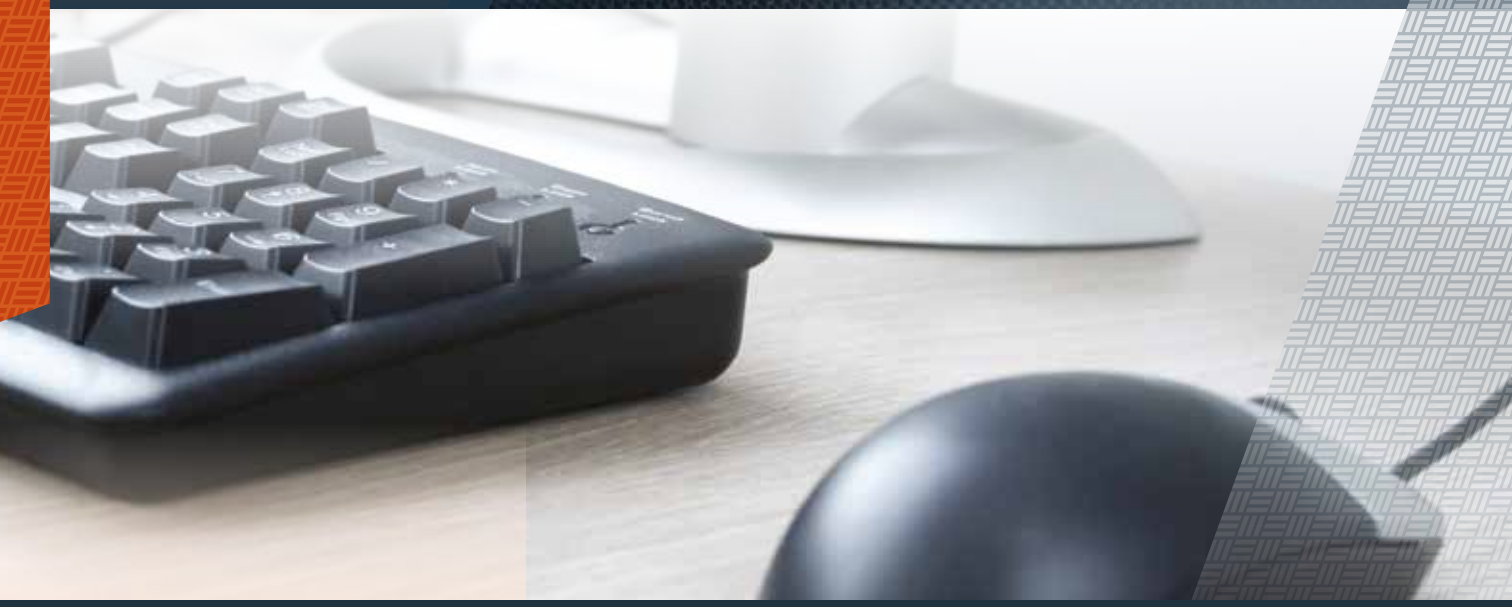

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- What is, and what are the types of tension control.
- How high quality tension control integrates into specific processes (prepreg, pultrusion, filament winding, laminating, converting, hand lay) and the benefits it supplies.
- What tension control products and new technologies are on the market.

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Carbon fiber thermoplastics a priority

Although traditional fiberglass weaving has been contracted out to another supplier, TPRC member TenCate's Nijverdal plant continues to weave carbon-fiber fabrics, which are eventually prepregged with thermoplastic resin at the facility to become CETEX thermoplastic sheet products, in one of three large presses. Source (both photos) | TenCate/© TenCate

Boogert, along with manager of engineering Winand Kok and sector sales manager Aerospace EMEA Marlie Koekenberg, demonstrated during *CW's* recent visit the evolutionary changes that have occurred in TenCate's business, starting with its legacy weaving rooms that feature English-style sawtooth glazed roofs that kept the fabrics from direct sun while allowing shadow-free light — the best light for evaluation of textile quality. Many automated looms, until recently, produced commodity fiberglass and aramid fabrics. These are now made under contract by Hexcel (Stamford, CT, US, and Les Aveniers, France), explains Kok. Five-harness, satin-weave carbon fabrics, typically 125-cm wide, will continue to be made in-house on high-speed, automated Lindauer DORNIER (Lindau, Germany) rapier looms, using 3K carbon fiber tow supplied by Toray Carbon Fibers Europe (Paris, France).

To convert its technical carbon textiles to thermoplastic composites, TenCate uses several processes and works with several polymer suppliers, including Victrex Plc (Cleveleys, Lancashire, UK), Arkema (Colombes, France) and Celanese Corp. (Irving, TX, US, and Oberhausen, Germany).

For the fiberglass/polyphenylene sulfide (PPS) material used by Fokker Aerostructures to form the J-nose fixed leading edge on the Airbus A380 aircraft wings, a PPS film is applied to both sides of an eight-harness, satin-weave (re-sized) fiberglass fabric in a heated laminating process, to form what Kok calls a semi-preg product. For semi-preg materials typically used in aircraft flooring and interiors, woven carbon, glass or aramid fibers are dip-coated with polyetherimide (PEI) in a solvent-coating process. But semi-preg also can be made in a powder-coating process that, Kok explains, eliminates the cost of forming thermoplastic laminating films. The process uses machinery designed by TenCate in-house.

"We've been perfecting this process for several years, and are currently involved in qualifying it for Airbus," he says, to show equivalency with filmed and solvent-based prepregs. The powder-coater can rapidly dispense any thermoplastic resin onto a fabric, which then passes through heated rollers and an oven to melt and crystallize the polymer as required. "We can achieve very tight thickness tolerances," adds Kok, and explains that if thicker products are required, the material can be sent through the machine twice for two coats of resin.

TenCate's well-known CETEX thermoplastic sheet is made in three, large, heated compression presses that operate around the clock. Workers lay up thermoplastic prepreg material to form the 3.6m by 1.2m sheets, in any fiber architecture from 1 to 24 plies thick, to customer specs. PPS is the most common matrix, says Kok, who explains that the layups are moved to the press, heated and consolidated in a heating, compression and cooling process that depends on sheet thickness and resin type, and desired resin crystallinity. The pre-consolidated, stiff sheet product is virtually void-free — all CETEX sheets undergo a C-scan inspection to verify quality and thickness before customer shipment.

> TRPC is a knowledge institute where members all along the value chain help to shape the research roadmap.

"We're continuously working to develop new products, with higher performance. For example, PEI has good fire/smoke/toxicity properties, but it doesn't stand up well to hydraulic fluid, so PPS or PEEK is a better choice for wet applications," concludes Kok. "An example of a recent product development is carbon fabric/PEI prepreg used as an air inlet liner in the engines on several Airbus aircraft." He adds, "Our participation in the TPRC allows us to stay abreast of advances in thermoplastics, and to conduct our own product research projects there — while allowing other partners to familiarize themselves with our products." »

Realizing robotic capabilities

A technician guides a Coriolis thermoplastic tape-laying robot through a flat demonstration panel. The robot heads can be configured to lay thermoplastic- or thermoset-impregnated or dry tapes, and can come equipped with the correct heating element and the capability to apply the compression force appropriate for each type of material. Source | CW / Photo | Jeff Sloan

Part prototyping & testing

In addition to its TPRC activities, Coriolis also operates a prototyping, testing and design service for its customers, including trials of part layup with a robotic setup, as shown here.

Source | CW / Photo | Jeff Sloan

Robots + thermoplastics = new markets

Processing thermoplastics rapidly is another key component of TPRC's mission. Automated work cells, such as those produced by Tier 2 member Pinette Emidecau, speed the thermoforming of blanks for relatively simple part shapes. For more complex shapes, fiber placement and automated tape placement technology holds promise. TPRC member and robotic fiber placement specialist Coriolis Composites has its eye on bringing greater automation to the composites industry. "TPRC provides an opportunity for open discussion with key players, and trials of new materials and equipment in a confidential environment, that is a real benefit for us," says chief technical officer and company co-founder Alexandre Hamlyn. "We appreciate the focus only on thermoplastics, which keeps the research focused."

Coriolis uses readily available, off-the-shelf robotic elements and integrates them with company-designed heads and software

to form a customer-specific, turnkey workcell. Robotic arms are typically supplied by KUKA AG (Augsburg, Germany), with up to eight axes of movement. "Medium" floor-mounted, robotic arms have a payload capacity of 250 kg, while the "large" option allows a 500 kg payload, and can support a correspondingly larger head. Optional are rotating "positioners," or headstock and tailstock parts, supplied by Güdel SAS (Mulhouse, France). Robotic motion is controlled by Siemens 840D CONTROLLER software from Siemens AG (Munich, Germany).

Heads, built and assembled by Coriolis, can be configured to lay thermoset towpreg, thermoplastic tape or dry tape, with appropriate heating strategies for the selected material, in widths from 6.4 mm up to 12.7 mm. Customers can specify single or multiple (4, 8, 16 or even 32 simultaneous) tows in the larger heads, explains Hamlyn. Minimum fiber laydown length is 90 mm, and speeds up to 1m per second are possible, for laydown rates up to 40 kg of material per hour. A key feature of the company's head design is that tows or tapes move from the creel and Multiwinch tension »

SIDE STORY

Thermoplastic composites: European consortia, *galore!*

There are many more European consortia, comprising private industry, university and government entities, which share the goals of exploring composites materials and methods for manufacturing them, including those with thermoplastic matrices:

The Thermoplastic Affordable Primary Aircraft Structure (TAPAS) consortium was launched in The Netherlands in 2009 with the goal of developing new thermoplastic composite materials and processes for use in Airbus (Toulouse, France) aerostructures. The consortium is starting its second phase of material and application development, and members hope, by 2017, to bring to market a thermoplastic composite fuselage and torsion-box concept that proves the viability of thermoplastics in commercial aerostructures. In addition to Airbus, the TAPAS consortium includes project lead Fokker Aerostructures (Hoogeveen), the Airborne Technology Center and Kok & Van Engelen (both based in The Hague), Dutch Thermoplastic Components (Alkmaar), Technobis Fibre Technologies (Uitgeest), TenCate Advanced Composites (Nijverdal), KE-works, CoDeT and Technische Universiteit Delft (all based in Delft), the University of Twente (Enschede) and the National Aerospace Laboratory, in Amsterdam (www.tapasproject.nl/en).

