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Automating Preforming:
FOUR PREFORMS PER MINUTE?

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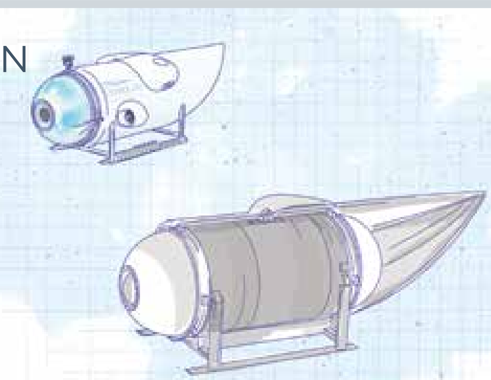
Robotics, modified "quick-release" automated fiber placement head technology, and a variety of material types, including towpreg, dry fiber and thermoplastic tape, come together in this workcell developed by Compositence (Loenberg, Germany) to build as many as four preforms per minute. Learn more about how systems scientists bring the complicated art of preforming up to production speed on p. 26.

Source / Compositence

FOCUS ON DESIGN



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It's almost impossible to travel anywhere within the world of composites these days without confronting the topics of employment, training, employee retention or automation. At trade shows, conferences and plant visits, there has been (for several years now) ongoing discussion about how to find and retain employees who either know and understand composite materials or demonstrate a willingness and aptitude to learn about them.

Baby Boomers, workforce development and automation.

This challenge is made all the more urgent by three complicating factors. First, Baby Boomers. The Baby Boomer generation, which includes anyone born between 1946 and 1964, is rapidly retiring from the workforce. In the US, they leave at the rate of about 10,000 per day, according to the US Social Security Admin. Baby Boomers represent the foundation of the modern composites industry, and with their departure goes not just the ability to do a job but, perhaps more importantly, the accumulated intellectual capital and experience that is extremely difficult — if not impossible — to replace.

Second, young people entering the workforce are not naturally drawn to composites manufacturing. As important as composites are to us, they represent a fraction of the overall global manufacturing economy. Drawing young people to composites requires outreach and marketing that we are unused to doing. That said, there are many universities and community colleges that teach about composites and produce technicians and engineers who understand the materials, but demand still far outweighs supply.

Third, employees, in general, are just difficult to find. In the United States, the unemployment rate has dropped to 4.3%, which represents, theoretically, "full employment." In my home state of Colorado, the rate has dropped to an all-time low of 2.3%, and it's rare, here, to see a retailer who does not have a "help wanted" sign posted on its door. In the 29 countries of the EU, the unemployment rate is higher, hovering around 8%, so ostensibly the supply of workers there is not as tight.

Against the backdrop of these workforce concerns, automation presents itself as an ideal solution, yet it also presents its own set of challenges.

To be sure, automation could solve a couple of major problems we face. First, it would enable us to move away from the touch labor required for hand layup of prepreg materials. This is easier said than done, because the dexterity and utility of the human hand is difficult to duplicate in an automated solution. But humans are also notoriously inconsistent and prone to error, so the business case for driving touch labor out of composites manufacturing is strong.

Second, and directly related to the first, automation can bring to many composites fabrication processes a level of repeatability, and cycle time and process control that could put the composites manufacturing industry on par with more established manufacturing processes and materials, such as CNC machining or plastic injection molding. In this way, composites manufacturing might become more "standardized" and less of an outlier in the broader manufacturing world. (And yes, I use the word "standardized" with some hesitation because I know some of us don't like to think that composites manufacturing might one day be commoditized.)

Third, automation is, in fact, already happening. Despite the technical challenges, a number of enterprising machinery suppliers are already offering, for example, production-line-worthy automated preforming processes (see "Preforming goes industrial," on p. 26).

Automation's principal problem, of course, is that it displaces humans in the workforce. Indeed, with little effort, one can find online a variety of dark predictions about the pervasive and insidious nature of automation throughout society — not just manufacturing — which might lead you to thoughts of *The Terminator*. The more optimistic among us, however, believe that automation will stimulate new opportunities for human work and endeavor that are nearly impossible for us to predict or anticipate. Time will tell.

In the meantime, I am eager to see how the composites industry addresses its workforce challenges, and we'll do our best to keep you up to speed.

JEFF SLOAN — Editor-In-Chief

Composite musings

» A week before writing this, I went to the hardware store to buy a pointed shovel. I had the choice of a shovel with a wooden handle, or one with a composite handle — pultruded fiberglass. I elected to buy the higher-priced composite-handled shovel, partly because I'm a composites geek but also because the shovel I was replacing has a composite handle that I broke prying up tree roots. The failure mode was benign in that the resin and fiber delaminated, but did not fully break under the heavy load. I could laminate some glass and resin over the top and it would still maintain some utility for light work. I know from empirical experience that the same force on a wooden handle would have snapped it in half, rendering that shovel completely unusable.

> How do we generate *pull* from consumers rather than depend on *push* through builders and contractors?

That shopping experience led me to take inventory of what other composite products I own — those that can be purchased by anyone. Turns out I own a set of bypass pruners that have fiberglass handles, as well as two tree pruners with lightweight, extendible fiberglass poles, which are also electrically insulative, in case you are trimming branches up around power lines — a positive attribute, for sure!

Among my other tools, I have a stepladder with pultruded side rails, and several types of hammers with fiberglass handles. These are really great for vibration damping. And my sporting goods collection is replete with composites, including a half-dozen carbon fiber tennis racquets (used frequently), a set of golf clubs with carbon fiber shafts (used less than I like), a couple of carbon/glass fishing rods (that I haven't used in years — need to correct that), two pairs of fiberglass downhill skis (used each winter) and a pair of carbon fiber downhill ski poles that have performed flawlessly for almost 15 years. I had a *prototype* pair of carbon fiber ski poles that I managed to break in under a season, prior to these. Considering the shovel and the poles, it sounds like I might have a future career as a product tester.

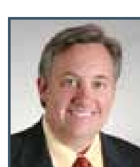
Speaking of sporting goods, why do manufacturers still use the term *graphite* when the product being used is what we insiders call *carbon fiber*? It's such an archaic term from the 1980s. The Ford *Econoline* driveshaft that won the SPE Automotive Division Grand Award in 1984 is listed in the archives as a "vinylester/graphite/glass" product when the fiber that was used was a standard-modulus, AS4-type of carbon fiber. Several of my newer Wilson tennis racquets, in fact, have "Braided Graphite + Kevlar" printed on them, when it is obvious that standard-modulus carbon fiber is used. The truth is that the overwhelming majority of carbon fiber is produced with a carbon content of 93-97%.

To be labeled graphite, the fiber needs to see heat treatment well above 2000°C, and typically has more than 99% carbon assay. When processed at these temperatures, the fibers develop highly oriented graphitic structures and achieve very high modulus, as well as high densities (often above 1.9 g/cm^3). Examples include Hexcel's HM63 and Toray's M60J in the PAN family, and the high-modulus and high-conductivity grades of pitch-based fibers. Very stiff and lightweight fishing rods and some golf shafts really *do* use high-modulus graphite fibers, often in combination with standard- and intermediate-modulus carbon fibers.

Although most of us deep in the industry call it carbon fiber, I've seen forums on fishing equipment sites where buyers are confused about terminology. In April of this year, I advocated here that we need a public relations effort to create more awareness of and provide education about composites among consumers. Perhaps something along the lines of the American Chemistry Council's "Plastics Make It Possible" campaign would help. Maybe "Composites – Built to Last" or something like that?

An article in the May issue of *CompositesWorld* about composite foundation walls for residential housing made me want to go out and build a new house just to take advantage of what these panels offer in durability and energy efficiency — what an exciting development! Like the fiberglass-handled shovel, the cost of composite foundation walls is a bit more, so how do we help the producers of these innovative building solutions reach critical mass and generate *pull* from consumers, rather than depend on *push* through builders and contractors? This is what a strong public relations campaign could do for our industry.

And speaking of housing, I've come full circle. I've got some yard work to do around my current residence. Time to put that new shovel to use.... CW



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

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Making an Impact in Michigan and Beyond

- Hosted at Michigan State University in partnership with Composites One
- The free, two-day workshop was focused on scale-up, lightweighting and high volume composite products and processes
- Attendees experienced LIVE demonstrations and facility tours of IACMI's Vehicles Technology Area

"It's rare to have the opportunity to spend time with so many industry experts in such a well-equipped facility. My team had more quality conversations here in a day than we may have in a week at a typical industry conference. This was my company's first IACMI/Composites One event and it was well worth our time."

– Steve Snow, Owner of Dynamic Corvettes

Learn more about IACMI events at *iacmi.org/events*

IACMI members have access to Composite Manufacturing Equipment at the Vehicles Scale-up Facility in Michigan

- Enabling technology development on full-scale prototypes
- 4,000 ton Schuler hydraulic press installed
- IACMI and RocTool launched a strategic partnership aimed for lightweighting research and collaboration with automotive

Now accepting project proposals for the Vehicles Scale-Up Facility

IACMI-The Composites Institute is managed by Collaborative Composite Solutions Corporation (CCS). CCS is a not-for-profit organization established by the University of Tennessee Research Foundation and part of the Manufacturing USA network.

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How ready are progressive damage analysis tools?

» In the past 15 years, progressive damage analysis (PDA) for composites, implemented in finite element analysis software, has been under development. Some PDA proponents argue that "virtual testing" of this sort is, today, reliable enough to reduce or even replace the conventional "building block" approach to composite design that relies on physical testing. Although that could, in some cases, save significant time and cost in the development of composite structures, the results of a recent evaluation of the state of the art in this area, overseen by the Air Force Research Laboratory (AFRL, Wright-Patterson AFB, OH, US), indicates that comparative experimental fatigue data do not yet justify such confidence.

Benchmarking PDA progress

An AFRL benchmarking exercise titled, "Damage Tolerance Design Principles (DTDP)," conducted by Steve Engelstad of the Advanced Development Program at Lockheed Martin Aeronautics Co. (Lockheed Martin, Ft. Worth, TX, US) and myself from January 2014 through April 2015 asked the question, *Can current PDA methods accurately predict initiation and growth of damage in composites?* An intensive effort, it involved both static and fatigue blind predictions, using several PDA methods. To evaluate existing tools for composites damage progression modeling and prediction for future application of damage growth analysis needs, AFRL, as an impartial organizer, provided identical physical test data results to program participants who would use the data for PDA model calibration/validation. The static data included 0° tension and compression, 90° tension and compression, V-notch shear, 90° three-point bend, Mode I double cantilever beam, and Mode II end-notched flexure. The fatigue data included 0° S-N, 90° S-N, ±45° S-N, 90° three-point bend S-N, Mode I double-cantilever beam fatigue, and Mode II end-notched flexure fatigue. Since brittle failure in 90° matrix-dominated tests resulted in low strength values and high fatigue scatter, AFRL is currently conducting follow-on research to improve test methods.

Although there is not room here to examine the entire project, comparisons of fatigue predictions derived via PDA against physical open-hole fatigue test data for three different layups will serve to illustrate what we learned. The ultimate goal of this effort was to generate quality fatigue test results, along with high fidelity X-ray CT images that would enable us to assess the ability of the PDA methods to predict damage and residual strength after fatigue.

The layups were of IM7 HexTow carbon fiber (Hexcel, Stamford, CT, US) and Cytec CYCOM 977-3 epoxy resin (Solvay Composite Materials, Tempe, AZ, US), in the following ply sequences: $[0°/45°/90°/\text{-}45°]_{2S}$, $[60°/0°/\text{-}60°]_{3S}$, $[30°/60°/90°/\text{-}60°/\text{-}30°]_{2S}$.

It should be noted that in the static phase of the AFRL benchmarking exercise, nine analysis teams had already performed blind static predictions and then recalibrated the parameters in their models based on the results of 12 experimental load cases. Lessons learned during the program's static portion included more accurate determination of material properties for some model inputs, appropriate mesh sizes and orientations, and accurate representation of boundary conditions. Additionally, some PDA teams identified and corrected algorithm errors within their analysis codes. Seven of the teams then applied these lessons learned to their fatigue predictions during the benchmarking exercise's second phase. The teams and their PDA methods are listed in Table 1 above.

TABLE 1	Analysis teams and codes used for fatigue predictions
Teams	PDA Methods
Vanderbilt University	Eigendeformation-based Reduced order Homogenization (EHM)
University of Dayton Research Institute (UDRI)	B-Spline Analysis Method with Mesh Independent Cracking (BSAM with MIC)
Global Engineering and Materials (GEM)	Discrete Crack Network (DCN)
NASA Glenn/University of Michigan (UM)	Micromechanics Analysis Code with Generalized Method of Cells (MAC/GMC)
Multi-scale Design Systems (MDS)	Multi-scale Design System for Linking Continuum Scales (MDS-C, now part of Altair)
AutoDesk/LM Aero	Helius PFA (formerly ASCA)
AlphaSTAR	GENOA

Calculating correlations

The benchmarking analysis protocol proceeded as follows: Each PDA participant initially submitted blind fatigue predictions for each of the three layups, after which the experimental (physical test) results were provided to each team, and then each participant was permitted to submit "recalibrated" fatigue predictions.

For 10 samples of each layup, the fatigue cycling was stopped after a predefined number of cycles to allow measurement of the static residual stiffness and strength properties. Five replicates were tested in tension and five replicates were tested in compression. The goal was to impart a measurable amount of damage into the open hole composite specimens in a reasonable amount of time so that the ability of the PDA codes to predict the right type, amount and location of damage as a function of cycles could be assessed.

As a result of screening tests, the maximum stress level in terms of percent of static ultimate strength for the $[0°/45°/90°/\text{-}45°]_{2S}$ layup was 50%, for the $[60°/0°/\text{-}60°]_{3S}$ layup was 80%, and for the $[30°/60°/90°/\text{-}60°/\text{-}30°]_{2S}$ layup was 40%. Static ultimate strength was 554 MPa for the $[0°/45°/90°/\text{-}45°]_{2S}$ layup, 543 MPa for the $[60°/0°/\text{-}60°]_{3S}$ layup, and 409 MPa for the $[30°/60°/90°/\text{-}60°/\text{-}30°]_{2S}$ layup. The residual tensile and compressive properties of the coupon with the $[0°/45°/90°/\text{-}45°]_{2S}$ layup were measured after 300K cycles while the residual properties of the coupons with the other two layups were measured after 200K cycles. Residual tensile stiffness also was »

TABLE 2	Average error reported for all layups by all teams				
	Strength (% error)	Stiffness (% error)			Overall average %error
After "x" cycles	200K/300K	200K/300K	1,000K	1,500K	
Blind	39	35	44	62	42
Recalibrated	19	14	17	26	18

TABLE 3	Average of errors reported by all teams for each layup				
After "x" cycles	Tension or compression	Bind or Recalibrated	[0/45/90/-45]2s (% error)	[60/0/-60]3s (% error)	30/60/90/-60/-30]2s (% error)
Residual strength 200K/300K	Tension	Blind	16	74	26
		Recalibrated	13	35	9
	Compression	Blind	15	69	33
		Recalibrated	10	30	15
Residual stiffness 200K/300K	Tension	Blind	10	72	21
		Recalibrated	4	23	5
	Compression	Blind	19	65	22
		Recalibrated	16	24	12
Residual stiffness 1,000K	Tension	Blind	30	82	21
		Recalibrated	9	37	5
Residual stiffness 1,500K	Tension	Blind	60	92	35
		Recalibrated	37	37	5

measured after 1,000K cycles and 1,500K cycles. The purpose of the higher cycle count tests was to assess the ability of the PDA codes to predict stiffness degradation resulting from increasing levels of damage from continued fatigue loading, or to predict the life of the specimen if two-part failure occurred. The $[0°/45°/90°/-45°]_{2S}$ specimens resulted in two-part failure prior to 2,000K cycles while the other two layups experienced a stiffness reduction but not two-part failure. This result proved to be a good indicator of the PDA capabilities, because many codes predicted two-part failure in some cases where the physical test specimens did not completely fail.

To enable observers to assess the ability of the PDA methods to capture the correct damage type and location in the open-hole fatigue specimens, X-ray tomographs were obtained intermittently during the physical fatigue testing portion of the program. "Recalibrated" models captured the location of damage relatively accurately, and the discrete damage models, BSAM and DCN, due to the discrete damage nature of their formulations, more distinctly captured the narrow features of matrix cracks than the other models.

The fatigue blind prediction and recalibration comparisons, in terms of average percent error, are presented in Tables 2 and 3. Table 2 shows the overall average residual stiffness/strength percent error across all teams and all layups, as a function of different cycle points. For the fatigue results, on average, the blind predictions of residual properties after fatigue differed from the test by 42%, and the recalibrations differed from the test by 18%.

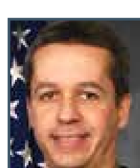
For a given layup, PDA participants' blind fatigue predictions generally correlated better to the physical test results at low cycle counts, with the poorest correlations seen after cycle counts greater than 1,500K. As Table 3 demonstrates clearly, the $[60°/0°/-60°]_{3S}$ layup showed by far the poorest correlation between the blind and recalibrated predictions and the physical test data. (It should be noted that in the static phase of the AFRL benchmarking exercise, the blind predictions differed from the test by 18%, and the recalibrations differed by 8%. Thus, the fatigue simulations differed from test more than the static simulations by a general factor of two.)

Conclusions

It is important to state one finding relative to a lack of capability found in many of the micromechanics codes. It was discovered that most of the codes were in the initial stages of development of fatigue capabilities (during the program timeframe), and did not yet have discrete interlaminar fatigue capability. However, some micromechanics codes attempted to simulate delaminations through element stiffness degradation. This capability is very important for many of the applicable aircraft problems. AFRL and Lockheed Martin are interested in assessing the current state-of-the-art and determined this area to be a technology gap.

All the PDA teams had more issues with residual stiffness/strength predictions after fatigue for the $[60°/0°/-60°]_{3S}$ layup than they did with the other two layups, both for the blind predictions and recalibrated results. In particular, many of the blind predictions failed to capture the correct fatigue failure mechanisms for the $[60°/0°/-60°]_{3S}$ layup. Note that this fatigue benchmark exercise was for an R-ratio of 0.1 (all tension) constant amplitude cycling. Much additional work is needed to handle compressive and spectrum loading. To improve the "predictiveness" and maturity of these fatigue analysis tools, a more extensive set of experiments and associated modeling studies should be designed to handle these general spectrum loading effects.

For the fatigue results, the blind predictions differed on average from the test by 42%, and the recalibrations differed by 18%. Thus, for fatigue, it was concluded that the current accuracy of the fatigue PDA tools is low for predicting the response of these notched R=0.1 constant amplitude tests. There are many formulations with a wide variation in the level of verification and validation for each. Improving these fatigue formulations is a necessity if PDA tools are to be used to accurately predict the effects of fatigue on aircraft structures. CW



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Dr. Stephen Clay is a principal aerospace engineer for the Air Force Research Laboratory (AFRL, Wright Patterson AFB, OH, US). After graduating with a BSME from the West Virgina Institute of Technology in 1992, he joined AFRL to conduct research on polymeric canopies and later focused on composite structures. Clay has an MS and Ph.D in engineering mechanics from Virginia Polytechnic Institute and State University and is an Associate Fellow and active member of the American Institute of Aeronautics and Astronautics (AIAA, Reston, VA, US).

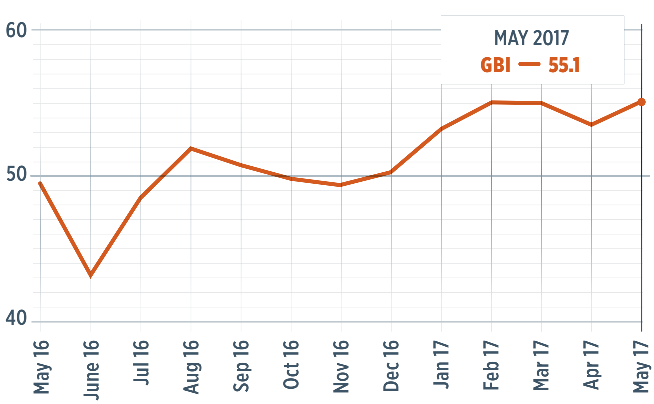
May 2017 — 55.1

US Composites index records its best reading in at least five years.

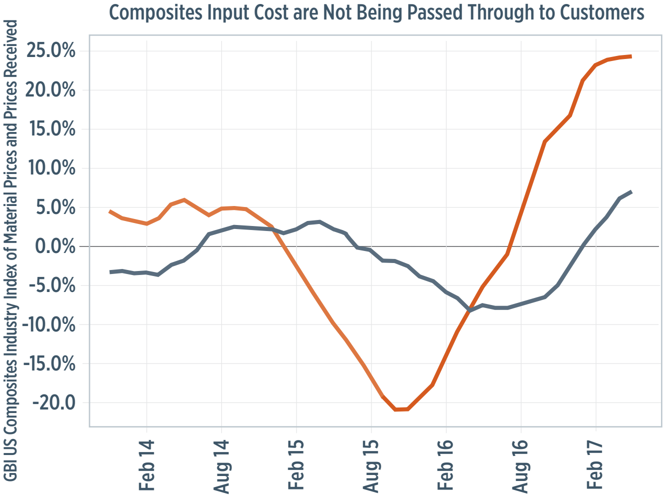
» Registering 55.1 in May, the Gardner Business Index recorded its highest value for the US composites industry in more than five years. Underlying that headline number, the drivers of the overall Index through the end of May include Material Prices, Employment, Production and New Orders.

The Production, New Order and Employment components of the Composites index increased by 13%, 12%, and 7%, respectively, for the three-month period ending May 2017, using a 12/12 rate of change calculation. Production and New Orders are two of the most significant components of the Gardner Business Indices, and they suggest strength in the composites industry. A 12/12 ROC is calculated by summing the data for the most recent 12 months and then dividing that number by the sum of the values in the previous 12 months.

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



Composites Input Cost are Not Being Passed Through to Customers



Conversely, the Exports and Material Prices components of the Index are damping further optimism. The Exports component, which has in the past 12 months averaged a reading of just over 46, represents a weak spot in the Composites Index. Gardiner Business Intelligence (GBI) will be watching currency markets very closely in 2017 for many reasons, including the progression of Brexit, America's changing stance on free trade and trade agreements, and the US government's efforts to make markets more fair for American companies. Any and all of these political factors could generate unexpected shocks to currencies and, thus, to import and export dynamics and volumes.

The Material Prices and Prices Received index components, based on May 2017 data, indicate that input cost increases are being felt broadly and that manufacturers have yet to pass these costs on to their customers to the same degree. A comparison of the Material Prices and Prices Received index components, using a 12/12 ROC, reveals that the Material Price index has increased by more than 24% while the Prices Received index has only increased by 7%. Given the size of this gap, the Index might be signaling that the prices of finished composite components could rise in the future as Material Prices increases are passed downstream.

GBI's view of the composites industry's future is bright. A recent study by the Congressional Budget Office indicated that between 20 and 40% of future GDP growth in the US will come from workforce expansion, with the remaining 60 to 80% of growth coming from productivity gains.

This growth in productivity will result from the use of better, smarter and more capable machines, computers and other tools that enhance the abilities and expand the productivity of workers. As increasing wages and a limited labor supply begin to make themselves felt in the economy, equipment consumers should consider working closely with equipment manufacturers to find ways to meet their growth objectives. Now is truly an opportune time for those who use composites manufacturing equipment to collaborate with those who manufacture it, to create the next generation of technologies that will power composites industry growth in an ever-expanding number of markets. CW

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Michael Guckes is the chief economist for Gardner Business Intelligence, a division of Gardner Business Media (Cincinnati, OH US). He has performed econometric modeling and forecasting work since 2004, first for the State of Ohio, then for one of the 20 largest banks in the US and, most recently, one of Cincinnati's largest insurers. Michael received his BA in political science and economics from Kenyon College and his MBA from Ohio State University. **mguckes@gardnerweb.com**

A challenge to "outside the box" thinking about prepreg, a thought-provoking composites program at AIA, and rethinking a crane stinger with carbon fiber for a more "uplifting experience."

AEROSPACE

Thinking outside the prepreg box in aerospace


Source | Boeing

Dr. Thomas Tsotsis, technical fellow, materials and process technology at Boeing Research & Technology (Huntington Beach, CA, US), was a keynote speaker at the Society of Plastics Engineers' (SPE) ANTEC conference in Anaheim, CA, on May 10. Tsotsis' presentation title was simple: "A path for composites." It might also have been titled, "My composites wish list."

Admittedly, the composites manufacturing strategy of a company as big as Boeing cannot be ascribed to one person at Boeing, but Tsotsis' long experience with aerocomposites gives his words weight, and what he had to say was intriguing.

First, he reviewed the history of prepreg use, noting that it became the preferred material form because it enabled manufacturers to achieve consistent resin/matrix ratios in finished products. Prepregs also have been well qualified and are well supported by material characterization data. He also acknowledged that prepregs are difficult to form into complex shapes, have a limited working life and must be kept frozen when not in use, and require expensive "monument" equipment — ATLs and autoclaves — that tend to become workflow bottlenecks.

Liquid molding, on the other hand, he said, offers fabricators the use of three-dimensional (3D) preforms, braids and weaves (i.e., the material flexibility to meet a greater variety of end-use requirements) eliminates the use of an autoclave and requires no freezer. Downsides? Fiber/resin ratios are more difficult to control with liquid molding, composites made via liquid molding are not as well qualified, and liquid molding processes require additional quality-control steps that prepregs don't require. Further, he admitted that companies like Boeing have invested millions of dollars in autoclaves, thus their use is, in many ways, imperative.

In short, said Tsotsis, he believes the aerospace industry needs to "get out of the prepreg box" and look more seriously at new chemistries, collaborate to develop reliable design models, increase automation, reduce assembly costs, more proactively address environmental concerns, and more effectively leverage already developed knowledge from other composites end-markets.

From the design side, Tsotsis said he would like to see more innovation in chemistry so that resins can be tailored to designs, rather than having to tailor designs to chemistries, which he believes is the current *modus operandi*. In addition, he said he would like to see molecular dynamics tools better developed and definitively linked to verifiable test data. And model development, on the whole, he said, is too "siloed" and needs to be addressed more cooperatively and collaboratively with suppliers, OEMs and researchers. Finally, he said, "modeling of strength needs a quantum improvement to be truly useful."

On the aerocomposites manufacturing floor, Tsotsis said, quality control drives everything, and because of that, process control is paramount. But, unlike the automotive industry, where quality is measured by process consistency, aerospace relies on 100% inspection of finished parts, regardless of process quality. The difference, of course, is the degree of risk involved, and in aerospace, it is assumed there is no room for error.

Tsotsis ended his presentation with a reminder of the value of change, and a desire for a willingness to see technical maturation continue: "Just because we've done something that way does not mean it's the best way."

INDUSTRIAL

Unweighting a crane to increase payload limit

The payload capacity of a crane depends on the strength and stiffness of the materials used to make the arm. It also depends, ironically, on the arm's weight. That is, the greater the arm's weight, the less payload it can bear. Conversely, you can increase the payload capacity of the crane by reducing the mass of its arm. In other words, the crane arm is an ideal application for composites.

The Manitowoc Co., a crane manufacturer located in Shady Grove, PA, US, recognized this advantage and decided to target the *stinger* or *fly jib* — the final segment of a articulating crane arm — on one of its truck-mounted cranes, replacing the traditional 24-ft (7.3m) steel structure with one of carbon fiber composite.

Sammy Munuswamy, senior principal engineer, global engineering and innovation at Manitowoc, says the company is "in the business of building lifting experiences for our customers around the world." And a quality "lifting experience," in Manitowoc's view, should be one where the tool (crane) facilitates the jobs to be done at a variety of jobsite environments, including buildings, roadsides, heavy construction sites and more. "Cranes are getting lighter," Munuswamy says, "and we need materials to meet that expectation. The stinger section was identified as an


Source | The Manitowoc Co.

ideal candidate for conversion into a carbon fiber lightweight structure since the outermost crane arm components generate the highest bending moments on the crane. Therefore, reducing weight in such members brings the most tangible benefits."

The stinger was developed by Manitowoc in collaboration with Riba Composites Srl (Faenza, Italy), which has extensive experience designing and manufacturing large composite structures. Munuswamy says one of the challenges the company faced was the reality that cranes, as a cost-sensitive, low-volume product, do (*continued on p. 16*)

(*continued from p. 15*)

not allow for expensively engineered structures. In addition, the composite stinger is a drop-in replacement for its predecessor.

Because the carbon fiber stinger works as a component retrofit compatible with existing cranes, RIBA's engineers exploited all the available design space, maximizing the moment of inertia and the geometric properties of the stinger. The result is a hybrid structure where steel and composite match to take advantage of the specific properties of each material. The junction between steel and composite relies on bonding and bolts, which allow an efficient solution.

Andrea Bedeschi, general manager at Riba, says the composite stinger is hand-laid, using carbon fiber prepreg and autoclave cure. The carbon fiber, standard-modulus 12K and 24K tow, is supplied by Mitsubishi and Toho Tenax. The resin is a toughened epoxy. Riba performed NDT evaluation of the stinger; physical load, stability and structural performance testing was done by Manitowoc.

The composite stinger is 35% lighter than its steel predecessor and, says Munuswamy, increases payload capacity 12-15% more than the steel version in some specific boom configurations. The composite stinger also is more expensive than its steel predecessor, but Munuswamy says this is more than compensated for by increased jobsite efficiency and transportability.

Will Manitowoc expand carbon fiber use to other crane components? "This [the stinger] is leading us in that direction," Munuswamy says. "The stinger was the first step."

BIZ BRIEF

Production-grade 3D printing solutions provider **Methods 3D Inc.** (Sudbury, MA, US) announced a partnership with **Markforged** (Somerville, MA), the inventor of a proprietary continuous carbon fiber filament 3D printing method. Methods 3D will provide sales, service and support for the Markforged line of 3D printers, including the Onyx series, Mark Two and Mark X. The partnership is expected to expand North American manufacturers' access to both companies' printing solutions and enable Methods Machine Tools' Automation Group to design, integrate and sell solutions for its CNC machining automation systems, with the ability to print unique end-of-arm tooling for robots, jigs, fixtures and more.