Dutch Thermoplastic Components, Kok & Van Engelen, National Aerospace Laboratory, TenCate Advanced Composites and VIRO (Hengelo, The Netherlands) are collaborating in the European Thermoplastic Automotive Composites consortium (eTAC, www.etac.info; see "Learn More," p. 43).

Machinery manufacturer Pinette Emidecau (Chalon-sur-Saône, France) is part of a four-company consortium that is combining technologies to provide automated, high-speed resin transfer molding (RTM) production technology. Under the name Global RTM, headquartered in Bellignat, France, the multi-faceted supplier will build and market turnkey production systems, drawing on the expertise of its three other France-based partners: toolmaker Compose (Bellignat), injection systems specialist Isojet Equipments (Lyon) and process control/monitoring specialist S.I.S.E. (Oyonnax). The goal is to supply turnkey systems capable of producing up to 150,000 parts per year (www.globalrtm.net).

A four-year project, called WALiD (Wind Blade Using Cost-Effective Advanced Composite Light-Weight Design), partly funded by the European Commission under the 7th Framework Programme, proposes to combine process, material and design innovations and introduce a thermoplastic composite wind blade for large, offshore wind turbine installations. The WALiD consortium, which will commit a total of €5.1 million (US$5.4 million) to the project, comprises 11 European organizations, including, from Germany, the Fraunhofer Institute for Chemical Technology (ICT, Pfinztal) and Windrad Engineering GmbH (Bad Doberan); from the UK, Smithers Rapra and Smithers Pira Ltd. (Shrewesbury); from The Netherlands, TNO Netherlands Organisation for Applied Scientific Research (The Hague), PPG Industries Fibre Glass BV (Westerbroek) and NEN (Delft); from France, Loiretech SAS, Mauves sur Loire) and Coriolis Composites SAS (Queven); as well as the following: APT Archimedes Polymer Technologies (Cyprus), Norner AS (Stathelle, Norway), and Comfil ApS (Gjern, Denmark). Visit WALiD at www.eu-walid.com.

The Lightweight Integrated Process Application (LIPA) project, envisioned by Georg Kaufmann Tech-Center AG (GK-Tech-Center, Busslingen, Switzerland) seeks to develop a process of forming and "back injecting" thermoplastic prepregs or commingled thermoplastic fabrics, which the group calls "organic sheets," to produce fiber-reinforced, lightweight thermoplastic components for eventual series production. The multi-company consortium includes GK-Tech-Center and Swiss partners ASE Industrie-automation GmbH (Näfels), Kistler Instrumente AG (Winterthur), Krelus AG (Oberentfelden) and Quadrant Plastic Composites AG (Lenzburg). The consortium has constructed a specially designed, flexible manufacturing cell at its new LIPA Development Center, in Busslingen; www.lipa-series.com/en/lipa-project.

The aim of the Stellar Project is to develop a manufacturing process for high-speed placement of carbon, glass and polymer fiber-reinforced matrices, in selected locations in a composite structure. The project will focus on development of automated tape laying (ATL) to selectively place reinforced thermoplastic tapes in three manufacturing modes: Selective reinforcement of existing components; direct additive manufacture of components; and manufacture of selectively-reinforced tailored blanks for compression molding (http://stellar-project.eu/). Partners include NetComposites Ltd. (Chesterfield, Derbyshire, UK), Toyota Motor Europe (Zaventem, Belgium), Airborne Development BV (The Hague, The Netherlands), HBW-Gubesch Thermoforming GmbH (formerly Jacob Plastics GmbH, Wilhelmsdorf, Germany), AFPT GmbH (Dörth, Germany), CGTech Ltd. (London, UK), ESI Group (Mérignac, France), Kunststoff Technik Leoben (Leoben, Austria) and Fraunhofer IPT (Aachen, Germany).

North Thin Ply Technology (NTPT, Penthalaz-Cossonay, Switzerland) has started a new research project on toughened thin-ply composites for aerospace applications, called TPCA, a two-year study. TPCA is partially funded by the Commission for Technology and Innovation (CTI) of the Swiss Confederation. NTPT joins forces with partners Huntsman (Salt Lake City, Utah and Basel, Switzerland), the Ecole Polytechnique Fédérale de Lausanne (EPFL), the University of Applied Sciences Northwestern Switzerland (FHNW), RUAG Aerostructures (Bern, Switzerland), and Decision SA (Ecublens, Switzerland). The goal of this research is to improve the toughness of thin-ply composites in order to meet or exceed aerospace requirements.

controller within individual, shaped plastic conduits to the head, at very low tension. "We have found that the tubes, together with lower tension on each tow, is better, as it allows faster placement speeds and reduces the chance for bridging or fiber deformation, as well as breakage," he points out.

At approximately 50 kg, a small Coriolis head is the most compact and lightest on the market, claims the company — small enough for female tool layup, and light enough to place fiber on honeycomb core without crush. Yet, says Hamlyn, the head can still provide a compaction force of 10 N/mm per band width, an industry standard at Boeing and Airbus. The company has developed a patented method for placing fibers on sharp corners or radii at 45°, an advantage for automating aircraft wing spar layup, for example. "We actually have 20 patents that cover various machine elements," he adds.

The software that controls head and fiber-placement functions was developed by Coriolis engineers. CADFiber and CATFiber are machine-independent and available for any AFP or ATL machine through Coriolis' subsidiary software company. CADFiber can be used to design parts for fiber placement, while CATFiber can program automated fiber placement cells. Both software packages directly interface with CATIA/DELMIA from Dassault Systèmes (Velizy-Villacoublay, France) or with SiemensSNX. Customers can try out software and actual machines, and critique the feasibility of projects, at Coriolis' technical center, where two robots and a team of 12 engineers are available for R&D collaboration.

Many important aerospace programs are reportedly employing Coriolis equipment for automated production. These include several machines at Airbus, with four machines in Stade, Germany, and one at Nantes, France, all working on A350 XWB parts. Two are located at Stelia Aerospace (Mérignac, Cedex, France, created by the merger of Aerolia and Sogerma) producing A350 XWB doors. Dassault Aviation (Saint-Cloud Cedex, France) has a machine at its Biarritz, France, facility for *Falcon 5X* composite parts, while Bombardier Inc. (Montréal, QC, Canada) is using two machines for production of *CSeries* aft fuselage parts and rear pressure bulkheads. Aeroengine maker Safran SA (Paris, France) is using a Coriolis machine for automated layup of the nacelle inner fixed structure on certain engine models.

In addition to these signs of success, Hamlyn drives home the point of thermoplastic part quality. A recent SAMPE Europe presentation, which Hamlyn co-authored with several Airbus engineers, compared thermoset carbon composite parts, consolidated out of autoclave, with carbon/PEEK parts produced robotically, using laser heating and partially consolidated on-the-fly. The thermoplastic parts were then edge-bagged and oven-cured for an hour to achieve final consolidation. Test results from the thermoset parts and the robotically produced PEEK parts showed no differences in part quality and performance. In addition, the study showed that thermoplastic composites can be readily

introduced into the production chain and at the same productivity rate as thermoset prepregs.

"Our goal is to make the automated process of forming composites less and less expensive over time, to bring this technology down to Tier 1 and Tier 2 suppliers, for more and more secondary structures. Our business model is based on taking cost out," states Hamlyn.

With several potential automotive customers in the wings, a special thermoplastic head for automotive parts may be coming, he adds, one that would reduce scrap rates to the minimum, and use industrial-grade, 50K tows to reduce cost.

On a growth trajectory

Thermoplastic composites are on the upswing, as the composites industry's reach continues to expand. Fokker's Offringa points out some of the current, qualified and flying thermoplastic aerospace parts that have already made the cut: the cockpit floor in the Airbus A400M; fixed leading edges for the Airbus A340-500/600 and A380; *Apache* combat helicopter avionics bay panels; floor panels for the Gulfstream *G4*, *G5* and *G6* families; and the rudder and elevators for the Dassault *Falcon F5X*. "The volume of some of these parts, particularly for Airbus and Boeing commercial aircraft, is going to grow to unprecedented levels as the build rates increase," he asserts.

Concludes Heerink, "We have the tools and the joint funding with our partners to successfully develop thermoplastics to meet the rate of innovation that's required by these large OEMs. I foresee continuous growth here at the center, and collaboration with more industries, including automotive and civil engineering, going forward." CW

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SFMOMA façade: Advancing the art of high-rise FRP

The fabrication and installation of 700+ composite panels has a backstory of detailed design and careful quality assurance.

By Ginger Gardiner / Senior Editor

» The San Francisco Museum of Modern Art (SFMOMA, San Francisco, CA, US) expansion has received *a lot* of press, and for good reason: It is, to date, the largest architectural use of fiber-reinforced plastic (FRP) in a US building project — more than 700 panels, some as large as 1.5m wide by 9m long, totaling 7804m^2 on a contoured 10-story façade. It is the first time a composite system has passed the rigorous fire-regulation testing that permits its use above the fourth story on a high-rise exterior in the US. Missing from the accolades for this high-profile example of the rapid change in building skin technology is the manufacturing story *behind* the headlines: The step-by-step production process used to make and, just as important, Kreysler & Associates' (American Canyon, CA, US) pre-production preparation for, the integrated cladding/unitized panels that helped make the SFMOMA expansion's façade a much heralded piece of municipal art.