Surface Generation (Rutland, UK) completed delivery of its largest-ever PtFS (Production to Functional Specifications) tooling system to advanced composites manufacturer **Quatro Composites** (Poway, CA, US). The modular PtFS system can be reconfigured for use in multiple projects and will be used on thermoplastic composite structures as part of a high-volume North American aircraft program. It is the first such system to incorporate more than 200 individually heated and cooled areas within tool faces, enabling compression and injection molders to adapt zoned heating and cooling levels and maintain more precise thermal control when forming complex components.

CW MONTH IN REVIEW

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

Décision SA expands into architectural market
The Switzerland-based composites manufacturer recently signed agreements for several composite roofs and other major structural elements.
06/12/17 | short.compositesworld.com/DecisArch

Hexcel to launch CFRP/metal hybrid solution
The technology combines a fast-curing carbon fiber/epoxy prepreg and a new film adhesive called Redux 677.
06/12/17 | short.compositesworld.com/HexcelHybr

Daher announces new thermoplastic composite wing rib
The rib will be used in the test wing box built as part of the Composite Aircraft of the Future platform.
06/12/17 | short.compositesworld.com/DaherTCRib

Chomarat joins UK-based Advanced Manufacturing Research Centre
The company, which will be the first textile producer to join AMRC, is also sponsoring a research collaboration focused on multiaxial carbon fiber fabrics.
06/12/17 | short.compositesworld.com/ChomAMRC

Airbus: 35,000 new commercial aircraft needed over next 20 years
Increasing numbers of first-time flyers, rising disposable income and new routes are expected to drive demand for US$5.3 trillion in new aircraft.
06/12/17 | short.compositesworld.com/Airbus2036

Web Industries opens ply cutting and kitting operation
The new facility includes five cutting tables, laser guidance devices and quality control systems that ensure every ply in a kit is in the correct order.
06/08/17 | short.compositesworld.com/WebPlyKit

DowAksa, Vestas sign agreement to develop carbon fiber spar caps for wind turbine blades
DowAksa expects to provide more than US$300 million worth of pultruded carbon fiber-reinforced spar caps over the projected four-year contract.
06/07/17 | short.compositesworld.com/DowAksaCap

***Stratolaunch* composite aircraft rolls out, to begin fuel tests**
The aircraft has a wingspan of 385 ft (117.4m) and is reportedly the largest composite aircraft ever built.
06/05/17 | short.compositesworld.com/StratoRoll

Revolutionary fuselage concept unveiled by MTorres
Made with carbon fiber composites but *without fasteners or molds*, this paradigm-changing monocoque could cut raw material cost by 10-30%.
06/05/17 | short.compositesworld.com/NuFuselage

SGL Group leads research into carbon fiber-reinforced thermoplastic components for the automotive industry
The project aims to develop the technology necessary to support thermoplastic composites for serial production at all levels of the value chain.
06/05/17 | short.compositesworld.com/SGL-TPC

ARCHITECTURE

ACMA's 4th Annual Composite Pavilion

Source | Fresh Air Building Systems LLC

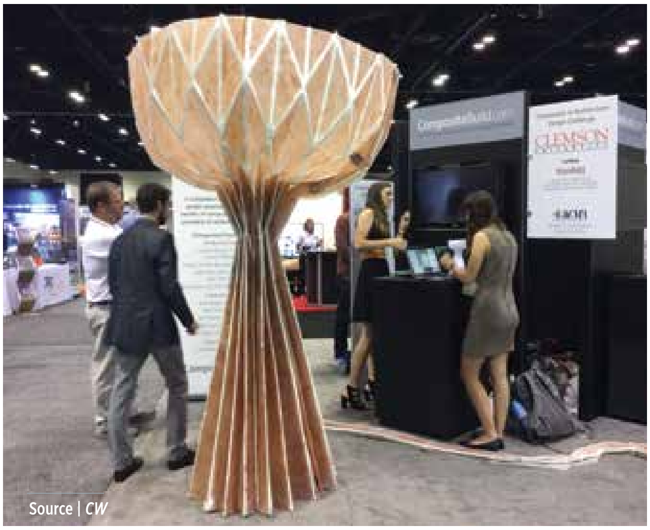
Composites continue to make inroads in fields of architecture and construction. At the 2017 American Institute of Architects (AIA, Washington, DC, US) exhibition and conference (April 27-29, Orlando, FL, US), there was again abundant evidence of that fact. The American Composites Manufacturers Assn's. (ACMA) Architectural Division exhibited its 4th annual Composites Pavilion, which included Composites Central, a schedule of educational sessions presented by Division members, and the second annual Composites Challenge.

Coordinated by David Riebe, vice president of Windsor Fiberglass (Burgaw, NC, US), the Composites Challenge design competition annually tasks teams of architectural students to develop novel architectural/building components and/or assemblies using composite materials. As part of the Challenge, a series of composites-oriented workshops, comprising both seminars and hands-on activities, were held this year at participating architecture schools, educating roughly 75 students — tomorrow's architects.

In addition to the winning teams, which hailed from Clemson University (Clemson, SC, US, see top photo, p. 20) and the University of Southern California (Los Angeles, CA, US), teams from the University of North Carolina Charlotte and Kent State University (Kent, OH, US) also competed. Projects completed by the first, second and third place winners were on display in the Composites Pavilion.

Also featured in the Composites Pavilion was Composites Central, a principal feature of which was a daily schedule of 30-minute educational sessions. Available to AIA attendees, they were presented by members of ACMA's Architectural Division.

(continued on p. 20)


Source | *CW*


Source | ReforceTech

(*continued from p. 19*)

Notable new exhibits in the Pavilion included an Active Modular Phytoremediation System, produced by Fresh Air Building Systems LLC, with composite housings built by Windsor Fiberglass (see photo, p. 19). This plant-based system reportedly provides healthier air filtration than conventional air conditioning systems by reducing airborne toxins and pathogens while increasing oxygen and leaving protective microbiota in place. Lightweight composites form the system's structure, providing both corrosion resistance and easy maintenance. The system reportedly is being installed in the Public Safety Answering Center in the Bronx, NY, US. It's presence at AIA in the Pavilion served to highlight the role composites can play, and are playing, in the growing wellness and health trend in the building construction and architecture markets.

Another eye-catcher was Owens Corning's (Midland, MI, US) contribution: concrete reinforced with MiniBars made by ReforceTech (Luftveien, Norway), a patented composite macro fiber that is mixed directly in to the wet slurry to enable "pre-reinforced" concrete (photo at left). It reportedly can eliminate the need for steel rebar reinforcement, decreasing structural weight and thickness yet increases durability and service life in built structures.

Read more online | short.compositesworld.com/AIA17Blog

CORRECTION

In *CW*'s recent coverage of the Google Lunar XPRIZE, (*CW* April 2017, pp. 34-38), it was reported that the privately funded, qualified participants in the Lunar XPRIZE race to Earth's Moon must be the first to *land* a spacecraft on the Moon's surface on or before Dec. 31 of this year. However, our article author and *CW* senior writer emeritus Donna Dawson tells us that this stipulation was altered in recognition of the participating teams' diverse mission plans, prior to article publication, and requires only that space system *launch* take place on or before Dec. 31. Landing a craft on the Moon's surface can occur after that date, but the winning mission must have been initiated before year's end. *CW* regrets missing the change in requirement.

ENERGY

Long-term North American wind outlook

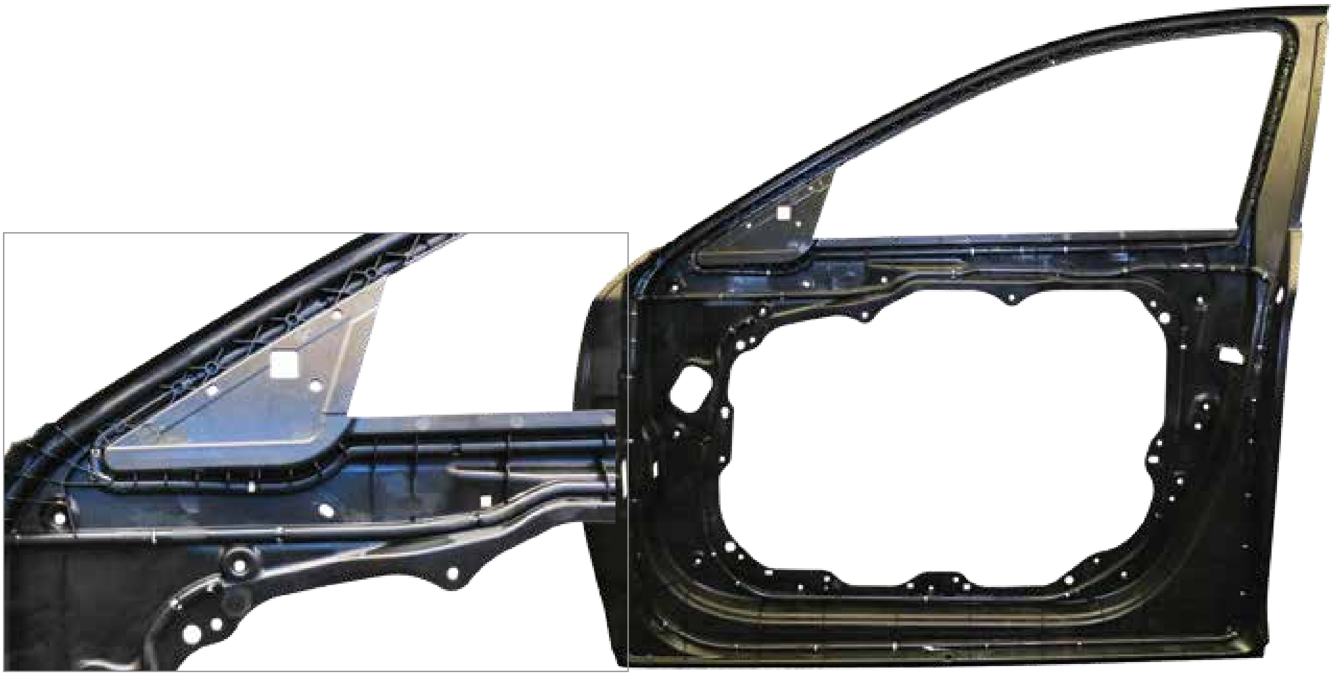
Wind energy industry consultancy MAKE (Chicago, IL, US) has issued its *2017 North America Wind Power Outlook*, and in it, says the US will install approximately 59 GW of wind capacity from 2017-2026. Much of this will be driven in the initial four-year period, through 2020, by the still full-value production tax credit (PTC), which is expected to help account for 40 GW of the total.

MAKE expects that asset owners also will embark on the most extensive repowering campaign, thus far, in the US: Nearly 1 GW of existing turbine nacelle and blade units will be replaced with new components, while smaller components will be replaced in another 6 GW of existing turbines with the aim of extending operational lifespans and requalifying for the PTC.

The PTC, starting this year, begins a phase out: Wind projects begun in 2017 get an 80% PTC credit; projects begun in 2018 get a 60% PTC credit; and projects begun in 2019 get a 40% PTC credit. Because of this, projects could be excessively concentrated in 2020, which could strain resources. Beginning in 2022, wind power effectively will be left to compete solely on a levelized cost of energy (LCOE) basis. MAKE says that competition amid sustained low natural gas prices and the rapidly falling cost of solar power will reduce new wind installations to the fraction of US states that then have favorable land availability, wind resources and transmission capacity. MAKE predicts that states in the central US "wind belt" will be particularly well-positioned to compete on LCOE, but to do so, will require major transmission build-out to access distant demand centers.

All wind projects will become more vulnerable in this coming low-margin environment: Previously surmountable hurdles, such as state-level policy changes and permitting difficulties, will run a far greater risk of becoming project-killing obstacles.

Offshore wind power, however, will be the exception to the economics-driven installations of the post-PTC period, says MAKE. Supported by robust state-level policies in the Northeast region, the first full-scale offshore projects will reach commercial operational level in 2021, and at least one new offshore wind farm development will be installed annually through 2026. Ultimately, according to MAKE, some 2.2 GW of offshore wind will enter commercial operation in US territorial waters within the forecast period.



3D TPC structural preforming process lightens car doors in volume process

Automated cell manufactures and pre-impregnates continuous-fiber 3D preforms for injection/compression overmolding of parts with complex shapes, and tailored structural properties.

By Karen Wood / Contributing Editor

» New lightweighting solutions for the automotive industry today must meet a plethora of demands. They must provide opportunities not only for weight savings but also cost savings in the finished part. They also require materials of reasonable cost that have the potential to be recycled. Thermoplastic-based composites could fit the bill, but historically have been held back by inherent processing challenges.

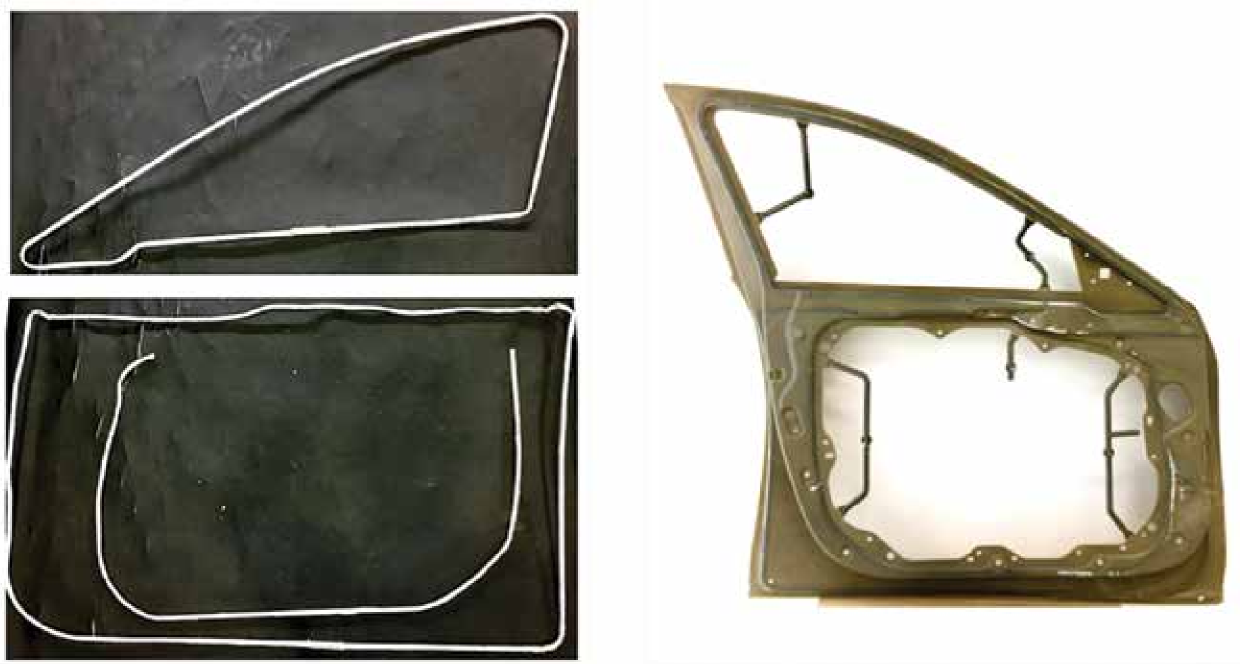
A novel thermoplastic composite preform technology called QEE-TECH, developed by EELCEE Ltd. (Gyeonggi-do, South Korea), and related processing equipment, offers a lightweighting solution that reportedly meets these challenges. QEE-TECH is said to enable complex 3D shaping of thermoplastic preforms. This, in turn, reduces the cost and time required for high-throughput processing of thermoplastic composites. The equipment was manufactured by a joint venture company, QEESTAR, created with Gyeonggi-do-based robotics company Robostar Co. Ltd. To show the capabilities of the technology, which the joint venture is ramping up, EELCEE conducted a demo project with an automotive supplier, involving a car door module.

Continuous fiber only where needed

The thermoplastic composite door produced using QEE-TECH 3-D preforms consists of only six parts, compared to 17 parts in the steel door. The overmolded preforms can be seen in relief, framing the door opening. Source | EELCEE

Too viscous to process

Processing issues have previously devolved from the relatively high resistance to flow of thermoplastic polymers, compared to their thermoset cousins. "The high viscosity of the thermoplastic resins place severe demands on impregnation methods, and subsequent forming operations raise important issues with regard to both preform integrity and tooling," explains Queein Chang-Manson, CEO of EELCEE. In answer, the company is forming



prepregged fiber constructs and then placing the pre-impregnated preform (the prepreg) into the mold and overmolding it. Thus, the problem of poor impregnation of continuous fiber *in* the injection or compression mold is avoided by impregnating the continuous fiber *outside* of the mold and then placing the prepreg in the mold.

"By encapsulating unidirectional fiber and textile composite inserts in injection and compression molded parts, QEE-TECH provides a step-change in the design space for high-volume composite materials and facilitates the integration of multiple functions in a single part," she explains. "This allows the designer the freedom to optimize both cost and performance by placing expensive, high-performance continuous fiber material *only* where it is required while still maintaining the shape freedom afforded by lower cost, lower performance '*flowable*' materials."

"We have demonstrated 20-30% weight reduction (in exceptional cases up to 50%) and 10-20% cost reduction in a range of applications," she adds.

CW first covered EELCEE back in 2013 after the company won a JEC Innovation Award at the 2013 JEC Asia event in Singapore for a thermoplastic bumper system manufactured via 3D QEE-TECH by molder Hanwha for Hyundai-KIA Motor Group, both based in Seoul, South Korea, (see Learn More, p. 25).

More recently, at SPE's 2016 Automotive Composites Conference & Exhibition in Novi, MI, US, Chang-Manson discussed the use of the company's technology in the high-volume manufacture of composite automotive parts.

Automated process

The QEE-TECH 3D preform cell is designed to manufacture parts with complex shapes, multiple functions and tailored structural properties in a single-step operation. The fully automated process begins by pulling multiple continuous carbon or glass fiber rovings or tows from a creel through a series of dies that wet out the fiber with the appropriate resin (PA, PP, ABS, PEEK, etc.).

"Glass fiber has shown to be a preferred alternative when strength is the main requirement, while carbon fiber may be preferred if high stiffness is a priority," says Chang-Manson.

The material passes through a preheating oven during the wet-out process. Next, the homogeneous molten tow is deposited on a jig fixed to a rotating, sliding or tilting table robot. A consolidation roller applies pressure to the tow during deposition. In all, the cell employs three robots — a head robot system that deposits the material, the table robot system, and a support robot system.

By rapidly placing the composite material into the desired 3D shape, an open, tailored 3D skeleton (prepreg) is created. Placed material is cooled via an air-jet system. The finished, solid composite preform is then automatically cut and moved to the overmolding operation.

Fully automated, the QEE-TECH cell can be synchronized to integrate overmolding operations, providing high layup rates at temperatures up to 400°C. The 3D preforming process is completed within a cycle time on the order of 60 seconds. »

Assembling a continuous fiber "skeleton"

The QEE-TECH Cell (see photo on p. 24) quickly lays out the door module's main structural strength components (above left), creating the pieces with which an open, tailored 3D skeleton can be assembled in the mold. Reportedly, the preforming process does not impact the cycle time of the overmolding process when placed in an integrated line. Source | EELCEE

Automated layout, forming, cutting and impregnation

The fully automated QEE-TECH cell employs a jig fixed to a table capable of rotating, sliding and/or tilting. It rapidly places the material into the desired 3D shapes. The resulting preform is then automatically cut, preimpregnated and then moved to the injection or compression overmolding operation. The 3D preform process is completed within a cycle-time on the order of 60 seconds. Source | EELCEE

"QEE-TECH is designed for the production of structural components in high volume," stresses Chang-Manson. "Each cell offers a cycle time of less than one minute, producing from 10,000 to 300,000 parts per year."

Typically, conventional neat or short fiber-reinforced polymers (PA, PP, PET, ABS, etc.) are used in the over-molding operation, typically injection or compression molding. "It is a non-isothermal process," explains Chang-Manson. "The insert is preheated to just below melt, and the overmolding material has a temperature above melt. By doing this, the injection molding pressure enables a low void content and good bonding between the insert and the overmolded polymer, with a cycle time that is the same as for normal injection molding," she adds. Reportedly, the preforming process does not negatively impact the cycle time of an overmolding process like injection molding when it is integrated into a production line. The cell can be integrated with other composites manufacturing technologies, such as RTM and thermoforming.

Composite door module

EELCEE recently partnered with Duckyang Ind. Co. Ltd. and MS Autotech Co. (both automotive parts manufacturers based in South Korea) to develop a composite door module. The research was supported by the Ministry of Trade, Industry & Energy (MOTIE), and the Korea Institute for Advancement of Technology (KIAT) through the "Encouragement Program for The Industries of Economic Cooperation Region."

"The value of this concept lies primarily in the weight, cost and sub-part reduction that it offers with respect to a metal door module in the same price range," explains Chang-Manson. By using continuous fiber preforms as local reinforcements in the thermoplastic door, a weight reduction of up to 20% can be achieved, she adds.

For the door module, EELCEE used a proprietary system it calls M-Tow — a braiding system that encapsulates the incoming unidirectional (UD) fiber tow with a suitable braid of fiber and/or polymer. This allows the tow to be heated and reshaped during the subsequent automated layup process without any loss of composite consolidation and polymer exudation. It also allows the braided tow to be self-supported during any form of 3-D layup.

LEARN MORE

Read this article online | short.compositesworld.com/3D-TDC

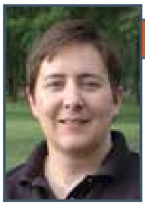
Read *CW*'s previous coverage of EELCEE's technology online in "Structural preform technologies emerge from the shadows" | short.compositesworld.com/Mqzr7Fg7

The QEE-TECH process enables users to place a variety of 3D preforms for dedicated load introduction and load distribution. With proper design, it also can reduce the number of subparts. In this case, the thermoplastic composite door module consists of only six parts, compared to 17 parts in the legacy steel door.

"In developing the part, the whole value chain needs to be considered: manufacturing process and tool design, assembly and end-of-life," notes Chang-Manson. "The introduction of local inserts can improve performance, but they entail an increase in complexity. It is very important to define which aspects of performance should be prioritized to keep complexity to a minimum."

Re-engineering of the door focused not only on reducing its weight but also on engineering in greater strength. Extensive testing is being performed on various preforms with different material combinations and shape configurations to verify process reliability and product performance.

"Our partners are pleased with the prototype parts that have been produced," says Chang-Manson. "They are dimensionally stable and the parts look promising for high-volume production." Hyundai Motor Co. reportedly has followed the door project closely and is considering adopting the technology for production. After testing is completed, EELCEE plans to contact other OEMs. CW



ABOUT THE AUTHOR

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Preforming goes industrial, Part 1

ATL- and AFP-based options now abound for processing dry and/or impregnated reinforcements as quickly as 1 minute or less with potential yearly part yields in the *millions*.

By Ginger Gardiner / Senior Editor

In the race to reduce the cost and cycle time of composite parts, automation has successfully transformed cutting, molding and machining into processes more suited to industrial production. However, when *CW* last looked at the manufacturing step of *preforming* — the process of preparing the reinforcements used to mold three-dimensional (3D) parts — it was still a production bottleneck: a complex, step-intensive, often manual process (see Learn More, p. 30). In the three years since, the emerging technologies that could automate preforming have proliferated and are finally reaching maturation. In Part 1 of a two-part series on the topic, *CW* looks at a wide variety of new commercially available systems that benefit from robotics combined with preform building processes adapted from automated tape laying (ATL) or automated fiber placement (ATL) technology.

Enclosed automated fiber placement cell

In 2015, Broetje Automation (Rastede, Germany), a supplier of specialized production systems (e.g., handling, preforming, assembly, machining) for the aerospace industry, introduced its STAXX Compact 1700 automated AFP workcell for near-net shape preforms (Fig. 1, p. 27). "When we started development, there were many companies focused on automated fiber placement for aerospace," says Dr. Matthias Meyer, VP of Broetje Automation's subsidiary BA Composites GmbH (Grenzach-Wyhlen, Germany), "So we focused on automotive and industrial parts, and also on using a low-cost input material — towpreg." This also motivated the unit's design as an enclosed, climate-controlled cell with a footprint of 3m wide by 6.5m long by 3m high — a *compact* system that could be put into production quickly in practically any facility.

Meyer, who defines towpreg as a carbon fiber roving impregnated with a typically epoxy matrix, notes that the STAXX also can process dry fiber with binder applied ready for subsequent liquid molding, or a thermoplastic product, which, after preforming, is simply thermoformed into finished parts. (STAXX also can process slit prepreg tape because it can remove the backing film, but its use increases cost because it requires post-prepreg slitting operations.)

Comprising two magazines, each housing 16 spools for towpreg feed, an AFP head with a compact clamp/cut/restart unit and a

Complex, tailored preforms in as little a minute

The Quilted Stratum Process was developed by a partnership between the French government, French composites suppliers, including Pinnette Emidecau Industries (Chalon sur Saône), and Nantes, France-based Cetim. It can feed, cut and assemble multi-thickness, multi-oriented unidirectional thermoplastic tapes into tailored preforms in 40-90 seconds. It can produce complex parts with molded-in holes and inserts in cycle times of 1-2 minutes. Source | Cetim

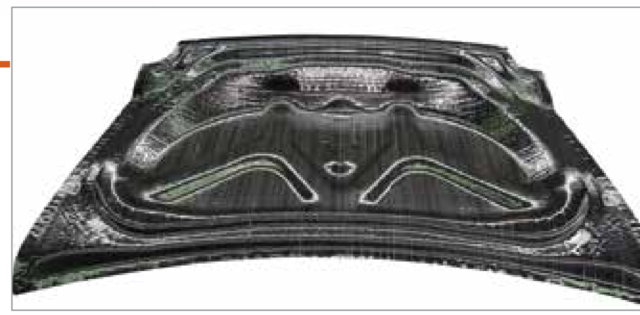

FIG. 1 **Cored preforms for auto parts at 100,000 per year**

The STAXX Compact 1700 automated fiber placement (AFP) workcell, developed by Broetje Automation (Rastede, Germany), can lay up preforms from towpreg or slit tape at 30 kg/hr, with integrated sandwich core and/or inserts, supporting production of as many as 100,000 automotive parts/yr. An exemplary automotive preform is above, with the formed part at top right. Source | Broetje Automation

rotary table, the STAXX Compact 1700 offers a material feed rate of 40 m/min, a layup rate of 30 kg/hr, and a pallet size (part layup area) of 1,525 mm by 900 mm. It also offers a scrap rate potentially below 5% vs. the 50% Meyer asserts is typical in textile preforming for parts of this size. The rotary table and buildup of layered blanks appears similar to Dieffenbacher's (Eppingen, Germany) Fiberforge RELAY Station. Meyer contends that RELAY is using automated tape laying (ATL) with ultrasonic spot-welding, not AFP with continuous compaction, and that the STAXX rotary table also can accommodate 500 mm of z-directional travel, which enables integration of sandwich core and specialized inserts.

"We use a zero-point clamping system for just this reason," Meyer notes, adding that, either manually or via automated pick-and-place robot, "you can take the pallet out and equip it very accurately with inserts, and then put it back into the cell with tolerances below 0.1 mm." He points out that although this is new for AFP, it is considered standard in the metal-cutting industry, as is much of the CNC control designed into STAXX. For example, "It has two bays," he says, "so that you are loading one part while laying up another simultaneously, in order to maximize throughput."

Meyer also claims a big advantage in design freedom with regard to fiber orientation. "STAXX can place fiber at any angle between 0° and 180°, in increments of 0.01°," he claims. Parts demonstrated, thus far, include automotive tunnels, floors and B-pillars. "We have shown that we can supply … B-pillars from a single machine for a luxury car at 100,000 units per year," Meyer contends. "We can also make aerospace parts, like ribs, clips and brackets, as well as industrial parts."

ATL at 10-15 seconds per layer

FILL Gesellschaft (Gurten, Austria) supplies innovative machinery for production in metals, plastics, wood and fiber-reinforced composites. "Preform automation is one of our main fields," says Wilhelm Rupertsberger, head of FILL's composites competence center, noting systems developed for BMW and Audi, including a machine for the carbon fiber-reinforced plastic (CFRP) rear wall of the new Audi model, as well as equipment for CFRP wheels at Tier 1 suppliers to other companies. "All of these machines automate preforms for RTM," he adds.

Although FILL has sold a number of units for cutting, stacking and hot-drape forming unidirectional and noncrimp fabric reinforcements into composite preforms, its latest development is an adaptation of ATL. The MultiLayup System (pat. pend.) uses dual arrays of vacuum rails to convey tape from two magazines of up to 16 reels each. Both material feeders unroll and cut the designated tape from each reel to a tailored length, as determined from the part's CAD file analyzed by FILL process software.