Design development partner

When asked how the façade construction process began, Kreysler & Associates president Bill Kreysler quips, "With over a year of *design* development," referring to the

US high-rise first: FRP building envelope

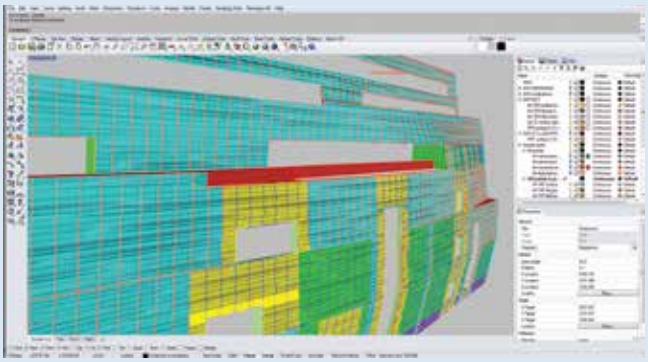
The SFMOMA expansion boasts the most extensive use of FRP in an US architectural building project, to date, with more than 700 panels, totaling 7804m^2, forming a 10-story curved façade. Source (left) | Snøhetta / Source (above) | Felix Weber/Arup

fact that, increasingly, architects such as Oslo, Norway-based firm Snøhetta, the designer of the SFMOMA expansion, are choosing to enlist potential subcontractors long before anything gets built. "Subcontractors are retained through a *design-assist* contract," Kreysler explains, "to work out the myriad design and construction details in collaboration with the architect." The goal is to explore issues and alternatives during the design phase, so that once construction begins, cost and schedule targets can be maintained. Kreysler adds that it was no small matter: "We had one employee working full-time for eight months, just on this."

To see the impact this early involvement had on the façade manufacturing process, it is necessary to understand high-rise building construction and where the FRP panels fit in. Typically, this building type begins with a foundation on which a structural frame of steel columns and beams is erected. Concrete slab floors are poured to the edges of the steel columns and beams, and in the space between the slabs, exterior weatherproof barrier walls — typically gypsum board faced with rubber — are erected. "This is pretty ugly," notes Kreysler, "so in order to have an aesthetic finish, they put up a rain screen." »

Variable surfaces, flat backs

These foil-coated foam molds with corresponding FRP parts lying on top show how edge return distance varied not only for each panel, but even on the left vs. the right side of each panel. Source | Kreysler & Associates



1 The FRP panel production program was driven by digital fabrication tools. This required careful management of the 3D computer models that governed panel geometry and coordination of those models between the Kreysler and Enclos façade fabrication teams.

3 After applying the mold release, Kreysler technicians sprayed on the Fireshield 285 coating.

2 Molds were CNC-machined from EPS foam.

4 An impregnator was used to wet out three plies of glass fiber woven roving for each panel, which were then applied to and rolled out on the molds by hand.

Typically made in panels, this aesthetic veneer was the focus of Kreysler & Associates' design-assist contract for the SFMOMA expansion. Snøhetta's striking design of a white undulating surface, reminiscent of rippling waters in nearby San Francisco Bay, originally called for glass fiber-reinforced concrete (GFRC). "But we suggested an alternative: lightweight FRP panels," Kreysler recounts. "At a fraction of the weight," he notes, "they opened up another interesting option for construction." A project's main contractor always prefers to minimize the number of subcontractors, particularly on a part of the building that is latent with liability, such as the exterior wall, he explains. But in the design *as conceived*, one subcontractor would be required to install the gypsum board, another would follow with the rubber facing, then yet another would anchor a secondary steel frame required to support the heavy GFRC rain-screen panels, which would be installed by a fourth subcontractor.

"However, our panels were light enough to be mounted onto unitized wall panels, pre-assembled off site and delivered as needed for installation." A unitized wall system (see "Learn More," p. 49) not only offered the highest grade of weatherproof wall for this high rise, but also significantly streamlined the construction process. "The whole façade was put up under *one* subcontractor," says Kreysler, adding, "Even though our system enabled the elimination of 1 million lb of steel, it turns out cutting three passes around the building was worth *more*."

FRP's moldability also was important. Typically, unitized panel systems — a modernized, computer-modeled update to traditional curtainwalls — feature glass or metal panels, each enclosed, typically, by a 203-mm thick aluminum frame. Frames lock together with gaskets to tolerances within 1.6 mm to form the building's weatherproof exterior barrier with an integrated aesthetic surface. "They are great, and work well for a flat wall," says Kreysler, "but not so much with complex, curved geometry." So each contoured SFMOMA FRP rain screen panel would be attached to a flat backing structure — a unitized wall panel that includes a vapor barrier, insulation and weather barrier for the building. The unitized wall system fabricator, Enclos (Eagan, MN, US), also a key player in the design-assist process, worked with Kreysler & Associates to finalize specifics

5 Attachment plates for aluminum framing were then bonded to the FRP, enabling aluminum stiffening ribs to be mechanically fastened down the length of each panel.

6 Sandblasting the gel coat to reveal the desired matte finish was the final step before shipping the panels to Enclos.

Source (Steps 1-6) | Kreysler & Associates

7 At the Enclos facility, technicians assembled each unitized wall system panel for the SFMOMA expansion, and then attached the matching Kreysler FRP rain screen panel, like the one shown here as it is lowered onto an Enclos wall system panel. Source (Step 7) | Enclos

for attachments, joints and installation. Kreysler's designers used AutoCAD (Autodesk Inc., San Rafael, CA, US) for construction documents, Rhino 3D (Robert McNeel & Associates, Seattle, WA, US) for 3D modeling (see Step 1, p. 46) and Revit (also by Autodesk) for building information modeling (BIM).

Fabrication begins

Under a design-assist agreement, a point is reached when the design is deemed ready to build, the project owner buys off on the final design with details, and the design-assist subcontractor is awarded the build contract — *if* it has maintained pricing and met all requirements. Kreysler explains, however, that when his company reached that point, "it was conditional upon our panels passing the NFPA 285 fire test. So that was the first thing we did." He adds that it was not trivial to develop a composite system that would pass full-scale testing (at a cost of $100,000) with no guarantee on the outcome. Failure, however, would preclude the system's use above the expansion's fourth floor. "But in the end, we succeeded," says Kreysler (for that story, see "Learn More").

Finally, fabrication began. Because the façade would have a complex, nonrepeating and textured surface, tooling was a significant undertaking. More than 700 unique molds were CNC-machined from expanded polystyrene (EPS) foam (see Step 2). PowerMill software by Delcam (Birmingham, UK, now a subsidiary of Autodesk) translated CAD files to CNC machine tool paths. After the foam was machined, it was covered in tin foil and waxed as a mold release surface. "We then attached flat aluminum sheets on the sides to make edges for each panel," says Kreysler. This turned the undulating foam into a rectangular box for easier handling.

Because the face of each panel would be uniquely curved, but the backs of the panels would have to be flat in order to mate and attach properly to Enclos' flat unitized wall panels, he points out that the distance of the edge returns (i.e., from the curved front surface to the flat back surface) was not only different for each and every panel, but even for each panel's left and right edge (see bottom photo, p. 45).

Gel coat was then sprayed onto each mold (see Step 3). The gel coat is composed of a Polynt Composites (Carpentersville, IL, US) polyester resin base, with additives for fire- and UV-resistance. »

Notably, a sand component is added to create a matte finish that resembles sandstone, yet also shimmers when directly lighted.

Behind the cured gel coat, three layers of woven glass fiber roving wet out with a resin impregnator were applied (see Step 4, p. 46). Kreysler used a polyester resin supplied by Ashland Performance Materials (Dublin, OH, US) and a special-order fabric sourced through distributor Core Composites (Bristol, RI, US). "We wanted an equal number of strands in both warp and weft directions, and also a custom width that matched our average panel width [1.7m]," Kreysler reveals.

Panels were allowed to cure at room temperature for several hours. But after demolding, they were postcured at 65°C for three hours in a custom-built oven. Although this is a rare step for polyester composites fabrication, Kreysler points out that in exterior applications, laminates will, indeed, postcure with sufficient time and/or exposure to temperature. "We did not want to risk that a panel not cure completely for some reason, get installed and then postcure on the building and warp," he explains.

Pre-installation framing

Because the uncored FRP panels were only 4.8 mm thick but 1.7m wide, aluminum framing was installed on all four edges with intermediate crossmembers to stiffen the panels and serve to connect each FRP panel to its Enclos-built unitized wall-panel backing structure. Steel rods were inserted into holes drilled along the lengths of the intermediate stiffeners. A 90° elbow at the end of each rod fit into a groove in a composite attachment plate, which was then bonded to the FRP laminate using Plexus methyl methacrylate adhesive from ITW Polymers Adhesives (Danvers, MA, US, see Step 5).

The final step performed at Kreysler's factory was sandblasting to produce a sandstone-like matte finish (Step 6). "We have used this finish on buildings for 20 years, and they still look great," touts Kreysler. "It is easy to repair, does not oxidize easily and does not stain like concrete because it does not absorb moisture."

After final quality assurance checks and documentation, the panels were ready to ship. Enclos leased a building in nearby Vallejo, CA — standard procedure for the company, which establishes an "assembly site" near each job site, where it receives aluminum extrusions, glass or metal panes, gaskets and attachment hardware from suppliers. Everything is computer-designed, pre-ordered to custom sizes and assembled into ready-to-install wall panels away from the job site, where quality control can be better maintained. This also reduces complexity and risk at the building site. Thus, as Enclos assembled each unitized wall system panel for the SFMOMA expansion, it received and attached the matching FRP rain screen panel from Kreysler & Associates (Step

7), producing an integrated, ready-to-install façade panel.