"Connection between CAD data to CNC control is one of our strengths," explains Rupertsberger. The cut tapes required for a given ply in the preform are then transferred by a vacuum gripper system to a segmented rotary deposit table with 100 mm of z-axis movement. The vacuum gripper's integrated heating strips join/consolidate each ply of tapes to the next layer on the table, producing a tailored near-net shape preform (Fig. 2, p. 28). The »

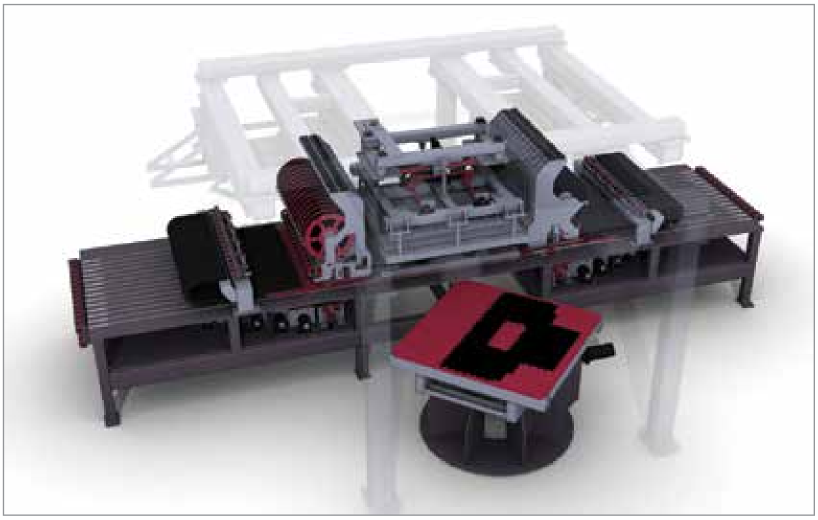

FIG. 2 Picks, places and consolidates 4-5 layers per minute

The MultiLayup System from FILL Gesellschaft (Gurten, Austria) feeds UD tape from two sides to a central station where a vacuum gripper with integrated heating picks, places and consolidates each layer's tapes to build preforms at 10-15 seconds per layer. Source | Fill

FIG. 3 Quick change head processes multiple materials quickly

Preforming systems developed by Compositence (Leonberg, Germany) can process towpreg, dry fiber and thermoplastic tape, using an exchangeable, quick-release AFP head to produce as many as four net-shape preforms, simultaneously, in 1 minute. Source | Compositence

FIG. 4 Millions of parts per year *and* 25% less scrap

Working with BMW and SGL, Compositence has developed stitched, dry fiber multifunctional tow and demonstrated preform production at rates up to 250 kg/hr — 3.5 *million* parts/yr — besting NCF with equal or better drapability and resin flow in subsequent molding but 25% less scrap.

Source | Compositence

system accommodates parts up to 2m by 2m, which Rubertsberger claims readily handles automotive parts, including roofs, hoods and backwalls at the upper limit of this range.

Rupertsberger cites an unusually short cycle time of 10-15 seconds per layer. "The dual feeders effectively double the rate of material delivery to the pick-and-place station," he explains. More importantly, the vacuum gripper collects and places each layer's tapes *simultaneously*, instead of one at a time. "We can also reduce the waste by integrating nesting of cut tapes digitally into the process," he says, adding, "We also check the direction of the fiber and the shape of the completed preform."

In addition to the MultiLayup System, FILL is working with Engel (Schwertberg, Austria) to develop *thermoplastic* tape preforming. "Our equipment makes the layup, and Engel has the machine to add the injection material and thermoform the part," says Rupertsberger. For automotive, the unidirectional tapes use polyamide (PA) as a matrix. He explains that these parts can use carbon fiber, but it is expensive and, therefore, important to place it with precision only where needed. "Our machine feeds, cuts, positions and consolidates the tapes to create a tailored organosheet *inline*, achieving the benefits of injection molding with the properties of composites," he claims. "We are exploring this technology for cycle time reduction and also for the recyclability of parts," he adds, but also notes, "Parts manufacturers would rather have the fiber and matrix already together in a semipreg thermoplastic material in order to simplify and avoid a chemical process in the line."

40-second preforms, 90-second parts

The Quilted Stratum Process (QSP) focuses squarely on thermoplastic tapes, pultruding them inline and then assembling them into preforms for use as inserts in a thermoforming process. Started in 2013, with a pilot production line completed in 2015, QSP is a

FIG. 5 More versatile version of a pioneer preforming process

Eppingen, Germany-based Dieffenbacher's new Fiberforge 4.0 preforming system boasts material throughput of up to 490 kg/hr, layup speed of less than 1 second per course and the capacity to combine up to four different types of tape in one part.

Source | Dieffenbacher

French development led by R&D facility Cetim (Nantes) in partnership with suppliers Pinette Emidecau Industries (Chalon sur Saône), Compose (Bellignat) and Loiretech (Malville) and local government Région Pays de Loire.

QSP feeds, cuts and assembles multi-thickness, multi-oriented inputs into tailored preforms in 40-90 seconds. Fast, robotic transfer (<5 seconds) then moves preforms through a two-step preheat before thermoforming them in a 500-MT Pinette press with a 2,000-bar, 0.4-liter shot KraussMaffei (München, Germany) injection unit for overmolding, using a 200-kW RocTool (Le Bourget du Lac, France) rapid heat/cool induction system.

The line begins with thermoplastic pultrusion of glass or carbon fiber unidirectional (UD) tape at the right thickness (1.5-3.0 mm) and width (100-300 mm) for the process. "With thin tapes, you need three to four layers in the preform," explains Franck Bordellier, lead QSP development engineer at Cetim. "We'd rather have these already plied in the tape." The goal is to produce tape at a cost of €3/kg (US$3.27/kg). "Pultrusion can reduce cost because it is a continuous process," says Bordellier. "If we run the line at 3m/min we can beat glass fiber/polyamide organosheet at €7/kg [US$7.64/kg]."

This tape is fed directly into the Pinette-supplied cutting cell and cut while flat, using an ultrasonic (UT) technology developed by Sonimat (Lencloître, France) that operates at 400 mm/sec. Cut tape patches are then transferred to storage or the preform assembly module, which uses a patent-pending tape placement concept to affix patches with UT welding. "It is very efficient because it is more of a parallel vs. serial build process."

Assembled preforms exit via conveyor and are moved by robot into a conduction oven, which heats the inside of the preform, and then into an infrared (IR) oven which heats the outer surfaces. "Conduction provides maximum calories inside the preform," says Bordellier, "which allows us to put a lot of heat into higher thickness areas without degrading the lower thickness areas." From the IR oven, located just outside the press, preforms lose only 15°C before thermoforming begins. "The preform's thermal profile has a direct effect on part performance," notes Bordellier.

Parts are demolded on the opposite side of the press by a robot with needle grippers from Schmalz (Glatten, Germany). Bordellier describes the line's process control, "We have integrated a thermal camera for IR heat control, a laser system for preform placement and an optical system for quality assurance through the process." He notes that QSP has demonstrated hundreds of parts. Among them is the L-shaped, multi-material automotive seat structure, developed with Faurecia, which integrates 13 patches of 1.5-mm, 2-mm and 3-mm thick organosheet and UD tape into a preform in 40 seconds. The 2.5- to 3-mm thick part, with integral plastic and metal fittings, is formed in a one-shot, 60-second molding cycle.

> Able to keep pace with part counts in the millions, preforming is no longer a production bottleneck.

Four parts/minute and multifunctional tow

Although Compositence (Leonberg, Germany) has developed an AFP-based method to produce near net-shape preforms, it has also moved beyond, working with BMW to develop what it calls *multifunctional tow*, which dramatically boosts drapability and material throughput. The main elements of its system include a spool creel, 2D (gantry) or 3D (robot) manipulating system with exchangeable, quick-release AFP head and a rotary table on a linear rail (Fig. 3, p. 28). Its newest system, ready for production later in 2017, will lay up as many as four preforms (e.g., 1.25m by 0.75 mm) simultaneously, in 1 minute. Both systems can handle towpreg, dry fiber and thermoplastic tape.

Thomas Dobiasch, head of sales at Compositence, says conventional AFP typically uses 0.25-0.5-inch (6.35-12.7-mm) wide tapes, derived from the process' aerospace origins. Developed for » automotive parts, the Compositence system uses tapes ≥12 mm wide with 150-600 g/m² fiber areal weight because, says Dobiasch, "placement of narrow materials takes too long. For us, the speed of the preform layup must be in the same range as the molding machines, which for injection molding is 1 minute." However, he cautions, "Wide tapes can produce more waste for certain types of parts. You must tailor your process for the part you are making."

In pursuit of speed, Compositence has patented its edge fixation technology for AFP. "We fix the fibers only at the beginning and end of placement," says Dobiasch, explaining that the AFP head lifts slightly up to fly freely, "accelerating across the layup in between, which speeds up productivity." However, this edge fixation technique cannot be used with towpreg, because it requires continuous compaction to avoid trapping air in the layup.

LEARN MORE

Read this article online | short.compositesworld.com/PreformPt1

CW's 2013 coverage of this subject, "Structural preform technologies emerge from the shadows," offers a good preforming primer on preforming and discusses a variety of early automation efforts, including the Dieffenbacher PreformCenter | short.compositesworld.com/Mqzr7Fg7

Read *CW's* earliest coverage of the Fiberforge RELAY station online in "Tailored carbon fiber blanks set to move into steel stamping arena" | short.compositesworld.com/LvFR7nP1

Another key driver in preforming productivity is drapability. "Our draping capability must be the same as noncrimp fabric [NCF] or better," notes Dobiasch. Since 2010, Compositence has worked on AFP preforming with BMW (Munich, Germany) and SGL Group (Wiesbaden, Germany). "With them, we have developed what we call multifunctional tow, where multiple rovings are fixed together with a kind of textile process," he explains (Fig. 4, p. 28). The stitching binds the tows to maintain precise width — typically 46 mm for dry fiber — and also aids resin flow vertically through the fibers, crucial in the next step, either resin injection or infusion.

"The fibers are not blocked from moving layer to layer as they are in stitched fabric," Dobiasch explains, "so drapability is very good and confirmed by BMW as being the same or better than NCF. They have also verified the improved resin flow." He concedes the material does require more time and cost to produce vs. towpreg, "but it is better to give the material some functions, and you then get cash back during the processing via less scrap and better cycle time in wet compression molding and RTM."

Dobiasch claims a 25% reduction in scrap vs. NCF due to AFP's net shaping ability compared to cutting waste with fabric. He adds, "We have also demonstrated with BMW that we can preform 3.5 million parts per year on one machine with an output of 250 kg/hr."

Back to the future, Fiberforge 4.0

The original automated tape/fiber preforming process was the Fiberforge RELAY Station, mentioned earlier, which *CW* reported on as early as 2004. A spin-off from high mileage/low-weight automotive development, it made its own tapes from large-tow carbon fiber or glass rovings and melted thermoplastic pellets (e.g., nylon), orienting the fiber into a semi-consolidated sheet, or *tailored blank*, which was then heated and pressed into a composite part. In 2008, it produced a unidirectional glass/polyethylene military backpack frame with integrated ribs in 70 seconds, with reported production of 20,000 units.

Although Fiberforge was liquidated in 2013, Dieffenbacher (Eppingen, Germany) acquired the RELAY technology and has continued its development. Dieffenbacher's Fiberforge RELAY Station, capable of 2m-by-2m parts and laydown rates to 150 kg/hr in 2014, has evolved into Fiberforge 4.0 (Fig. 5, p. 29). This more recent development boasts material throughput of 490 kg/hr with a layup time of less than 1 second per course, and it has the ability to combine as many as four types of tape in one part. Further, version 4.0 reportedly can interface with other Dieffenbacher automated systems to produce more than 1 million parts/yr from a single production line. "Fiberforge 4.0 is a game changer," contends Dieffenbacher's director of technology and business development Matthias Graf, "and we expect that it will bring a breakthrough for composites in the automobile industry."

More to come

The examples mentioned here are not exhaustive. Other early preforming pioneers, such as Coriolis Composites (Queven, France), also are at work on faster evolutions of AFP for automotive preforms, including glass fiber/polyamide prepreg tape loops, which are overmolded to produce composite engine mounts. And new players continue to emerge. Voith Composites (Garching bei München, Germany), for example, launched its Voith Roving Applicator at JEC World 2017 (March 14-16, Paris, France).

More detailed discussions of additional players and other preforming processes, plus news about standardized drapability testing, preform simulation software and specific solutions for aerospace and wind energy structures, can be found online in the *CW Blog Automated Preforming* series | **short.compositesworld.com/AutoPFBlog.**

All that to say this: Given the ongoing activity — already commercial and potential — it's already clear that preforming is unlikely to remain a composites production bottleneck. And in Part 2, *CW* will explore new solutions for forming fabrics, 3D and continuous preforming processes and the latest in tailored fiber placement (TFP) technology. CW

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Polyurethane's processing speed, properties enable bigger blades

Decade-long developmental effort reaches key wind energy cost-reduction milestone using epoxy-besting infusion resin.

By Ginger Gardiner / Senior Editor

» Wind turbine blades remain a key market segment for composites. According to the new report "Wind Turbine Composites Material Market: Global Trends & Forecast to 2020" by MarketsandMarkets (Magarpatta City, India and Seattle, WA, US), the market for composites in wind turbines — comprising mainly nacelles and rotor blades — totaled US$7.2 billion in 2015 and is expected to grow at a CAGR of 9.3% to reach US$12.2 billion by 2021, thanks especially to increasing demand in China, India, South Korea and Japan.

The wind industry consultancy MAKE (Chicago, IL, US and Aarhus, Denmark) estimates that roughly 650,000 wind turbine blades will be produced between 2017 and 2025, with a 12-15% increase in the average rotor diameter. "Blade lengths continue to increase," says MAKE partner Dan Shreve, "offering an enormous market opportunity for blade OEMs and their strategic materials providers."

A key facet of that opportunity is to find new ways to reduce blade cost. Although the cost of building and operating wind turbines has decreased significantly over the past two decades, "blades are still 25-35% of the total wind turbine cost," says Covestro's (Leverkusen, Germany) Kim Harnow Klausen.

Klausen is the head of Covestro's program to develop polyurethane (PU) as an optimized matrix resin for composite wind blade production. Begun in 2009, the program produced a demonstrator glass fiber/PU spar cap for a 45m long wind blade — the focus of this article — using resin infusion in 2015. "We have now made the first polyurethane wind blade in Asia, a 37.5m long blade for a 1.5-MW wind turbine in China," says Klausen. For this blade, all of the components — spar, web, root and shell — were infused using Covestro's PU resin. "We are also going to make a larger blade this year," he adds.

PU infusion resin for wind blades

Polyurethane specialist Covestro (Leverkusen, Germany) has developed a PU infusion resin — soon to be the first certified for wind turbine blades by DNV GL — aimed at cutting production cost by 10-15% while also reducing weight and enabling high performance at increasing lengths. Source | Covestro

Why polyurethane? "The resin we have developed is 10-25% stronger than epoxy," Klausen claims. PU also offers inherently lower viscosity — below 100 cps at 25°C — for faster infusion, as well as a faster cure and less exotherm during cure vs. epoxy, vinyl ester (VE) and polyester systems. Further, as blade length increases, so does the need for improved properties and fatigue performance, as well as fabrication speed.

MAKE sees the potential of polyurethane in blade production. "We have identified this as an early-stage material advancement

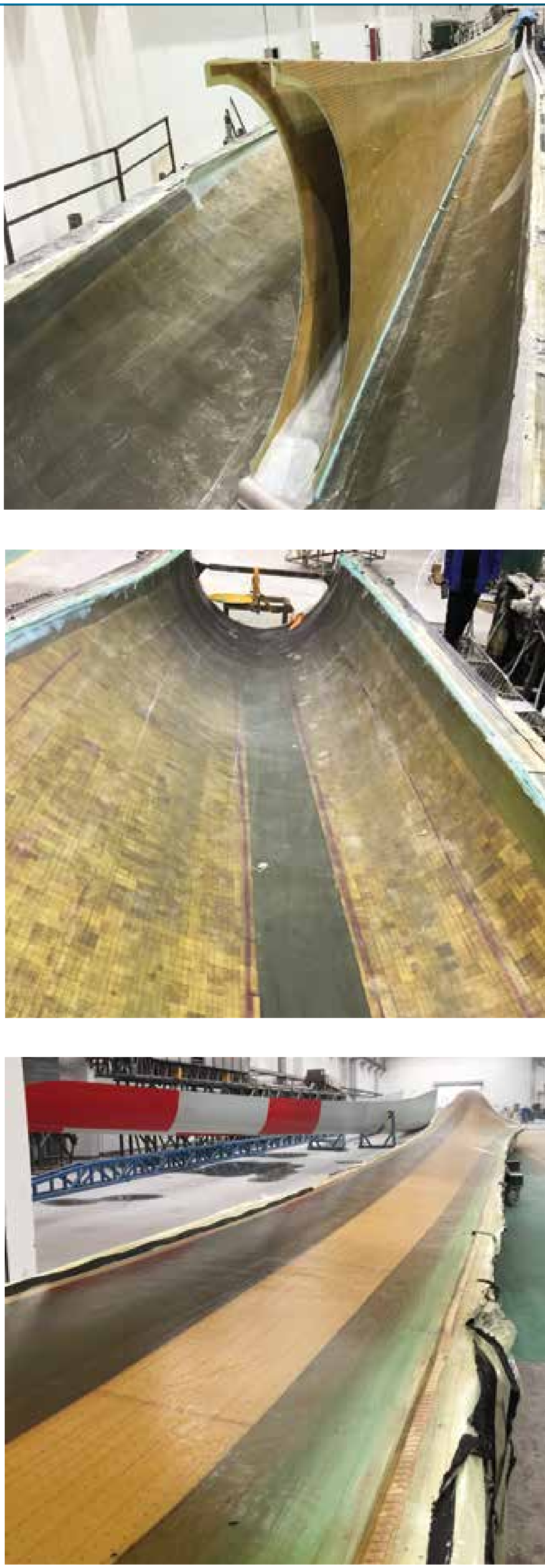


FIG. 1 PU blade an industry first

Covestro recently built the first polyurethane (PU) composite wind turbine blade in Asia (seen here, in process), a 37.5m long resin-infused blade designed for a 1.5-MW turbine installed in China. Source | Covestro

that can help reduce blade production cycle times while also cutting nonconformance costs due to irregular wet out of larger blades," says Shreve.

"It's all about lowering the levelized cost of energy [LCOE]," Klausen contends. "If we can make blades 10-15% cheaper to produce while decreasing their weight and enabling them to perform well at increasingly longer lengths, then we can drop LCOE even further."

Early promise, long development

In 2009, Covestro, then Bayer MaterialScience (Leverkusen, Germany), received a grant from the US Department of Energy (DoE) to research PU composites for use in wind turbine blades. Researcher Marcio Loos at Case Western Reserve University (Cleveland, OH, US) investigated the processing and properties of a 0.74m-long wind blade made using infusion, glass fiber fabrics and PU resin.

In 2011, Loos reported that the PU composite bested glass fiber/epoxy, lasting eight times longer in fatigue testing and showing a fracture toughness roughly eight times higher in delamination tests. Further, fracture growth rates were shown to be a fraction of those for epoxy and vinyl ester composites.

The following list of additional ways PU bests epoxy were compiled in a 2012 presentation by Loos' co-researcher Usama Younes at Sandia National Laboratories (Albuquerque, NM, US), based on multiple investigations of PU with glass and carbon fiber, including resin infusion molding of a thick, glass/PU root ring for a 42m long wind blade:

- 34% less time required for infusion of thick (50-ply) laminates.
- >17% greater tensile strength.
- Almost double the interlaminar fracture toughness.
- 30% lower stress crack growth rate.
- Better adhesion to glass fiber.

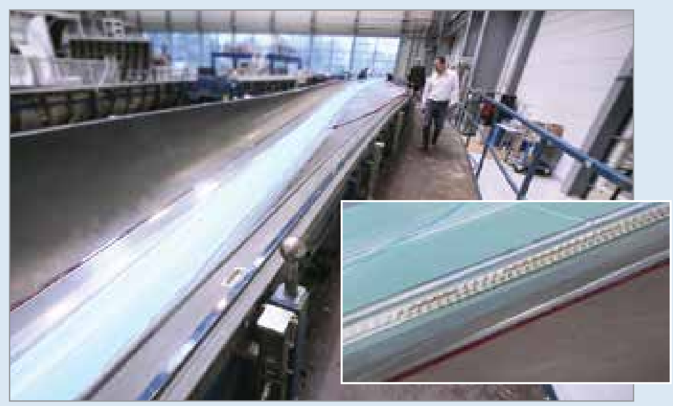
That same year, Bayer announced it would establish a global wind energy competence and development center in Otterup, Denmark. The facility would go on to spearhead and coordinate global development of Covestro's advanced materials for wind energy applications (after the name change in 2015) under Klausen's leadership, then managing director of Bayer MaterialScience A/S, Denmark.

Although the idea to use polyurethane as an infusion resin originated in the US, Klausen notes that today, development and optimization of the PU resin chemistry are being performed cooperatively by Covestro's Polymer Research »

1 Covestro tested its latest polyurethane resin, glass fiber reinforcements and infusion setup, including injection equipment, prior to the spar cap demonstration. Source (all step photos) | Covestro

2 Mold release film is applied to the 45m blade's mold surface.

3 Glass fiber unidirectional reinforcements are placed into the mold.



4 The vacuum bag, resin supply lines and vacuum lines are installed.

& Development Center (PRDC, Shanghai, China) and the wind energy center in Otterup, with oversight from Jan Drescher, head of the European infusion resin project in Leverkusen.

"The formulation we are working with now," he points out, "is quite different than what was presented at Sandia in 2012."

Are the property and processing improvements similar? The advantages in terms of reduced infusion time and improved mechanical properties compared to epoxy and vinyl ester infusion formulations have been maintained, Klausen confirms, but he prefers not to reveal specific property values until this infusion resin's certification by DNV GL (Oslo, Norway) is complete. That process, he estimates, will conclude sometime this year. Notably, a previously formulated Covestro PU resin was the world's first PU resin to receive DNV GL certification.

In 2015, Klausen partnered with the Center for Lightweight Production Technology (ZLP) in Stade, Germany, a division of the German Aerospace Center (DLR, Cologne) that collaborates with the DLR Institute of Composite Structures and Adaptive Systems in Braunschweig and the Institute of Structures and Design in Stuttgart. Established to enhance cooperation between science and industry, it works to optimize composites production technologies. The ZLP contributed significant blade design and manufacturing experience and a 45m wind blade mold, previously used by turbine maker Nordex (Hamburg, Germany).

Finalizing fibers and process

The project to demonstrate Covestro's latest developments in a polyurethane resin for wind blades was now set — infusion of a

5 The resin infusion is completed in 46 minutes.

6 Insulation blankets are then placed over the infused laminate.

7 The mold is closed to help prevent heat loss.

8 The finished spar cap is demolded.

45m long spar cap, the primary structural element of a wind blade. At this point, two final project partners were invited to participate: reinforcements and core materials supplier SAERTEX (Saerbeck, Germany) and process engineering specialist and equipment supplier Hübers Verfahrenstechnik Maschinenbau (Bocholt, Germany).

"We received a request from DLR to provide unidirectional [UD] glass fiber reinforcements," recalls SAERTEX account manager Alexander Winter. "These UDs are a material we commonly supply into wind blade spars," he notes. They comprise two layers: a stabilization layer of 90° fibers, weighing only a few grams per square meter, and the unidirectional 0° layer, which provides strength along the length of the spar. "The fabric used in the spar cap demo project was one we had specifically developed for a 45m spar," says Winter. It featured a 1,182-g/m^2 areal weight and 670-mm width. SAERTEX has made this type of noncrimp fabric (NCF) with glass fiber as heavy as 4,000 g/m^2 and as light as 230 g/m^2. It also can slit this type of fabric into widths that range from a few centimeters up to 3m. "For many fabrics, the normal production width is 50 or 100 inches [1.3 or 2.5m]," says Winter, "but UDs are typically 200-600 mm in width." To help speed layup, especially for blade skins, SAERTEX also kits fabrics for a variety of manufacturers — e.g., 100 cut and labeled NCF pieces per box.

"We selected glass fibers with a sizing that is compatible with the Covestro PU resin," Winter recalls. Covestro also completed smaller-scale infusion tests in advance (see Step 1, p. 34).

Like other infusion resins used in wind blade construction, PU requires the metering, mixing and dispensing (MMD) of two » components, typically achieved using specialized equipment (see Learn More, p. 38). Klausen explains selection of the final project partner. "Hübers was brought in because we wanted to use very advanced process control," he says. "One reason for this was to minimize the processing variability, so that we could see what the resin was achieving. But we also pursue top-class solutions for industry as a general approach."

Klausen did not seek traditional polyurethane machine specialists because they lacked familiarity with vacuum degassing in the resin tank. He explains, "Hübers' background is in cast polymers for electrical transformer applications, where any bubbles can generate a spark. So, they have developed very tight process control along with inline vacuum degassing of the resin, which provides very reliable, consistent and high-quality infusion results."

FIG. 2 Infusion control equipment a key

Hübers provided resin meter/mix/dispense equipment with inline degassing that ensured reliable, consistent and high-quality infusion results. Source | Hübers

Demonstration and future development

All project partners were on site for infusion of the 45m spar cap. "The team worked well together. DLR was very experienced and there also were some staff from a rotor blade manufacturer who provided assistance," says Winter.

First, the mold was prepared by applying a release film using standard materials and process (Step 2, p. 34). Next, 52 plies of the dry glass fiber uni materials were placed into the mold (Step 3, p. 34). Then the vacuum bag, resin supply/feed lines and vacuum lines were installed (Step 4, p. 34) and the infusion was started (Step 5, p. 35). The setup used just one central feed line; two additional lines were available as backups only. Infusion of the spar cap was completed in 46 minutes.

Klausen explains that the T_g of the PU resin is slightly higher than epoxy, but the cure temperature is very similar, at 80°C. This was achieved using heated molds, a standard practice in blademaking. Once infusion was complete, insulation blankets were placed over the infusion setup, per standard blade manufacturing practice, to reduce heat loss for a more efficient heating and cure cycle (Step 6, p. 35). A video of the spar cap infusion (see Learn More) shows the wind blade mold closing (also shown in Fig. 7, p. 35), but Klausen says this was not necessary for curing just the spar cap, but was done more as a demonstration of the process necessary to mold a complete blade. Four hours at 80°C is enough to cure the polyurethane resin, but Klausen believes his team can reduce the cure duration significantly.

Capturing savings in cost and time

"We were able to cut both infusion time and cure time compared to epoxy," says Klausen of the spar infusion, who estimates that *overall blade production* time could be cut by >10%. "The price of this polyurethane is competitive with epoxy," he explains, "but the process savings would then give an overall advantage." Is this possible for *all* resin-infused blades? "You can never state that it is possible for all blade types or designs," replies Klausen, "because there are so many different solutions and production methods, which create individual challenges. However, the lower viscosity and curing time of our resin can save time." He estimates that most parts can be produced 10-20% faster with this PU system vs. epoxy, adding that "It will probably be necessary to adapt the injection equipment and flowlines to make use of the higher infusion speed."

This single PU resin can be used for all blade components, Klausen points out, including root, spar cap, spar web and shell, as has been demonstrated in the 37.5m long blade in China. "It is also possible to use it only for one of these components while maintaining the others in vinyl ester or epoxy," he notes. "This resin is compatible with vinyl ester and epoxy, so you can achieve good adhesion." Because the wind blade industry is conservative, Klausen acknowledges that blade manufacturers may want to switch over one structure at a time, to build experience and confidence.

He notes that blade designers can simply drop in the PU system to replace the current infusion resin, "but if you really want the full savings possible, then you look at your design and how to exploit the higher resin properties." Because of the resin's higher strength — including higher compression vs. epoxy — designers can either cut weight out of the blade or use these advantages to achieve, longer, slimmer blades for bigger turbines and/or more power. "We are working with a well-known wind »

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blade design firm now, WINDnovation [Berlin, Germany], to calculate the design advantages of using this polyurethane resin."

Klausen believes that even designers who prefer to take the drop-in approach one structure at a time on their current production blades will nevertheless redesign their next-generation blades to fully capture the PU property benefits. "This is why we are fully documenting the design possibilities with WINDnovation," he adds.

"We will also move forward with further demonstrating the resin in larger blades," says Klausen. The current plan is to build further full-blade prototypes and test them extensively during the next year. "Our goal is to provide test results that will be accepted internationally," he notes, "so we will choose a well-recognized test facility for this demonstration."

There is also the possibility to do more demonstrations with DLR. For its part, SAERTEX would like to participate in larger blade demonstrations using its new core material, SAERfoam. "This would replace balsa wood core for a 25% weight reduction, depending on the blade design," says Winter, who sees applications for the new core beyond wind, such as in marine and construction/infrastructure.

Klausen also sees opportunities beyond wind for Covestro's new PU infusion system, but for now, the focus is on finishing the development for rotor blades. "We will spend 2017 documenting all of the resin and composite mechanical properties as well as the aging properties," he observes. "We will also do a lot of health, safety and environmental testing and documentation." Klausen explains that Covestro has many internal standards that exceed, sometimes significantly, others in the industry, such as DNV GL. "We must fulfill all of these first — for example, performing grinding on cured composites with this resin, collecting the dust and analyzing it," he notes. "We will then be able to present a complete package to the end-users." In the meantime, his team is finalizing further demonstrations, and aiming for final commercialization in 2018. CW

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Composites Events

July 4-7, 2017 — Bologna, Italy
3rd International Conference on Mechanics of Composites (MechComp 2017)
events.unibo.it/mechcomp3

July 16-22, 2017 — Rome, Italy
ICCE-25, 25th Annual International Conference on Composites and Nano
icce-nano.org

July 17-20, 2017 — Ottawa, ON, Canada
CANCOM 2017
cancom2017.org

July 24-30, 2017 — Oshkosh, WI, US
2017 EAA AirVenture
eaa.org/en/airventure

July 25-27, 2017 — Dayton, OH, US
IACMI Summer Members Meeting
iacmi.org/ohiomembersmeeting

Aug. 20-25, 2017 — Xi'an, China
ICCM21 – 21st International Conference on Composite Materials
iccm21.org

Aug. 22-24, 2017 — Detroit, MI, US
6th Global Automotive Lightweight Materials Congress 2017
global-automotive-lightweight-materials-detroit.com

Sept. 6-8, 2017 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
speautomotive.com/acce-conference

CW **Sept. 11-14, 2017 — Orlando, FL, US**
CAMX (Composites and Advanced Materials Expo) 2017
thecamx.org

Sept. 12-15, 2017 — Husum, Germany
HUSUM Wind 2017
husumwind.com/husumwind/en

Sept. 13-15, 2017 — Nagoya, Aichi, Japan
ICOLSE – 2017 International Conference on Lightning and Static Electricity
icolse2017.org

Sept. 18-20, 2017 — Toulouse, France
SpeedNews 18th Annual Aviation Industry Suppliers Conference in Toulouse
speednews.com/aviation-industry-suppliers-conference-in-toulouse

Sept. 19-21, 2017 — Tampa, FL, US
IBEX 2017
ibexshow.com/show-info

Sept. 19-21, 2017 — Stuttgart, Germany
Composites Europe 2017
composites-europe.com

Sept. 19-23, 2017 — Vancouver, BC, Canada
39th IABSE Symposium: Vancouver 2017
iabse.org

Oct. 4-5, 2017 — Los Angeles, CA, US
SpeedNews 22nd Annual Business & General Aviation Industry Suppliers Conference
speednews.com/business-and-general-aviation-industry-suppliers-conference

Oct. 5-7, 2017 — Istanbul, Turkey
TURK Kompozit 2017 Composites Summit Turkey
www.turk-kompozit.org/en/home

Oct. 10-12, 2017 — Knoxville, TN, US
Additive Manufacturing Conference 2017
additiveconference.com

Oct. 17-19, 2017 — Wichita, KS, US
ASIDIC 2017: Aerospace Structural Impact Dynamics International Conference
asidiconference.org

Oct. 23-25, 2017 — West Lafayette, IN, US
32nd Annual American Society for Composites Technical Conference
cdmhub.org/groups/asc2017

Nov. 1-3, 2017 — Seoul, Republic of Korea
JEC Asia 2017
jeccomposites.com/events/jec-asia-2017

Nov. 15-16, 2017 — Madrid, Spain
Composite Spain
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Nov. 14-16, 2017 — Stuttgart, Germany
SAMPE Conference 17 Stuttgart
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SOFTWARE SHORTENS DESIGN PATH TO LONGBOARD

Materials information program helps optimize materials selection

When FORCE Technology (Brøndby, Denmark), a technology consultancy to the energy, oil and gas, maritime and manufacturing markets, wanted to teach its staff about composites, the challenge was how best to do it. To communicate which materials to use and how they should be combined to optimize their performance, composites specialist Benjamin Hornblow (on long-board in bottom photo) had his staff design a demonstration composite "longboard" skateboard. He turned for help to **Granta Design** (Cambridge, UK), a materials information technology firm founded 20 years ago as a spinoff from Cambridge University's engineering department.