Kreysler points out that when Enclos loaded completed panels on a flatbed truck for shipment to the SFMOMA job site, the average 10 panels per truck was twice the number of heavier GFRC panels that could have been carried. At the job site, one of two tower cranes removed each panel and hoisted it to the appropriate location for installation. "At one point, they were installing 19 panels per day," Kreysler recalls. "Which is why we were the *first* subcontractor to begin production. We had to have the necessary panels ready prior to the installation schedule." He explains that his company could CNC-machine only four molds for the unique panels per day and knew that once installation began, panels would go up much faster than he could produce them, so he used that knowledge as the basis for calculating the production rate he could maintain for the project, then added a cushion for contingencies. "You must meet the production rate you commit to in the contract," Kreysler points out. "If you fall behind, you can be liable not only for a delay in opening the building, but also for delaying the other subcontractors." With monetary penalties that can easily reach six figures per day, there is little room for error.

Mitigating risk

Understanding and avoiding such liabilities, was in fact, the biggest challenge in this, the company's biggest FRP project, says Kreysler. "We had to identify where the risk was and how to mitigate that."

High on the list was façade color. "Color consistency was critical," Kreysler points out. "This project would last over a year, but the gel coat color consistency was only guaranteed for 90 days. We were also adding inorganic fillers, whose colors vary. So this required a lot of effort on our part." Long before production, the company spent significant time with gel coat supplier Polynt Composites, finalizing what the latter would guarantee in terms of color matching and then making sure that was written into Kreysler & Associates' build contract. "We could not promise a better color consistency than the resin supplier could provide," Kreysler notes.

The sand in the gel coat raised another concern. "There is no guarantee that one scoop would be the same color as the next," says Kreysler. To minimize inconsistency, »

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"we bought all of the sand for the whole job at once, paid to put it all in one hopper and tumbled it to mix out the color variation." The sand was then bagged and inventoried, with color samples taken and recorded for every bag. Gel coat samples were made and recorded for every bag as well.

Finally, the company took 10 spectrophotometer readings for each panel to measure color consistency. That data was entered into an Excel spreadsheet and graphed to monitor variation throughout the project.

"Postcuring was similarly a matter of risk mitigation and insurance," Kreysler adds. "By taking that extra measure, we had confidence that the variation in the panel properties was minimized to the level needed."

Success for the future

As *CW* went to print, façade panel installation was nearing completion. When the exterior envelope is closed, the building contractor will finish the extension's interior for the museum's re-opening, scheduled for first-quarter 2016.

"Everyone is thrilled with how the project has turned out," says Kreysler. He notes that even Enclos, which bought in early to the FRP approach and has been an excellent partner throughout, nevertheless "anticipated that our elevation would have the most problems. But ours [Kreysler & Associates and Enclos] has actually ended up having the least." Enclos VP and SFMOMA project manager Kevin Mannen applauded the subcontractor *and* the use of composites: "In my 27 years with Enclos Corp., I can honestly say that I'm most proud of the SFMOMA project and it's largely because of your FRP."

Will this success change how composites are viewed in large architectural projects? "I think this proves the potential of composites to provide a solution," Kreysler replies. "But I worry that companies will try to complete such projects without the significant construction experience required." He explains that this entails knowledge about not only FRP but also contracts, insurance, working with other subcontractors, pricing, codes and regulations, movement in buildings due to temperature and seismic events *and* how to allow for that, to name a few key areas. "You can't survive the cost of a serious mistake," he warns but sees opportunities for companies willing to start with smaller projects and progress slowly, step by step.

"There *are* opportunities for new materials," Kreysler sums up, "but they demand close cooperation with the building design team in order to move beyond traditional construction methods and mindsets." CW

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Paris Air Show
www.siae.fr/EN

June 16-17, 2015 — Stade, Germany
9th Int'l CFK-Valley Stade Convention
www.cfk-convention.com

June 16-17, 2015 — Anaheim CA, US
SAMPE Seminar: Composites Technologies & Applications Overview
http://www.nasampe.org/events/event_details.asp?id=620348

June 17-18, 2015 — Rosemont, IL, US
ameri*mold* 2015
www.amerimoldexpo.com

June 18-19, 2015 — Dresden, Germany
19th Int'l Dresden Lightweight Engineering Symposium
leichtbausymposium.de/en

June 22-26, 2015 — Marina del Rey, CA, US
14th Int'l Symposium on Nondestructive Characterization of Materials
www.cvent.com/events/14th-international-symposium-on-nondestructive-characterization-of-materials/event-summary-f653e94ffff04d5289e9a9249aca22f5.aspx

June 28-July 1, 2015 — Seattle, WA, US
ICCE-23, 23rd Int'l Conference on Composites and Nano Engineering
www.icce-nano.org

July 12-18, 2015 — Chengdu, China
American Architectural Manufacturers Assn. (AAMA) 2015 National Summer Conference
www.aamanet.org/events/1/11/48/aama/219/aama-national-summer-conference

July 19-24, 2015 — Copenhagen, Denmark
ICCM20- 20th Int'l Conference on Composite Materials
www.iccm20.org

Aug. 17-20, 2015 — Edmonton, AB, Canada
CANCOM 2015
cancom2015.org

Sept. 8-10, 2015 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
www.speautomotive.com/comp.htm

Sept. 9-11, 2015 — Toulouse, France
2015 Int'l Conference on Lightning and Static Electricity (ICOLSE)
www.icolse2015.org

Sept. 9-11, 2015 — Cambridge, UK
ACIC 2015 – 7th Biennial Conference on Advanced Composites in Construction
www.acic-conference.com

Sept. 14-16, 2015 — Toulouse, France
SpeedNews 16th Annual Aviation Industry Suppliers Conference
www.speednews.com/all/conference

Sept. 15-17, 2015 — Louisville, KY, US
IBEX 2015
www.ibexshow.com

Sept. 15-17, 2015 — Amiens, France
SAMPE Europe Conference 2015
www.sampe-europe.org

Sept. 15-18, 2015 — Husum, Germany
HUSUM Wind 2015
www.husumwind.com/content/en/start/welcome-2015.php

Sept. 15-18, 2015 — London, UK
Defence & Security Equipment International (DSEI) 2015
www.dsei.co.uk

Sept. 21-22, 2015 — Stuttgart, Germany
1st Int'l Composites Congress (ICC)
www.avk-tv.de/events.php?page=&year=2015&month=09

Sept. 22-24, 2015 — Stuttgart, Germany
Composites Europe
www.composites-europe.com/startseite_1.html?sprache=englisch

Sept. 22-24, 2015 — Seattle, WA, US
SAE 2015 AeroTech Congress and Exhibition
www.sae.org/events/atc

Oct. 5-7, 2015 — Orlando, FL, US
2015 Polyurethanes Technical Conference
polyurethane.americanchemistry.com/Polyurethanes-Technical-Conference/2015-Conference.html

Oct. 20-21, 2015 — Knoxville, TN, US
Additive Manufacturing 2015
www.additivemanufacturinginsight.com/conferences/am-workshop

Oct. 26-29, 2015 — Dallas, TX, US
CAMX – The Composites and Advanced Materials Expo
www.thecamx.org

Nov. 4-5, 2015 — Birmingham, UK
Advanced Engineering UK 2015
www.advancedengineeringuk.com

Nov. 4-7, 2015 — Sao Paulo, Brazil
Compocity 2015
www.almaco.org.br/video4.cfm

Nov. 12-14, 2015 — Istanbul, Turkey
PUTECH Eurasia/Eurasian Composites Show
www.eurasiancomposites.com

Nov. 17-19, 2015 — Seville, Spain
2nd Aerospace Structural Impact Dynamics Int'l Conference
asidiconference.org

Dec. 8-10, 2015 — Knoxville, TN, US
Carbon Fiber 2015
www.compositesworld.com/conferences/compositesworlds-2015-carbon-fiber-conference

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FIRST ALL-CARBON YACHT A WINNER

Vacuum infusion with customized fabrics enables demanding yacht build

Gold Coast workers tend to a partially layed-up *B53* hull section in preparation for eventual bagging and infusion. Source | FORMAX

The *B53*, now renamed *Fūjin*, is Gold Coast Yacht's first yacht built entirely of vacuum-infused carbon fiber composites.

Source | Gold Coast Yachts

› Gold Coast Yachts (Christiansted, St. Croix, US Virgin Islands) is a 30-year old boatbuilder with a portfolio of 113 custom multihulls for the yacht market, ranging in length from 12m to 30m. Over the years, its construction methods had evolved: It had begun with wood/epoxy and then moved into composites, with hand layup of dry fiberglass, wet out with epoxy via the bucket-and-brush method. Later, Gold Coast adopted wet-bagging methods, where reinforcements are wet out by hand or with a wet-preg machine (impregnator), then layed up on the mold, vacuum bagged and cured at room temperature, relying on the exotherm in the resin. Most recently, the boatbuilder has incorporated some vacuum-infused carbon fiber for selected composite elements.

In the face of strong competition, however, Gold Coast recently won a contract to build its first *all-carbon* boat, the *B53*, for competitive racing as well as comfortable cruising. To realize the *B53*, carbon fiber was required to meet weight and engineering requirements, but prepreg was too costly. The company was concerned about wet bagging of carbon materials, but infusion on that scale seemed problematic as well because a common fear is that smaller-diameter carbon fiber filaments might pack together more tightly than E-glass does and make resin wetout of the fiber difficult. The company contacted Philip Steggall, now the director of North American business development for **FORMAX** (Leicester, UK) and a long-time marine composites expert, for advice on what materials and process might best meet the laminate performance specified by the vessel's designer, Paul Bieker of naval architecture firm Bieker Boats LLC (Seattle, WA, US). Steggall suggested a testing program to compare wet bagging and vacuum infusion. Identical laminate panels were created with both methods, using FORMAX stitched biaxial fabrics and resins appropriate for both methods. The test results, from several laboratories, showed that the vacuum-infused panels exhibited superior properties, including a 15% gain in compression strength. The wet-bagged panels, Steggall reports, were inconsistent in fiber volume and had significantly higher void content. The high-viscosity resin used in wet-bagging does not travel through the carbon and expel air as well as a lower viscosity infusion resin will, he reports, adding that the fiber content for the infused panel was consistently within 2% tolerance, with no noticeable voids. Armed with this information, Gold Coast decided it could meet the challenging specifications with infusion and use lower-cost molds and lower cure temperatures than prepreg demand.