Hornblow employed Granta's 2017 CES Selector software tool to quickly identify candidate materials and evaluate ways in which they could be combined to optimize results. The first step was to investigate materials currently used in longboards and compare their performance. Although typical longboards feature maple, bamboo or composites, a state-of-the-art board, comprising a sandwich panel of carbon fiber on the bottom, maple in the core and glass fiber on the top, was used as a reference. The next step was to consider the performance of reinforcing fibers, the board's main structural component. With Granta's MaterialUniverse data product, the performance of five natural fibers — cotton, flax, hemp, jute and kenaf — was quickly compared/contrasted with glass fiber, carbon fiber and aramid fiber.

Source | Granta Design

Source | Granta Design

Source | FORCE Technology

Within CES Selector, Hornblow and staff could plot Young's modulus and see that flax fibers lie within the same stiffness range as glass, but that both fall far below carbon fiber. Although natural fibers couldn't compete with carbon or glass when tensile strength was plotted, their performance was deemed acceptable because longboard designs are stiffness-driven. When the fibers' mechanical loss coefficients were compared, it was clear that the damping capability of flax fiber was three orders of magnitude greater than that of either glass or carbon fiber.

Hornblow then proposed a combination of carbon and flax fibers in a longboard to benefit from the stiffness of the former and damping properties of the latter. CES Selector's Synthesizer Tool enabled him and his team to model the performance of the reference board and theoretical boards. Graphs were created in Selector to compare flexural modulus with density, using a performance index, so the team could easily identify materials that outperformed others. The CES graphs showed that a longboard made from a solid flax fiber/epoxy composite would be outperformed by a maple board, and that the reference board would perform no better than the one built with less-expensive bamboo.

Next, the team modeled the performance of a carbon fiber/PET foam-cored sandwich panel, and determined that this could lead to a large improvement over the bamboo and composite reference boards. Based on this, carbon and flax fiber were combined in a 7-layer cored panel model within CES Selector. Ultimately, it featured a 3-layer facesheet with carbon fiber twill as the outer layer, a uni carbon fiber layer, then a layer of biaxial flax fabric, with a PET foam core. The final design plot showed a big improvement over previous iterations. The design was refined in **Dassault Systèmes'** (Waltham, MA, US) CATIA 3D CAD program, then prototyped and tested. The final longboard, slightly thicker than the reference and slightly less stiff in three-point bending, was 30% lighter, providing greater acceleration and a smoother, more enjoyable ride.

Says Hornblow, "It was great to use the multilayer Synthesizer Tool in CES Selector to 'test out' different materials, concepts and configurations early in the design process. This saved valuable time by reducing the number of iterations required for the more labor-intensive CAD modeling and prototyping stages." Notably, FORCE Technology is working with a US skateboard start-up to revise the prototype, using a higher percentage of sustainable materials. CW

New Products

» INJECTION MOLDING SYSTEMS & ACCESSORIES

Portable chiller line expanded

Mokon (Buffalo, NY, US) has expanded its Iceman SC Series line of portable chillers. Mokon's new ASL and WSL portable chillers have the same features of the Iceman SC but provide a lower temperature range. Currently, the Iceman SC Series line offers 0.5- to 40-ton chillers and has a fluid temperature range of -7°C to 18°C. The new ASL and WSL chiller line will have a fluid temperature range of -15°C to -1°C and a capacity of 1.5-7.5 tons. Other features include air-cooled or water-cooled condensing, scroll compressor, efficient brazed plate evaporator, microprocessor-based controller, insulated nonferrous plumbing and components, and heavy-duty insulated plastic tank with sight glass. **www.mokon.com**

» POLYMER RESIN ADDITIVES & MODIFIERS

New silicone additive reduces FR additive loading

Dow Corning Corp.'s (Midland, MI, US) new Dow Corning 43-821 additive is an advanced silicone technology formulated to resolve mechanical performance degradation and corrosivity issues typically caused by high loadings of organic phosphorous-based flame-retardant (FR) additives in polyamide (PA) compounds. Although many compounders and their customers prefer halogen-free FR solutions for their sustainability, those who use organic phosphorous additives (e.g., aluminum phosphinate, often blended with melamine polyphosphate) must use them at loadings as high as 20% to meet regulatory requirements. Such high phosphorous content in PA compounds can degrade mechanical properties (impact, elongation and maximum force at traction) and present high corrosivity. Dow Corning 43-821 used at low levels (1-2%) reduces the loading of organic phosphorous additive needed in PA6 and PA6.6 compounds by 40%, while still providing high levels of FR performance. And, it reportedly restores key mechanical properties of PA resin, minimizes corrosion of metallic parts that contact the formulation, and also reduces compound cost by 10% or more. Thus, users can benefit from halogen-free organic phosphorous FR additives without the downsides. The new product's synergistic effects on PA resin yield desired FR properties, including char formation, anti-dripping and reduced heat generation. Tests indicate that 30% glass-filled PA compounds incorporating 13 wt% of aluminum phosphinate and 2 wt% of *Dow Corning* 43-821 additive met the requirements for UL-94 V-0 at 1 mm. Further, 43-821, supplied in powder form for easy blending with leading aluminum phosphinate additives, are stable at the high processing temperatures needed for glass/PA. **www.dowcorning.com**

» ADDITIVE MANUFACTURING EQUIPMENT & MATERIALS

New resins for additive manufacturing

SABIC (Pittsfield, MA, US) has launched six new filaments for fused deposition modeling (FDM) and a new family of reinforced compounds for large-format additive manufacturing. The first product family is based on technology that enables laser sintering of polycarbonate (PC) materials with good mechanical properties and part densities greater than 96%. These materials might provide an alternative to polyamide 12 (PA 12) and can be processed using commercially available printers. Second, EXTEM polyimide (PI) filaments are designed for high-temperature solutions for additive manufacturing and offer performance greater than the company's ULTEM polyetherimide (PEI) filaments. Finally, high-impact-strength PC filaments offer improved impact resistance compared to other commercially available PC filaments, and can be processed at standard PC conditions. Potential advantages include reduced part damage in secondary operations, and higher levels of performance in end-use applications. **www.sabic-ip.com**

» MOLDMAKING MATERIALS & EQUIPMENT

Elastomeric tooling system for high-temperature molding

Rubbercraft (Long Beach, CA, US) introduced at the recent SAMPE Seattle 2017 show a new impermeable elastomeric tooling system. Now commercially available, the new flexible tooling product was developed by Rubbercraft for high-temperature molding of complex structural aircraft composite parts where a bladder or reusable vacuum bag is required, to provide higher surface quality and improve productivity. This innovative new 'tri-layer' flexible tooling technology improves part quality by reducing leaks and avoiding surface porosity. It also provides an extra layer of security against leaks due to punctures or manufacturing defects. Because the tri-layer tooling system has an integrated breather layer, it can be used as an elastomeric reusable vacuum bag to infuse complex parts where it is not possible to use an internal breather. Additional benefits include: 1) reduced profile, improved fit and superior surface finish on part inner surfaces; and 2) easier and more accurate leakage checking by simply applying a vacuum to the breather layer, with no need to use a specialized test station. According to the company, the elastomeric tooling's fully integrated central breather layer protects the surface of a molded FRP composite part form unwanted contact with gasses during production, even at high pressures and temperatures. Further, the breather layer not only enables removal of trapped air between the part and the tool but also acts as a gas barrier, countering the inherent permeability of elastomers, such as Viton or silicone, on the high-pressure side, while removing unwanted air or volatiles on the part side. Read a technical white paper about the technology online | **www.rubbercraft.com**

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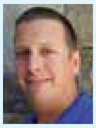
MIKE DITZLER
Engineer, Vectorply


GARY WILDE
Account Manager, Polynt-Reichhold


ERIC HEILSHORN
Product Manager, 3A Composites

Improving Cosmetics in Closed Mold Applications

EVENT DESCRIPTION:

Customer expectations for FRP part appearance continue to increase as FRP is used in more and varied applications and as manufacturers continually work to improve products. Increasing use of closed molding processes to fabricate FRP parts brings new challenges to achieving high quality surface finishes. A panel of industry leading experts from Polynt-Reichhold, 3A Composites, and Vectorply will discuss cosmetic standards and sources of cosmetic flaws. They will review material selection including gel coats, barrier coats, resins, coring, internal flow media, and engineered fabrics. Processing methods for improving cosmetics in closed molded FRP parts will also be discussed.

PARTICIPANTS WILL LEARN:

- Root causes of cosmetic flaws in FRP
- Material selection considerations for cosmetic improvements
- Laminate design suggestions for cosmetic improvements
- Processing suggestions for cosmetic improvements

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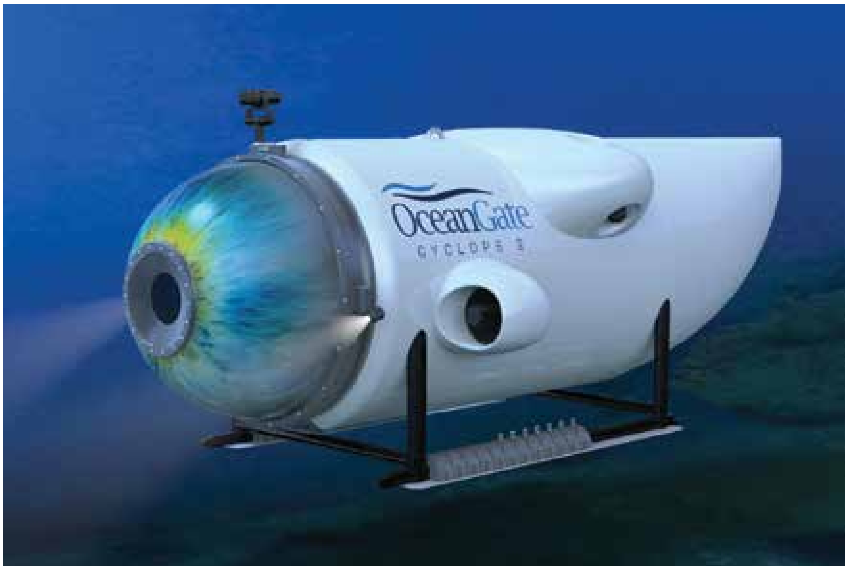
Composite submersibles: Under pressure in deep, deep waters

Manned deepsea exploration calls for a highly engineered solution that, at 6,500-psi service pressure, will maintain buoyancy and preserve life.

By Jeff Sloan / Editor-in-Chief

»Even as massive amounts of money, energy and attention are being paid to the development of privately funded launch and delivery systems for space exploration — and the application of composites therein — an environment much closer to home is, despite its proximity, as remote and difficult in its own way to access and study.

At an average depth of about 3,810m, with a maximum depth, at Challenger Deep in the Pacific, of 10,916m, the world's oceans offer a formidable challenge to explorers. Scientists, marine biologists or oil and gas engineers and others who would dive to such depths require a vessel that can withstand deepsea water pressure that, at the 3,810m average, is a massive 5,551 psi or 378 atmospheres.