FORMAX developed custom biaxial carbon fabrics, ±45°, at areal weights of 400 g/m^2 and 300 g/m^2, and another 0°/90° biaxial of 300 g/m^2, which were optimized for the infusion process. To facilitate air evacuation and enable resin flow through the laminate layers, a thin, randomly oriented monofilament web of polyamide fibers was placed between the carbon plies, FORMAX reports. Additionally, the stitched multiaxials perform better during infusion processes than woven or hot-melt-bonded fabrics, says the company, because they offer z-axis air-escape routes along the threads through the thickness, resulting in fewer voids.

"The FORMAX fabrics allowed us to get air out ahead of the resin front, instead of entrapping it within the laminate, as can happen with wet bagging, and even with prepreg," reports Gold Coast Yachts' president Rich Difede. "That's how we hit the target weight as well as the strength requirement for this boat,"

"Some remain skeptical about the quality and properties of infused carbon laminates," adds Steggall, but maintains, "Our work with Gold Coast Yachts proves that infusion, when done correctly, yields a significant strength advantage. Part of the story is training of the personnel and part is material choice."

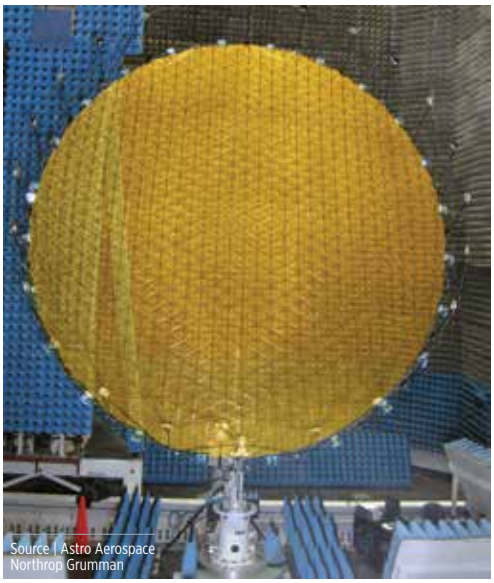
The *B53*, now renamed *Fūjin*, has an overall length of 16.3m, a displacement of 5,500 kg, and was launched this year, at the end of May. CW

IN-ORBIT-DEPLOYABLE RADAR DISH

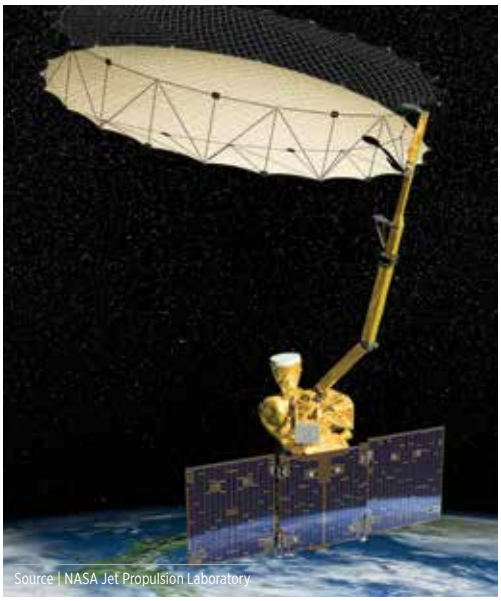
Aramid/PEI delivers flexibility, strength and precision for space-based reflector

A manufacturer of deployable space structures since 1958, Astro Aerospace Northrop Grumman (Carpinteria, CA, US) has a long history with composites. Its latest project, a radar dish that enables global soil moisture measurements from the Soil Moisture Active Passive (SMAP) observatory, was launched by NASA's (Washington, DC, US) Jet Propulsion Laboratory (JPL, Pasadena, CA, US) on Jan. 31, 2015.

The SMAP AstroMesh dish comprises a circular carbon fiber-reinforced plastic (CFRP) truss with a metal mesh stretched across it, like a drumhead. The taut mesh reflects the microwave energy used to take SMAP measurements.



Source | Astro Aerospace Northrop Grumman



Source | NASA Jet Propulsion Laboratory

Hundreds of aramid-reinforced polyetherimide (PEI) tapes support this mesh. Pultruded by **TenCate Advanced Composites** (Morgan Hill, CA, US), the webs, some as long as 6m, were welded together to form a lattice of triangular facets, which gives the mesh its parabolic shape, stiffness and structural properties.

Notably, the complete structure must be collapsible. "Because there is only a finite amount of room on a rocket," explains Astro Aerospace product development manager Daniel Ochoa, "you want to compact the structure and then open it up, once in orbit." The AstroMesh antenna, therefore, had to transform from a 0.3m diameter by 1.5m tall structure during launch to its full 6m diameter upon deployment. Analysis manager Michael Beers says the thermoplastic composite material offers "a good balance between flexibility, allowing us to stow the webs, and deployed stability and stiffness." The fiber-reinforced tapes use Twaron T2200 aramid fiber (2,420 dtex), supplied by **Teijin Aramid** (Arnhem, The Netherlands), and Ultem 1010 PEI from **SABIC** (Pittsfield, MA, US).

"Most aramid-reinforced PEI is produced in tapes, which are then used in a secondary process, like filament winding or overwrapping," says Ochoa, "but we use it right off the production line." He notes this material was chosen because of its unique combination of the desired strength, stiffness, coefficient of thermal expansion and coefficient of moisture expansion and the necessary consistency.

"The tapes define the parabolic shape of the reflector surface, which forms the beam that scans the earth," explains Beers. "This is why it must be so stable and consistent. The aramid fiber offers high stiffness and strength, plus withstands the temperature of our post-processing." The webs are reinforced at their intersections by ultrasonic welding, made possible by use of a thermoplastic. Ochoa says the PEI also wet out the aramid fiber well.

Ochoa says this is the tenth AstroMesh deployable dish to successfully deploy in orbit. Previous dishes have been as large as 12m in diameter, but were used on commercial satellites as RF antennas. This, he says, is the first for a science mission and, suspended on a 3m-long boom, also made using TenCate composite materials, the first deployable *spinning* reflector. "This arrangement," says Ochoa, "allows it to spin at 15 rpm and scan the whole earth in 2-3 days." The SMAP reflector is also a low-mass AstroMesh Lite version, weighing in at a mere 25 kg — the system with boom totals 58 kg. "Mass is very important for most spacecraft applications," Ochoa notes. "We had to provide very good mass data on all of the parts, performing a thorough survey, down to weighing nuts and bolts." Beers also points out that because the reflector is larger in size than the spacecraft itself, "its mass and balance is critical to avoid the 'tail wagging the dog' in orbit."

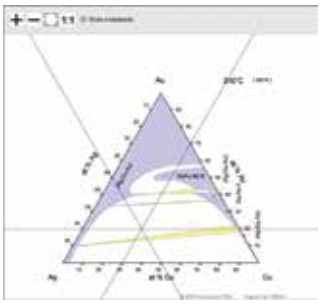
Ochoa says TenCate provided consistent, high-performance materials with a very high yield for each of the contracted production runs of this custom-made product. This also helped in the complicated deflection predictions that were required to ensure the reflector dish's performance. "We had to predict the exact orientation and shape of the reflector, which is already difficult just for a stationary dish in orbit at zero gravity," says Beers. "But we also had to account for the deformations in the structure and mesh due to spinning, including how much the boom will deflect with the mass and spin of the dish and how the reflector reacts as a result." JPL claimed in the end "fantastic agreement with predictions." Astro Aerospace Northrop Grumman says it looks forward to using thermoplastic composites in future deployable space structures. CW

Product Showcase

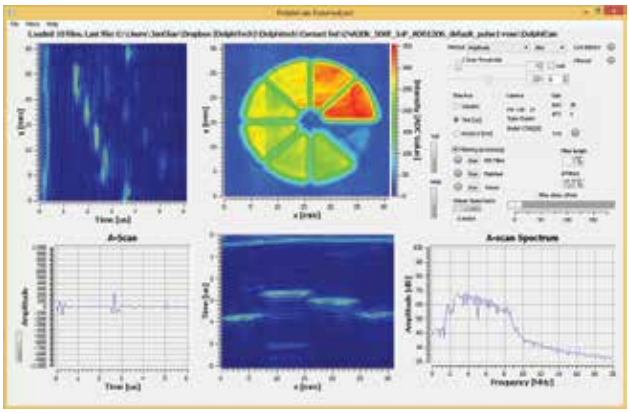
» DESIGN & ENGINEERING SOFTWARE

Materials data management tool update

Granta Design Ltd. (Cambridge, UK) has released GRANTA MI Version 8.1, software for managing complex, valuable, strategic materials knowledge in engineering enterprises. New features include easy Web-app control over user groups and support for workflows, such as composites qualification. GRANTA MI reportedly enables an enterprise to manage all of its materials data (e.g., from testing, research, QA or design), all relationships between those data and any supporting information. A key feature is access control for different user groups; for example, design teams see only data relevant to specifying materials in design; other project data remains within organizational boundaries. This is said to protect intellectual property, ensure regulatory compliance and improve utility. Granta also reports that it is easier to get data into a GRANTA MI database. The MI:Explore web-app interface now supports uploading and editing of data, including drag-and-drop for images. More users can contribute data and more data-entry workflows can be supported. A new, multi-step importer capability also is said to make it easier to get complex data into the system.



www.grantadesign.com



» NONDESTRUCTIVE TESTING SOFTWARE

Advanced signal analysis/post-processing

DolphiTech (Raufoss, Norway) has released DolphiCam Research, a software package for manufacturers and researchers engaged in advanced nondestructive testing (NDT). Built on the DolphiCam Handheld Ultrasound Camera, the new release adds advanced signal analysis and postprocessing functions: Users can now modify pulses, save and postprocess full 2D matrix (124 by 124 element) raw data sets, apply custom filters, and export VTK (Visualization Toolkit) files to create 3D visualizations in Paraview or compatible software. Features include full DolphiCam camera control and imaging, user-defined pulses, the ability to save raw data (filtered or unfiltered) and access and post-process that data, using sample Matlab/Octave scripts and/or using DolphiCam DataAnalyzer software. Separately available, DolphiCam DataAnalyzer software has extended features that further facilitate analysis of ultrasound data from the DolphiCam. These include advanced gating and gate-locking, dataset post-processing, A-scan spectrum, file averaging and VTK file export to Paraview or similar. DolphiCam DataAnalyzer is freely available for download at the company Web site.

www.dolphitech.com/software

» RESIN SYSTEMS TECHNOLOGY

Marine gel coat

HK Research (Hickory, NC, US) has introduced to the marine industry its new ReFlex, part of the company's Revolution series of gel coat polymers, which via a "proprietary grafting technique," have had their molecular makeup "completely re-engineered." As a result, says the company, the gel coat can "flex" thanks to the elasticity of its molecular structure, and it also provides better weathering properties and water resistance than conventional gel coats, but does so at a price competitive with those products, a fact the company considers quite a breakthrough. Although ReFlex is available in a variety of colors, HK Research says it is most often applied in its pure white form.

www.hkresearch.com

» FIBER REINFORCEMENTS

Highly aligned flax tapes and NCFs

NetComposites Ltd. (Chesterfield, UK), in collaboration with **Tilsatec** and **FORMAX** (Leicester, UK), has developed a highly aligned, flax fiber-based tape and noncrimp fabric. The material is said to be suitable for thermoset composite applications and reportedly offers improved properties compared to conventional woven natural fiber-based composite materials. NetComposites says its materials have a higher stiffness per unit of weight than similar materials reinforced with glass fiber. The material is designed for a range of applications, including automotive, sporting goods and consumer goods. Variants with thermoplastics, such as PLA and polypropylene, and bio-based prepregs, also are under development.

www.netcomposites.com

» INFUSION PROCESSING TECHNOLOGY

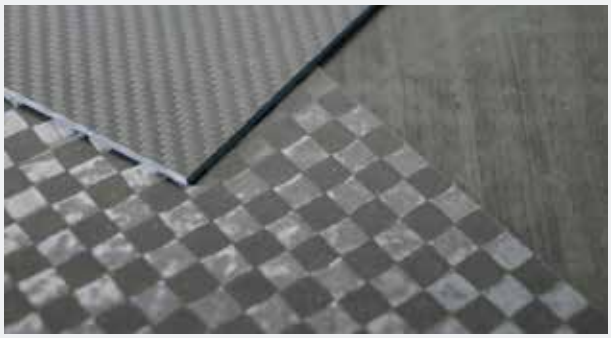
Silicone sheeting for reusable vacuum bags

Composites molding supplies distributor **Rudolph Bros. & Co.** (Canal Winchester, OH, US) says vacuum bags made with Fenner Precision's (Mannheim, PA, US) trademarked FenForm silicone sheeting are reusable and, therefore, provide a cost-effective and environmentally friendly alternative to disposable plastic bags used in both the VARTM (vacuum-assisted resin transfer molding) and SCRIMP (Seemann Composites Resin Infusion Molding) processes. Advantages of the material include the following: Greater UV, ozone, flame, chemical and tear resistance than disposable plastic materials; durability over a wide temperature range (-40°C to 200°C); translucence (resin flow front can be observed), does not crease like nylon, and is competitively priced. The sheeting comes standard in 1 mm-3 mm thickness, in widths to 1,450 mm. It's available in both uncured and cured forms (cured material has a fine fabric impression to aid removal) in standard translucent or gray.
www.rudolphbros.com

» MATERIALS TESTING TECHNOLOGY

Characterization of functionalized graphene materials

Haydale Ltd. (Ammanford, UK) reports that it has developed a rapid, in-house characterization test method to confirm functionalization of graphene materials. Haydale notes that most particles, including surface-functionalized carbon nanoparticles, dispersed in an aqueous system, acquire a surface charge, principally either by ionization of surface groups, or adsorption of charged species. These surface charges modify the distribution of the surrounding ions, resulting in a layer around the particle that differs from the bulk solution. Haydale's new dispersion stability method provides what is said to be a rapid, simple and repeatable test that confirms the effectiveness of its HDPlas graphene functionalization process. Further, the method is able to indicate the level of functional groups added and to discriminate between different functional groups. Complementary to traditional chemical characterization methods currently used by the graphene industry, Haydale says its new dispersion stability tester provides an affordable and reliable quality-control tool for functionalized graphene process development and manufacturing.
www.haydale.com



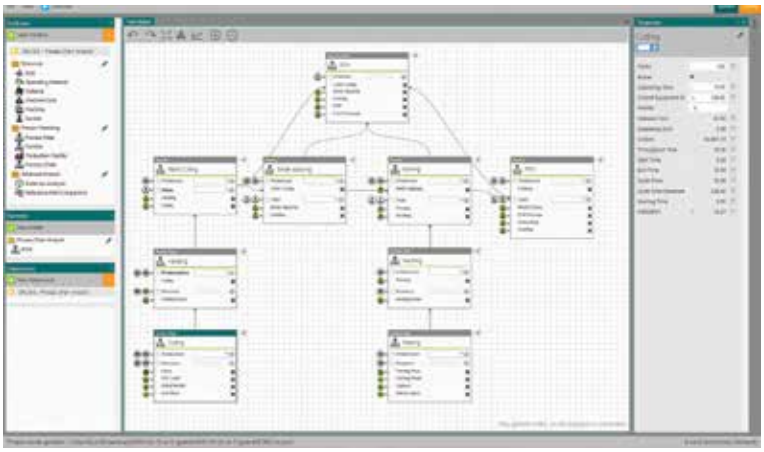
» FIBER-REINFORCED THERMOPLASTICS

Pre-consolidated organosheet

SGL Group (Wiesbaden, Germany) is expanding on its SIGRAFIL C T50-4.0/240-T140 carbon fiber product line, optimized for thermoplastics, with the addition of organic (thermoplastic) sheets reinforced with carbon and glass fibers. SGL notes that components made from the organic sheets can be shaped into almost any final-product geometry, and can be repaired and recycled. Two standard sizes are available, but SGL Group also offers individualized laminate structures, which can be customer-specified in terms of fiber orientation, textile architectures and wall thickness. www.sglgroup.com

» PRODUCTION MANAGEMENT SOFTWARE

Process chain cost-modeling tool



AZL Aachen GmbH (Aachen, Germany) has developed OPLYSIS process-optimizing and cost-modeling software for both technical and economic evaluation and optimization of production process chains. AZL Aachen worked on the software in cooperation with software specialist **engidesk GmbH** (Herzogenrath, Germany); it has been launched worldwide and is distributed under license by **Conbility GmbH** (Aachen, Germany). OPLYSIS is flexible, designed to find out where, in an existing manufacturing process, that chain efficiency can be increased, taking into consideration all parameters, from material to machines to labor. Users can create, analyze and optimize their production processes, according to individual requirements and key performance indicators. Ultimately, OPLYSIS helps users detect where they can save and gain time and money. The software helps visualize and model simple to highly complex manufacturing process chains, from the material input to the single-part cost of the end product; it can be used, for example, to ramp-up production capacities or to evaluate cycle times and cost drivers of new production process chains. Information can be shared with colleagues; individual calculation procedures can be stored and integrated. OPLYSIS also offers the possibility to operate a "white-and-black-box" system, enabling the user to share selected information outside the direct working environment with customers, yet protect sensitive calculation details. The software is available worldwide, and can be ordered in English, German and other languages on request at Conbility's Web site: www.conbility.com

RESIN SYSTEMS TECHNOLOGY

Water-based binder for natural fiber preforms

BASF AG (Ludwigshafen, Germany) has launched a new binder, Acrodur Power 2750 X, designed for the production of natural fiber preforms for lightweight automotive applications, such as interior car door panels or shelves. A low-emission alternative to formaldehyde-based reactive resins, the new binder is said to provide natural fiber composites with high mechanical stability. At the same time, the product offers thermoplastic processability and, unlike conventional thermoplastic binders based on polypropylene, it enables the use of up to 75% natural fibers in lightweight components. BASF also says the use of Acrodur Power 2750 X helps make natural fiber components up to 40% lighter than conventional plastic products. Further, says BASF, the water-based binder is a health-compatible alternative to conventional formaldehyde-based reactive resins: Neither during processing nor as part of the final product does it release any organic substances. BASF says natural fibers bonded with Acrodur Power 2750 X can be processed using traditional thermoplastic cold-forming methods and combined in a single processing step with complex plastic elements, such as reinforcing ribs or supports.
www.basf.automotive.com

» VACUUM-BAGGING SUPPLIES

Rubber-adhesive pressure-sensitive tapes

Airtech Advanced Materials Group (Huntington Beach, CA, US) has introduced Econobreaker 2R, an inexpensive, multi-purpose, pressure-sensitive

tape with a rubber-based adhesive. This tape is designed to hold down vacuum-bagging materials, thermocouples and other lay-up items used in composites fabrication. Econobreaker 2R is suitable for room-temperature applications and heat cures to 177°C. Reported benefits of the tape include good adhesion yet easy removal after part cure, as well as abrasion resistance when used against rough surfaces, and easy conformability to irregular surfaces.
www.airtechonline.com