A deepea submersible "first"

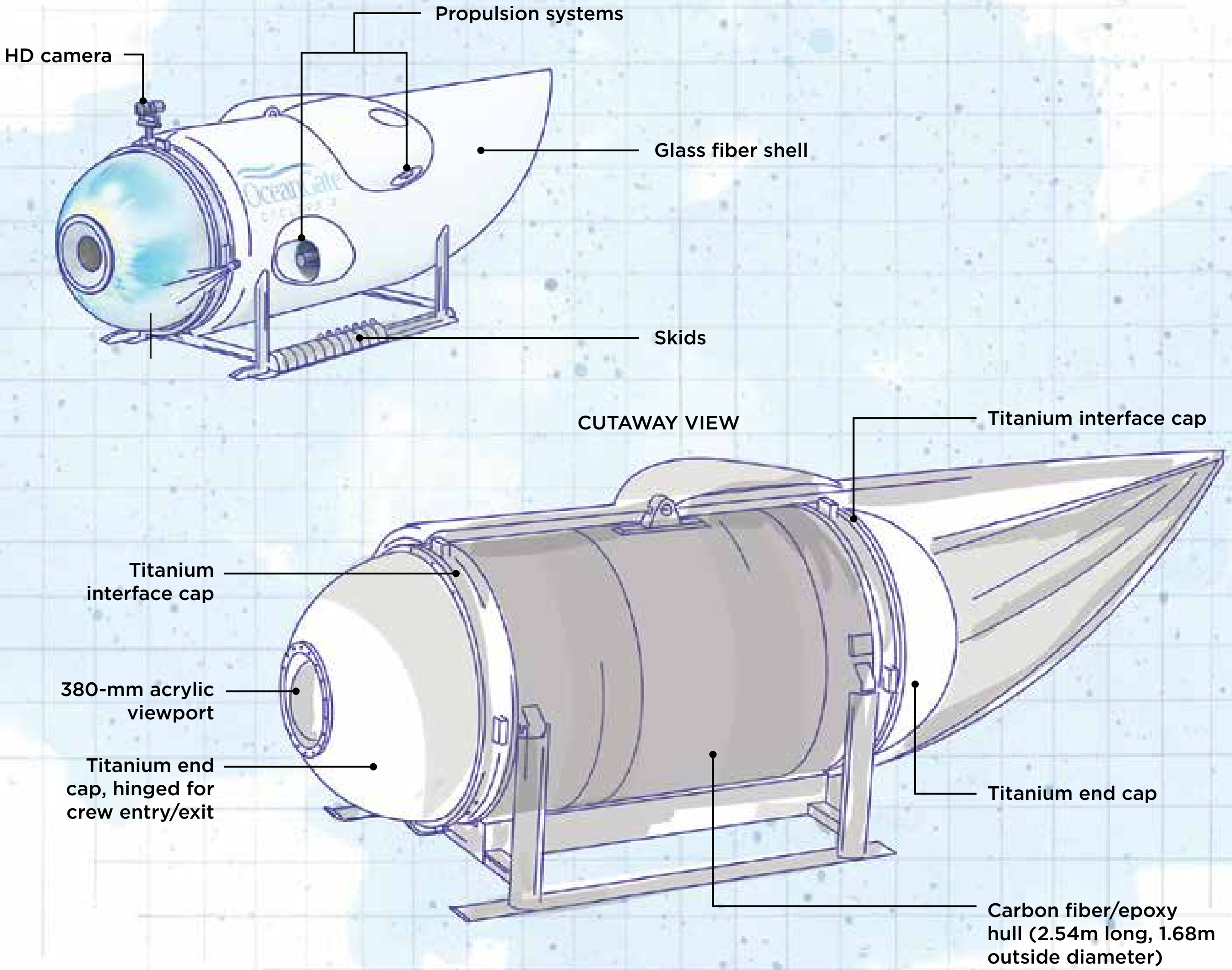
Rated for ocean depths to 4,000m, OceanGate's (Seattle, WA, US) Cyclops 2 five-person submersible features the submersible industry's first commercial carbon fiber composite hull, designed and manufactured by Spencer Composites (Sacramento, CA, US). Source (all photos) | OceanGate

Such vessels, called submersibles, offer capacity for three to five occupants, can explore depths from 1,200m to 6,500m, provide a viewing porthole or portholes, and are equipped with lighting systems and cameras. Conventional submersibles feature steel, aluminum or titanium hulls. Metallic hulls, however, because they are not buoyant in designs for depths of more than 2,000m, present challenges when it comes to managing ballast for ascent and descent. In particular, metal-hulled craft require the use of syntactic foam attached to the outside of the craft to achieve neutral buoyancy.

In 2014, submersibles manufacturer OceanGate Inc. (Seattle, WA, US) was coming off the successful launch of *Cyclops 1*, its steel-hulled, five-person craft, rated for underwater exploration to a depth of 500m. The company was set to embark on development of *Cyclops 2*, a five-person research-class submersible, designed for a maximum depth of 4,000m.

OceanGate CEO Stockton Rush says the company had been evaluating the potential of using a carbon fiber composite hull since 2010, primarily because it permits creation of a pressure vessel that is naturally buoyant and, therefore, would enable OceanGate to forgo the use — and the significant expense — of syntactic foam on its exterior. So, for *Cyclops 2*, OceanGate decided to avoid the metallic hull altogether and began a search for a manufacturer that could help it develop a composite hull.

It is believed that the first time carbon fiber composites were applied to the hull of a deep-diving, manned submersible was for the one-person *DeepFlight Challenger*, commissioned by adventurist Steve Fossett in 2000 for a dive to the bottom of Challenger Deep (see Learn More, p. 47). Designed and built by famed marine engineer and submersible designer Graham Hawkes, a principal at the time of Hawkes Ocean Technologies (Point Richmond, CA, US), it featured a cylindrical carbon fiber/epoxy composite hull with 6-inch-thick walls. It was nearing completion in 2007 when Fossett was killed in a light-aircraft crash. The *Challenger* was subsequently sold, and has yet to be fully tested or deployed in



DESIGN RESULTS | **Spencer Composites OceanGate *Cyclops2***

- Carbon fiber/epoxy hull proves both exceedingly strong and naturally buoyant.
- Micromechanics analysis for high service pressure.
- Alternate prepreg (axial) and wet winding (hoop) maximize strength, stiffness, achieve <1% porosity.

Illustration / Karl Reque

a deepsea dive. Spencer Composites Inc. (Sacramento, CA, US), a designer/manufacturer of composite parts and structures for a variety of end-markets, had designed and fabricated the *Deep-Flight Challenger's* hull.

"I knew of the submersible Graham Hawkes designed for Steve Fossett," says OceanGate's Rush. "And I knew Spencer Composites manufactured that cylinder."

Spencer Composites' president Brian Spencer signed a contract with OceanGate for the *Cyclops 2* hull in early January 2017 and was presented with very basic — but challenging — performance parameters: Length, 2,540 mm; outside diameter, 1,676 mm; service pressure, 6,600 psi; pressure safety factor, 2.25. "They basically said, 'This is the pressure we have to meet, this is the factor of safety, this is the basic envelope. Go design and build it,'" Spencer reports. And he was given six weeks in which to do it.

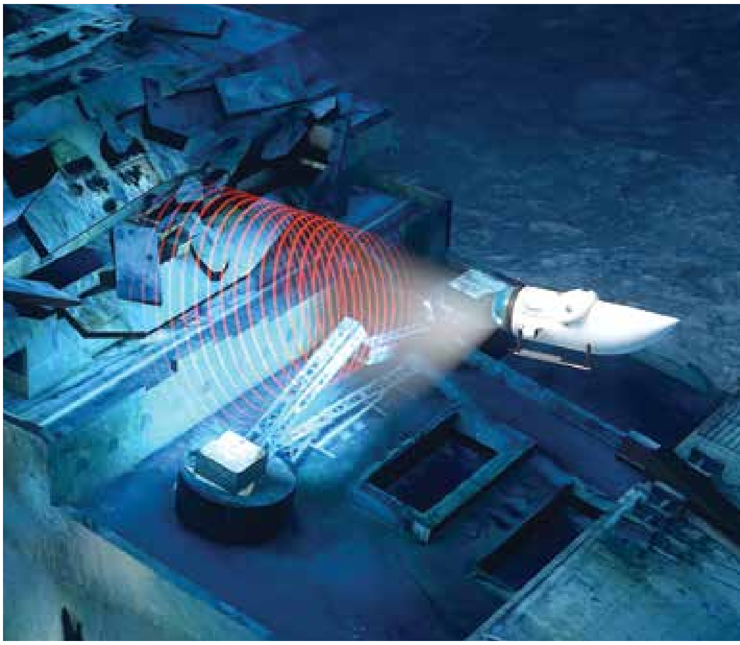
A room with a view

Cyclops 2 will consist of six primary structures:

- A cylindrical composite hull with room for five adults (a pilot and four passengers).
- Two titanium interface caps (one bonded to each open end of the hull). »

Manufacturing in a generous safety margin

The carbon fiber/epoxy hull of the *Cyclops 2* features alternating layers of UD prepreg in the axial direction, and wet-wound carbon fiber filaments in the hoop direction. The hull is 127 mm thick (5 inches vs. the 6 inches planned for Fossett's earlier craft) and has tested to 2.5 times the 6,500-psi service pressure.



Travel to the *Titanic* and beyond

Cyclops 2 will be used for scientific research, deepsea exploration and oil and gas exploration. Its first mission, scheduled for May 2018, will be to shoot photos and video of wreckage from the Titanic, which is located in about 3,688m of water in the North Atlantic. This rendering depicts the *Cyclops 2* above the *Titanic*.

- Two separate titanium hemispherical domes, the front one featuring an integrated 380-mm-diameter acrylic viewport.
- A glass fiber composite outer shell, bolted to flanges on the titanium interface caps.
- A landing skid structure, also attached to the interface caps.

Nothing will be mechanically attached to, or penetrate, the composite hull other than the titanium caps.

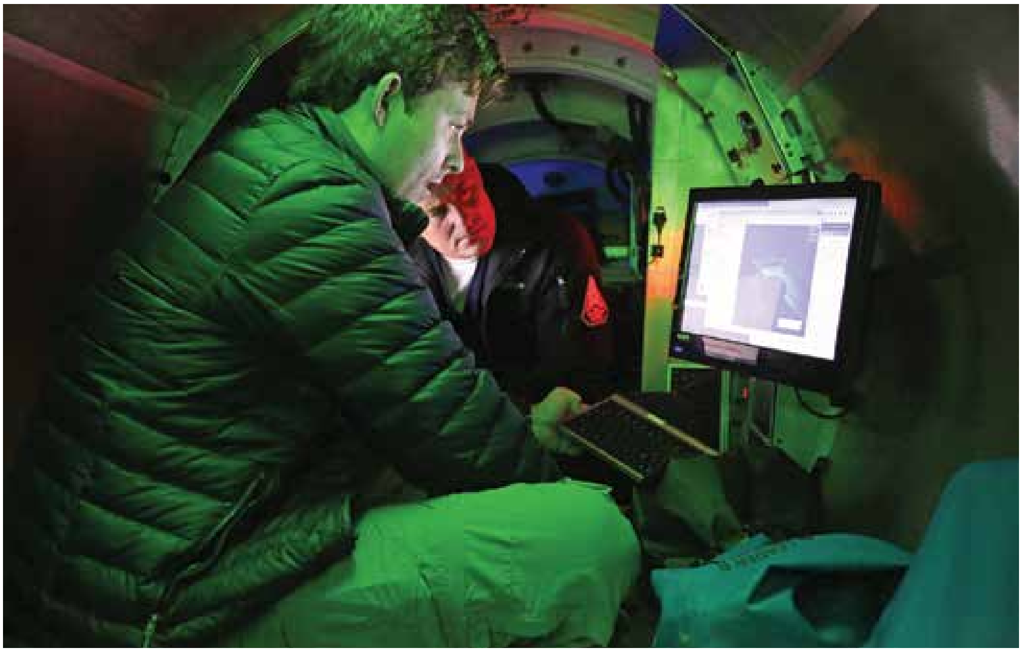
Deep-sea exploration — even in a well-designed, well-engineered, pressurized submersible — is not trivial and does carry with it substantial risk. The world record free-dive depth for a human is 214m (312 psi), and for most people the "safe" depth is probably half that. Thus, in the event of catastrophic failure of a submersible at any depth greater than even 250m, deepsea water pressure would instantly kill every passenger on board. And this is the primary concern of OceanGate and, by extension, Spencer Composites.

Cyclops 2 faces potential failure in any one of three structures: the composite hull, the titanium end caps and the acrylic viewport. OceanGate designed a real-time health monitoring system that will acoustically monitor the composite hull to detect the pings and pops that signal to the pilot the risk of potential failure. Strain gauges will measure the health of the titanium end caps, which will see a maximum axial end dome load of up to 22 million lb. The viewport, says Rush, because it is acrylic, fails optically long before it fails structurally — and in this case, catastrophically — thus the crew will detect a problem visually first. In any case, the goal is to alert the pilot of potential catastrophic failure in time to enable movement of the craft to shallower, safer water.

Designing, building the perfect cylinder

The design of the *Cyclops 2* hull, says Spencer, is based in large part on the strategy applied to Fossett's *DeepFlight Challenger*. Thickness, he says, was estimated using micromechanics, and then verified with finite element analysis (FEA). Modeling was done in SolidWorks (Dassault Systèmes, Waltham, MA, US) and analysis was done with COSMOS/M, supplied by Dassault Systèmes subsidiary Structural Research and Analysis Corp. (Santa Monica, CA, US).

The biggest challenge, Spencer reports, was developing a manufacturable design that "would produce a consistent part with no wrinkles, voids or delaminations." And without use of an autoclave. Spencer opted for a layup strategy that combines alternating placement of prepreg carbon fiber/epoxy unidirectional fabrics in the axial direction, with wet winding of carbon fiber/epoxy in the hoop direction, for a total of 480 plies. The carbon fiber is standard-modulus Grafil 37-800 (30K tow), supplied by Mitsubishi Chemical Carbon Fiber and Composites (Irvine, CA, US). Prepreg was supplied by Irvine-based Newport Composites, now part of



Five down deep for a whole shift

Crewmembers are shown here inside *Cyclops 1*, the steel-hulled predecessor of *Cyclops 2*. The 2.54m long hull of *Cyclops 2* will hold as many as five people and will provide 8 hours of normal service, with 96 hours of emergency life support available.

Mitsubishi Chemical. The wet-winding epoxy is Epon Resin 682 from Hexion (Columbus, OH, US). The curing agent is Lindride LS-81K from Lindau Chemicals (Columbia, SC, US).

Initial design work indicated that the hull, to be rated for 4,000m depth with a 2.25 safety factor, should be 114 mm thick or 4.5 inches, which OceanGate opted to round up to 5 inches (127 mm) to build in an additional safety margin.

After layup and winding was complete, the cylinder was bagged with cellowrap and then cured in an oven at 137°C for 7 days. There was no postcure. Spencer says initial assessment of the cured cylinder shows that it has porosity of <1%. As *CW* went to press, the cylinder was being prepared for machining to cut it to length, square up the ends and bond it to the titanium end caps. It will then be sent to OceanGate in Seattle to be instrumented before undergoing pressure testing. Assuming the hull passes muster, it will then become part of the first *Cyclops 2* unit.

The finished *Cyclops 2* will measure 6.7m long, 2.8m wide and 2.5m tall. It will weigh 8,600 kg and have payload capacity of more than 1,043 kg. Integrated into the outer shell of *Cyclops 2* will be four electric thrusters for propulsion, buoyancy-control and navigation systems, four 20,000-lumen LED lights, HD cameras and other accessories. The crew will enter and exit *Cyclops 2* through the front of the hull, which will be accessed via its hinged titanium end dome.

+ LEARN MORE

Read this article online | short.compositesworld.com/Cyclops2

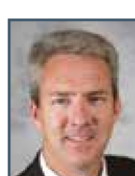
Read more about the Steve Fossett capsule in "Deepsea submersible incorporates composite pressure capsule" | short.compositesworld.com/6TjCL4Lz

OceanGate's Rush says *Cyclops 2* will offer a nominal descent/ascent rate of 50m/min. Its standard life support systems can accommodate an 8-hour dive, but emergency systems are designed to provide an additional 96 hours of life support. The service limits of *Cyclops 2*, therefore, says Rush — water depth not withstanding — "are bladder, food and attention span."

Notably, its 380-mm acrylic viewport, says Rush, is twice the size of any viewport on a competing submersible and should offer passengers unprecedented views of the waterscape.

Cyclops 2 will enter the water for the first time in November of this year, followed by a deep-dive test in early 2018. If that goes well, its first mission, in May 2018 in the North Atlantic, will be a descent to the wreckage of the *Titanic*, which sits 3,688m under the surface. The goal? Capture high-definition still and video images of the *Titanic*, and gather sonar and laser measurements of the ship and the ship's debris.

After the Titanic mission, *Cyclops 2* will be off on a variety of other missions that, says Rush, will keep the craft busy for the rest of 2018. OceanGate, he says, will build at least four *Cyclops 2* submersibles, and as many as 20, depending on demand. Rush says *Cyclops 3*, *4* and *5* are already on the drawing board, will target depths of 6,000m and likely will feature carbon fiber composite hulls. CW



ABOUT THE AUTHOR

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