» RESIN ADDITIVES & MODIFIERS

Nano-based toughener

Zyvex Technologies (Columbus, OH, US) has launched ZNT-boost, an epoxy-composite toughening system based on carbon nanotubes (CNTs) for carbon and glass fiber composites that reportedly delivers increased toughness without compromising the composite's strength and stiffness. Zyvex says that ZNT-boost doesn't force the user to compromise one property to increase another. ZNT-boost reportedly increases the toughness of the composite as much as 100% while increasing the stiffness and strength a much as 30%. In addition, says Zyvex, ZNT-boost can be used with standard composite processing systems and reportedly is the simplest way to leverage the benefits of carbon nanomaterials. No process changes need to be made and no changes are required in catalysts or curing agents when using ZNT-boost. It is available in two forms: liquid and dry flake (powder) for most epoxy-based composite applications that include prepreg, vacuum-assisted resin transfer molding (VARTM), infusion and hand layup. ZNT-boost works with most epoxies, vinyl esters and polyesters.
www.zyvextech.com

» SPRAY EQUIPMENT

Quick-change chopper gun

Graco (North Canton, OH, US) has launched its RS chop gun for the flexible and precise application of fiber-reinforced plastic (FRP) in the marine and other markets. This 13:1 chop system proportioner is said to offer precise on-ratio dispensing with easy transition from wet-out to chop. The system is designed such that no surge bottle is necessary and a low amount of solvent and resin is needed to prime the pump, so material costs are kept low. A dual trigger function enables operators to change from wet-out to chop without turning the chopper off. Additionally, the gun has what Graco says is a uniquely designed blade cartridge in which the are blades are molded directly into the cartridge. Operators can change blades without touching individual blades and without use of a special tool, thereby increasing operator safety and making it possible to change blades in less than a minute.

www.graco.com/composites

» DISPENSING EQUIPMENT

Retrofittable pumping system for liquid/paste application

UK Flowtechnik (Nottingham, UK) has launched the trademarked VISCO.pump, designed by **Beinlich Pumpen GmbH** (Gevelsberg, Germany), the renowned manufacturer of gear and radial piston pumps designed specifically to enable the precise dosing of fluids and pastes proportionate to the rotational speed. Its pumping principle enables precise dispensing of beads and dots as required, as part of an automated process. VISCO.pump is said to accurately dispense liquids and pastes with up to 60% filler content. The dosing quantity can be set to be absolutely linear, with dosing accuracy/repeatability of ±1% or less. The company claims the pump's linear volumetric efficiency and high predictability on delivery makes the pump almost "plug-and-go" — it is reportedly much easier to use than other pump designs and the cost of installing and commissioning it is comparatively low, and it can be retrofitted into existing systems, if required.

www.ukflowtechnik.com

» FIBER-REINFORCED THERMOPLASTICS

Long glass-fiber polymers

Trinseo (formerly Styron, Horgen, Switzerland) has launched the ENLITE line of structural polymers, targeted at semi-structural applications. The line is designed to be customizable to the application. Its first two products in the line are branded ENLITE long glass-fiber polypropylene (LGF-PP), and ENLITE glass-fiber (GF) alloys. ENLITE LGF-PP provides glass-fiber loadings to a maximum of 60% in a polypropylene matrix. But Trinseo says that customers, working with the Trinseo technical team, have the flexibility to achieve the direct proportion of glass-fiber content they need for a particular application by diluting the product with neat PP. ENLITE GF is designed, says Trinseo, to "provide a bridge between the glass-filled polypropylene solutions of today and the enhanced carbon-fiber solutions of the future." For example, when the design of the part necessitates thick walls to meet stiffness requirements, or must replace a steel or aluminum original, GF alloys are said to provide a possible solution. The first product designed in the GF alloys range is the GF-ABS alloy, which is a glass fiber-reinforced concentrate, the fiber volume fraction of which can be adjusted by dilution with ABS.
www.tinseo.com

» RESIN SYSTEMS TECHNOLOGY

Two new cycloaliphatic epoxies

Daicel USA (Ft. Lee, NJ, US) has launched two new grades of cycloaliphatic epoxies, Celloxide 8000 and Celloxide 8200, offering good heat resistance and strong flexural modulus properties. These improvements, says Daicel, have been achieved without sacrificing the superior transparency of the Celloxide brand. Molded properties of Celloxide 8000 neat resin include a T_g of 354°C (TMA) and a flex modulus of 3,705 MPa, as compared to a T_g of 155°C and a modulus of 2,532 MPa for a bisphenol-A epoxy. The Celloxide 8200 is said to exhibit an even higher modulus of 4407 MPa. Daicel says the Celloxide epoxy systems are known for their propensity to be molded with less energy in a short time, resulting in a cured product with good mechanical strength. Furthermore, the cycloaliphatic epoxies manufactured by Daicel are reportedly naturally very low in viscosity and solvent-free, thereby allowing for green processing.
www.dalcel.com

» COMPOSITE STRUCTURES

Composite panels with antibacterial surfaces

LAMILUX's (Rehau, Germany) new LAMILUX AntiBac composite panel system features a nanosilver-coated surface, designed to provide antibacterial properties. The material was initially developed specifically as a wall coating for operating theaters in hospitals. LAMILUX notes that medical experts estimate that 15,000 patients die from hospital infection every year. Other applications could include refrigerated warehouses and vehicles as well as in processing areas and slaughter houses. The material is under trial at the Asklepios Clinic in Bad Abbach, Germany. LAMILUX developed the technology with nanosilver specialist Rent-a-Scientist (Regensburg, Germany). www.lamilux.de

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SHOWCASE

Prepreg compression molding makes its commercial debut

Ultra-thin, preformed laminate designs enable CFRP decklid manufacture at lower-than-expected mass and at cycle times approaching mass-production speed.

By Peggy Malnati / Contributing Writer

PCM test case
The Nissan *GT-R* supercar's decklid was a good test platform for the new out-of-autoclave, prepreg compression molding (PCM) technology. The high-end vehicle's two models made it possible to start small and grow into fairly high-volume production.

Source (decklid, top) | SPE Automotive Dv. / (car) Nissan Motor Co. Ltd.

» One of the biggest hurdles for automakers is developing faster production processes to mold laminate-based carbon fiber-reinforced polymer (CFRP) parts, particularly those with thermoset matrices, which need extra time to crosslink. Conventional autoclave-cured prepreg produces parts with exceptional mechanical performance, but is capital- and labor-intensive, generates significant consumables waste, requires a great deal of energy and has production cycles typically measured in hours.

Fortunately, in the past decade, out-of-autoclave (OOA) processes have been developed that offer autoclave-like performance and quality at less cost and several orders of magnitude faster cycle times (see "Learn More," p. 64). One of these is prepreg compression molding (PCM), which makes use of specially formulated CFRP prepregs that are preformed, transferred to a conventional hot compression molding press, and become Class A parts.

Developed by Mitsubishi Rayon Co. Ltd. (MRC, Tokyo, Japan), PCM made its commercial debut on 2014 model year decklid inner and outer panels for the *Nissan GT-R* supercar, produced by Nissan Motor Co. Ltd. (Yokohama, Japan). But the composite decklid's successful debut was the result, in part, of resourceful design work under a somewhat restrictive set of goals and imperatives.

Developmental-turned-commercial part

Researchers at MRC started developing the PCM process and its special prepreg around 2007. During development, the viscosity of the prepreg's epoxy resin was increased to prevent resin running out of the tool during high-pressure molding. Further, rapid-cure hardeners were used to achieve either a 3- or 5-minute cure — the latter offering longer shelf life at ambient temperatures. The 5-minute-cure prepreg grade used in this project, called Pyrofil TR361 E250S, was developed by MRC at its Toyohashi Research Center.

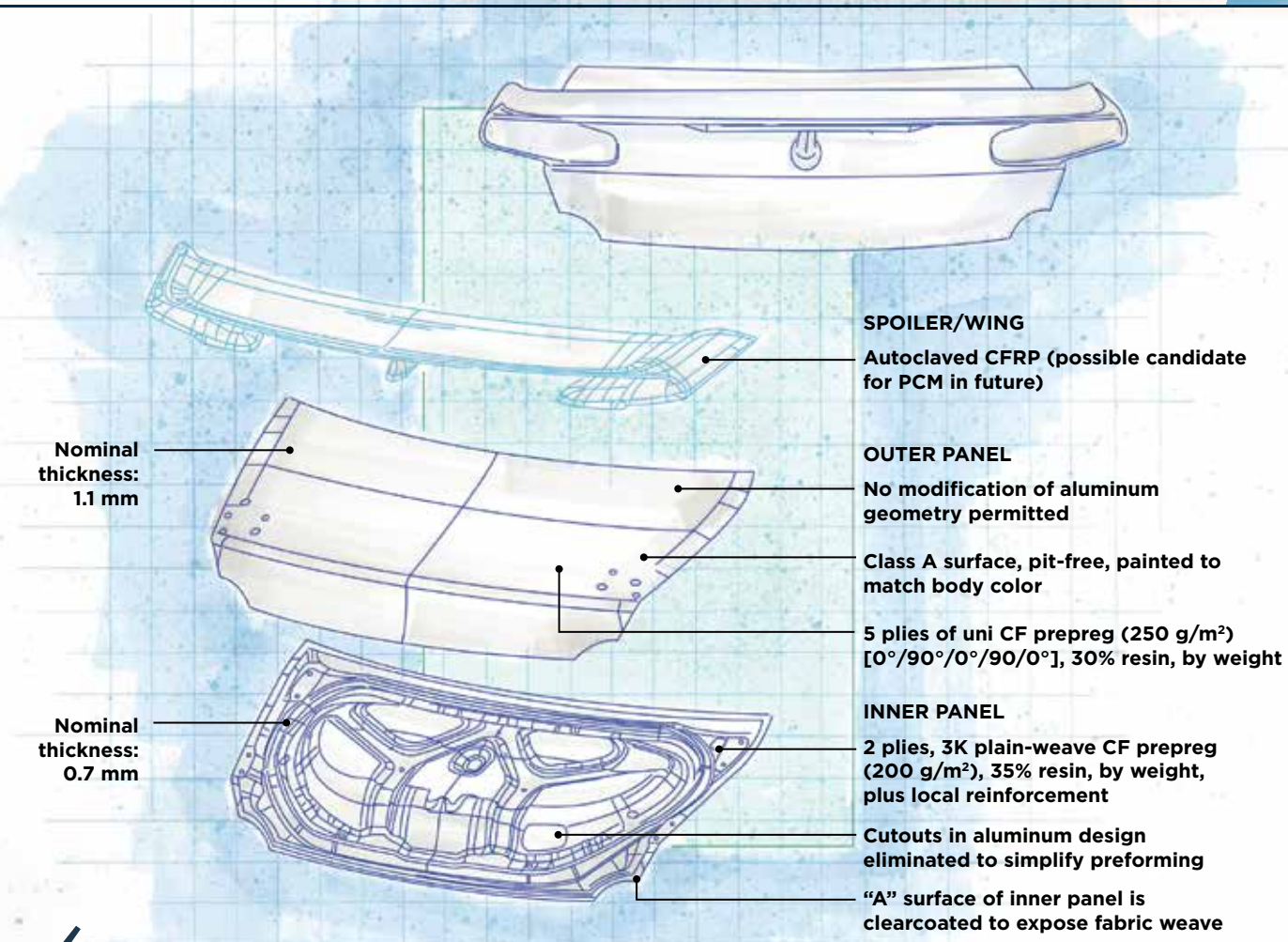
As work progressed beyond simple test plaques, researchers looked for a prototype automotive part with more complex surfaces to validate the material/process and to demonstrate to OEMs that the system made sense for high-volume part production. MRC had a longstanding relationship with Nissan, and the automaker, for its part, had its own aggressive programs for improving vehicle fuel efficiency. Because it recognized that CFRP held promise for mass reduction if cost and cycle-time could be managed, Nissan agreed to share with MRC the geometry and CAD files for the design of a decklid (trunk lid) on its flagship *GT-R* supercar. The understanding was that if MRC's development work showed promising results, then Nissan's engineering team would consider using a PCM'd CFRP part on an upcoming vehicle.

MRC's design team worked with the *GT-R* decklid data between 2009 and 2011. At that point, both organizations believed the material/process had evolved to commercial-part readiness. The design for a 2014 *GT-R* model's aluminum decklid was selected, and work on a CFRP version began in 2012.

Program goals & challenges

As the commercial program began, Nissan and MRC were joined in a team effort by system supplier Chiyoda Manufacturing Corp. (Ota, Japan), material processor Challenge Co. Ltd. (Sayama, Japan) and tooling supplier Yasuda Moldtec Inc. (Kinokawa, Japan). Goals were to produce a part with equal or better mechanical performance but at least 30% less mass than the benchmark aluminum assembly. Because this is a performance car often used on the racetrack, energy management/crash performance was important. Although the failure mode of CFRP parts differs from that of aluminum, the decklid must manage energy well enough to survive a high-speed rear collision, without shattering into small projectiles/debris.

Molding speed also was important. Although the first commercial decklid was for the highest performance and, therefore, lowest-volume *GT-R* model, Nissan was interested in expanding it to higher volume models, and that required a fast process. Further, no one expected CFRP parts to be less costly than aluminum, but they had to remain affordable. Finally, aesthetics mattered. The decklid's inner and outer panels had to meet automotive Class A requirements. The outer shell would be painted to match body color; the



DESIGN RESULTS Nissan *GT-R* Compression Molded Prepreg Decklid

- Decklid inner panel's exposed, clearcoated, CFRP fabric weave provides consumer-pleasing trunk aesthetic.
- Mass reduction of 40% and lower vehicle center of gravity vs. legacy aluminum part exceeds program goals despite design restrictions.
- Class A surfaces on inner and outer achieved without pinholing common to autoclave prepreg processing.

Illustration / **Karl Reque**

inner shell would feature clearcoated/exposed-weave CFRP, the imperfections of which would be readily visible.

These imperatives posed a challenge: This was a *running change* on the original aluminum part, that is, there was little leeway for significant alterations, let alone for a complete system redesign. In fact, no modification was permitted on outer panel geometry and only minor adjustments could be made to the inner panel. For example, the aluminum predecessor featured cutouts on the inner panel, but the team decided to leave them solid in the CFRP design because creating cutouts would take longer and complicate preforming. Other small changes were made to enhance stiffness and achieve appropriate failure modes during crash testing. The restrictions eliminated opportunities to consolidate subcomponents and integrate attachment hardware (which is bonded during final assembly), either of which could have helped reduce finishing and final-part costs.

Because geometry couldn't be modified and the composite panels would be very thin — outer panel, 1.1 mm; inner panel, 0.7 mm — the team anticipated challenges, including handling the thin, preformed prepregs during transfer from preforming station to mold. Another worry was achieving a Class A surface on the inner panel, given its exposed weave and complex contours. It took much trial and error, but the fabric used on the inner panel worked well with minimal resin flow and fiber distortion.

For the outer panel, five plies of unidirectional carbon fiber reinforcement (fiber areal weight of 250 g/m^2; resin content of 30 wt-%) are used in a 0°/90°/0°/90°/0° layup. The inner panel features just two plies of 3K plain-weave carbon fabric (fiber areal weight, 200 g/m^2; resin content, 35 wt-%), plus local reinforcement in several locations, using an additional two plies of the same prepreg.

The decklid was evaluated first, via computer-aided analyses and physical tests. For example, Nissan placed a fully assembled/bonded part in a special test apparatus and compressed it until it broke; this enabled comparison of failure modes for CFRP and aluminum assemblies. Results were used to optimize the design of the decklid's inner panel and the bonding scheme. Durability »

Challengingly thin ...

The decklid's outer panel, based on the aluminum lid's geometry, was limited to a very thin 1.1 mm — just five plies of unidirectional carbon fiber reinforcement were used in a 0°/90°/0°/90°/0° layup. Source | Nissan Motor Co. Ltd.

... and even thinner

At 0.7-mm thickness, the aluminum inner panel's geometric limits posed an even greater challenge. Here, a mere two plies of 3K plain-weave carbon fabric, plus local reinforcement, were enough to meet requirements. Source | Nissan Motor Co. Ltd.

(including repetitive open/close, ball impact and hot/cold and humidity resistance) was likewise evaluated. The capstone was a long-term driving test on Germany's famed Nürburgring track (Nürburg, Germany). The driver reported the test car handled better with the lighter decklid, which lowered the vehicle's center of gravity.

In production, prepreg is first layed up, debulked and cut out. Next, the prepreg is preformed by heating for 1 minute until it reaches 60-70°C and immediately shaping it in an air-cylinder press under light pressure (0.3 MPa) using a two-sided tool made from polyurethane modeling board. Preforms are then cooled to room temperature for a total preforming time of <5 minutes. An optional step, when aesthetics are critical, involves covering the preform with a silicone rubber sheet and pulling a vacuum to smooth out wrinkles prior to demolding. If they won't be molded right away, they are stored in containers to keep their shape. Normally, a few preforms accumulate, press-side, before being molded. The molding cycle in a hydraulic compression press is 8 minutes at 140°C, using 8 MPa forming pressure.

LEARN MORE

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"Class A CFRP body panels: Six-minute cure" | short.compositesworld.com/WTJigQb9

Because both panels are molded to net shape, post-mold trimming is limited almost entirely to removal of a thin parting line flash. Thanks to high molding pressures, parts reportedly exit the mold with a very smooth surface and none of the pinholing seen in autoclave-cured parts. Only light sanding is done to ensure mold release residue is removed prior to painting. Demolded, deflashed parts are bonded together with an epoxy structural adhesive.

Interestingly, the decklid features a fixed CFRP spoiler/wing. On lower-performance *GT-R* models, the part is blow-molded in acrylonitrile butadiene styrene (ABS) and painted to match the body, but the premium model with the CFRP decklid features an existing autoclave-cured, clearcoated CFRP spoiler with visible weave. Although only the decklid was produced by the PCM process for the 2014 *GT-R* changeover, it's possible the wing will be re-engineered for PCM on future models.

Challenge buys prepreg from Mitsubishi, cuts patterns, lays up laminates, preforms and molds inners, outers *and* the autoclaved spoilers, and then bonds the decklid panels. The unpainted assemblies are then shipped to Chiyoda, which paints the exteriors, clearcoats the inners and spoilers, bolts on the spoilers, and then ships the completed deck/spoiler assemblies to Nissan's vehicle-assembly facility.

Many benefits

Despite the curbs on design freedom, the team exceeded its 30% mass-reduction goal, reducing weight by 40%. Mass-decompounding effects followed, thanks to assembly lightweighting: The lighter decklid opened and closed much faster with the struts used on the existing aluminum decklid, so Nissan switched to lighter struts and mounting hardware, reducing mass further. For the car owner, the CFRP decklid opens and closes with less effort, emissions are reduced, and fuel efficiency, aesthetics and handling (via the lower center of gravity) improve.

The PCM process reportedly can produce 84,000 parts per year per tool, using the 3-minute-cure prepreg, and 50,000 per year per tool, using the 5-minute-cure prepreg. That and the fact that PCM components can be molded on conventional — read, *readily available* — compression presses means CFRP is now accessible to more molders and practical for higher volume platforms. CW

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